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Disclaimer

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INTERNATIONAL FINANCE CORPORATION (IFC)

IFC fosters sustainable economic growth in developing countries by financing private sector investment, mobilizing capital in the international financial markets, and providing advisory services to businesses and governments. Over the years, the IFC has shown that good investment performance is compatible with creating employment, a healthy environment and an improved quality of life in developing countries. IFC, as a partner of choice, can help companies gain a competitive advantage through environmental and social risk reduction and management and identification of opportunities to enhance business value. Specifically, IFC's work aims to enhance the achievement of the triple bottom line of financial profitability, environmental sustainability, and social responsibility of private companies that are interested in contributing to sustainable utilization of resources.

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PGBI brings together a team of highly acclaimed technologists who offer a variety of specialist services to the Sugar, Ethanol, Bio-fuels, Timber and Power Generating Industries. These services include specialist project development, engineering, management and feasibility advice. Its unique and innovative approach to program management is based on entering into strategic partnerships with clients and establishing an on-site presence to manage the program until full commissioning and operational targets have been met. PGBI is based in the Republic of South Africa and operates internationally.

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(ii) FOREWORD

Why does the sugar world need another book on sugarcane? Perhaps the answer to this question is that there are no other books on sugarcane management which cover the subject from initial land selection, survey and development to the multiple final products of sugar, ethanol and electricity (plus cellulosic biomass in the future) and integrate this with the environmental, social and developmental aspects of the business, to ensure long term sustainability in a market that is increasingly being driven by customer and stakeholder demands.

A renowned international sugarcane specialist, Dr Graham Kingston from Australia said: “I am looking forward to its publication as it is likely to be a first in terms of an international reference for sugar industry management.”

Who is the book aimed at? The prime targets are the developers of new, and expanders of existing, sugarcane projects, who wish to source funding from the International Finance Corporation of the World Bank. They need to know what constitutes good management practices by world standards. It is also for IFC executives who are charged with the selection of such projects.

The book is compiled by a team of experienced sugarcane specialists from Southern Africa. This area has produced excellent scientists, many of whom trained at two of the world’s top sugarcane and sugar research institutes (South African Sugarcane Research Institute and Sugar Milling Research Institute, Durban). Apart from research, they have had experience in developing, managing and rehabilitating new and existing sugarcane projects in many parts of Africa. The team was led by Jan Meyer (plant nutrition and soils) with Peter Rein (factory), Peter Turner (agronomy) and Kate Mathias (social and smallholders). They were assisted by a number of others who are listed below. In the course of compiling the book, team members visited Brazil, Argentina, Guatemala and India as well as many parts of Africa. It is presented in three main sections:

- Background, Environment, Land Development and Sugarcane Agriculture
- Processing, Sugar, Ethanol, Power and Byproducts
- Regulation, Social, Labor and Community issues

The world sugarcane industry has expanded enormously over the past two decades with perhaps the most fundamental change being the expansion of ethanol production. Brazil, the world’s largest sugarcane producer, devotes more than half its cane to ethanol, producing over 25 billion liters annually, which results in enormous savings in greenhouse gas emissions compared with fossil fuels. In order to meet the future demand for ethanol mandated by the European Union, new projects are being developed in many areas, mainly in South America and several parts of Africa. Allied to this is an increase in electricity exports through the use of high efficiency boilers and turbo-alternators combined with greater efficiency in power use in the factory. There has been a long-term downward trend in inflation-adjusted sugar prices, necessitating continuing improvements in production costs.

The book is primarily targeted at the basic factors leading to Good Management Practices, starting with the primary requirements of solar energy, water and plant nutrition, and including manpower and mechanization aspects in the quest for economic sustainability. However social responsibility, biodiversity conservation and lowering the carbon footprint have become increasingly important and throughout the book the “triple bottom line” (financial, social and environmental) is continuously stressed.

Dr Jerry Gosnell, May 2011
(iii) PREFACE

In the literature dealing with tropical and subtropical crops, sugarcane occupies a prominent place as it has played an important role in the history of human civilizations. Today it is the strategic economic sector in many developing economies where agricultural activities provide the best potential for labor absorption in rural areas. Unlike the early years of regulated prices, sugarcane industries around the world are facing multiple challenges to the sustainability of production systems, because trade for global sugar has become more competitive as the production environment becomes less regulated. This has led to a greater focus on improved production efficiencies by either improving yield output or reducing costs, or a combination of both options. The increased pressure and competition for water, nutrients and other resources and consequent increased risk of environmental impacts, such as degradation in soil health, climate change and atmospheric pollution, has led to increasing scrutiny from regulatory agencies, community and consumer groups into the environmental sustainability of current sugarcane production systems.

A number of sugar industries have pre-empted these pressures through the introduction of self-regulation monitoring schemes such as in Australia (COMPASS evaluations, NSW Industry Code of Practice), Brazil (Jalles Machado ISO 14001), India (EID Parry, 2006), and South Africa (Standards and Guidelines for Conservation and Environmental Management and Susfarms, 2007). Brazil, which is the world’s larger producer of sugarcane with more than half of its production channeled into ethanol, has in recent years been very progressive with the introduction of environmental legislation and self-monitoring schemes. The most recent of these is the UNICA ‘Green Protocol’ initiative launched in 2007, to accelerate the elimination of sugarcane burning and protect the environment through the implementation of soil conservation and water resource plans in the State of Sao Paulo.

Concurrent with these developments are the International NGO efforts to promote market driven regulation for sugar and ethanol, including Bonsucro, formerly known as the Better Sugar Cane Initiative and Fair Trade International, while the Roundtable for Sustainable Biofuels was established to set standards for the production of biofuels from all crops. Bonsucro was launched to fill the need for an international set of sustainable sugar standards by which industries, companies and investors could establish their sugar purchasing principles. Customer and stakeholder demands, as channeled through these organizations, will become an important part of the future sugarcane value chain which will include the production of sugar, ethanol and power.

Although the literature on sugarcane husbandry and milling is extensive, only a few texts have dealt with the environmental and social impacts of the sugar industry and preferred good management practices to mitigate these impacts. The International Finance Corporation (IFC), the private sector arm of the World Bank and active investor in sugar industries worldwide, recognized the need for a comprehensive guide to Good Management Practices (GMP) in the cane sugar industry. In 2010, the IFC assembled a team of contributors, with a wide range of experience in sugarcane agriculture, environment, processing, social and economic fields, with access to strong technological support networks, to produce this much needed manual on good management practices. The initiative complements the IFC’s Biodiversity and Agricultural Commodities Program (BACP), funded by the Global Environment Fund (GEF), which is aimed at reducing habitat destruction. Sugar is one of the main commodities covered by the BACP.

While the manual is primarily intended to provide guidelines on good management practices to agricultural, field and mill managers of IFC-financed estates, it is also envisaged that the manual would be shared with IFC sugarcane sponsors and potential clients to assist them to implement advantageous environmental, social and production practices. Agronomists, soil scientists,
consultants, extension officers, sugar technologists, specialists in the fields of research, teaching or technical assistance and human resource personnel will also find it a useful reference text.

The 21 chapters in the book are divided into three sections, with 14 chapters covering agricultural management topics ranging from crop establishment to harvesting the crop, three chapters devoted to processing, co-product and effluent management topics and four chapters covering social, community and outgrower topics. Throughout the manual, authors have where possible, adopted the general theme of sustainability, to ensure that any good management practices that are recommended, comply with the tenets of the triple bottom line:

- Ensuring profitable production and more efficient use of production resources
- Minimizing or avoiding both on and off-site detrimental impacts on the environment
- Ensuring that production takes place in a socially equitable environment.

Although the chapters can be read independently, the subject matter has been arranged to provide continuity of material with the environment and physiology and cultivars described in chapter 1, followed by the soil and its environment in chapter 2 and then proceeding through the various field operations from planting (chapter 3), weed control (chapter 4), fertilizing (chapter 5), irrigation and drainage (chapters 6 and 7), disease and pest control (chapters 8 and 9), ripeners (chapter 10), harvesting and transport (chapter 11), agrochemicals and farm safety (chapter 12), biomass management (chapter 13) and computer based decision support programs (chapter 14). Continuity of subject material is maintained in the processing section with the measurement of cane quality, cleaning of cane, water use and recycling, chemical and energy use and management of wastes and recycling. The third section deals with regulatory frameworks, human resource management, social welfare and community initiatives and a valuable review of outgrower development. The Appendices provide further details of selected field good management practice guidelines as well as a cross reference guidance index, that links appropriate IFC and Bonsucro standards to each chapter. The manual ends with a detailed glossary of important technical terms as well as an explanation of abbreviations and symbols that have been used in the manual.


Oliver Cheesman’s (2004) book on *Environmental Impacts of Sugar Production* was a valuable starting-off point for our literature search on environmental impacts, and this was updated with information derived from CAB Direct. CAB Direct is a database of over eight million abstracts from the world’s literature on agriculture and applied life sciences, based on material going back to 1973. Use was also made of other data bases, including the International Society of Sugar Cane Technologists, the South African Sugar Technologists’ Association, the Australian Society of Sugar Cane Technologists, and the American Society of Sugar Cane Technologists. Other valuable sources of information, such as the annual reports, bulletins, manuals and information sheets produced by various sucargane research institutes such as CTC in Brazil, SASRI in South Africa and BSES in Australia, were scrutinized in the effort to present the latest and best scientific results and practices. References cited in the text are listed at the end of each chapter.

Finally, where appropriate, examples of good management practices, documented in a report prepared for the IFC and based on visits by the principal authors to some of the most highly productive and efficient mills in Brazil, Guatemala, Argentina, India, and Swaziland are referred to in various chapters, mostly in box format highlighted in a light blue color.

**Jan Meyer May 2011**
(iv) ACKNOWLEDGEMENTS

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We are also greatly indebted to Mrs. Dorothy Carslow for her meticulous checking and correction of the text and references in each chapter, to ensure compliance with the set of instructions that was giving to each contributing author. Finally, we are deeply grateful to Mr. Peter Bailey, CEO of PGBI, for hosting this manual and providing logistical administration support through his staff, particularly Mr. Cameron McGregor as resource manager, and secretarial assistance through Ms. Lee Zuccarelli and Ms. Lorna Carlstein who assisted in the front cover design.
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1. SUGARCANE AND ITS ENVIRONMENT

1.1 Introduction

Sugarcane, *Saccharum* spp, is a strongly growing grass with a C4 carbon cycle photosynthetic pathway and a high chromosome number. It is highly adapted to a wide range of tropical and subtropical climates, soils and cultural conditions and is propagated in over 100 countries situated between 37 °N in southern Spain, to 31 °S in KwaZulu-Natal in South Africa. The sugarcane production cycle typically lasts five to six years in most countries, during which time four to five harvests are made, but under irrigation and with the right cultivar, the cycle can be extended to over 30 harvests, as is the case with some growers in Swaziland.

There can be little doubt that as a source of food and renewable energy, and supplier of income to millions of people, occupying more than 20 million hectares of land, sugarcane must rank amongst the top agricultural crops in the world.

This chapter briefly examines the rapidly changing landscape affecting global sugar production as well as associated environmental and social issues, before dealing with the more technical aspects related to the good management practices of this crop.

1.2 The changing global sugarcane landscape

1.2.1 Sugar supply and demand dynamics

Modern sugarcane production began when the noble cane *S. officinarum*, originating in New Guinea, reached Tahiti in 1768 and replaced *S. barberi*. By the end of the twentieth century, the crop had spread throughout the world, with changes from mainly small scale farming to cultivation on large estates. In recent history, the largest expansion in sugar from sugarcane production occurred between the 1965 and 2010 with countries such as India (3 to 30 Mt) and Brazil (5 to 40 Mt) of sugar dominating global production, while other countries, such as Cuba and the West Indies, have experienced a decline in sugar production (Hartemink 2003).

Today, sugarcane agriculture is a key economic activity in over 100 countries, particularly in developing economies with a high proportion of poor and unemployed groups. As a provider of income and employment, sugarcane based agriculture has an important role to play in the economic growth of developing economies, especially in the upliftment of under-skilled rural people. This is particularly true of Africa, where agriculture is a cornerstone of economic development and transition in the region.

Global sugar production from both sugarcane and sugar beet grown in 130 countries was just over 168 Mt in 2010 (ISO Quarterly Market Outlook 2011), with sugarcane’s share increasing to 79 % of global production. Developing countries share of sugar produced from sugarcane has grown from 67 % in 1998 to approximately 72 % in 2010. Production is becoming more concentrated within countries, with the top ten increasing their share from 56 % in 1980 to around 70 % in 2010. The main driver for this expansion is increased world sugar consumption resulting from rising incomes and changes in food consumption patterns, particularly in Asia and Africa.
1.2.2 Trade liberalization

Various socio-political policies continue to influence sugar prices and increase its volatility. WTO agreements are expected to liberate the sugar trade from distortions but progress in this regard is expected to be slow. The major beneficiaries of these sugar reforms would be the lowest cost of production countries with potential to expand production. The domestic market prices are lower than the average world trade price at present in countries such as Brazil, Thailand, India, Pakistan and South Africa, and if the world price of sugar continues to remain high, these countries are likely to face pressure from domestic consumers and political lobbies to continue to contain the local price. However, this current price differential is likely to be temporary and in general, import tariffs will continue to protect local prices when the world market price falls below the domestic price again.

The sugar markets from both sugar beet and sugarcane production, have over the centuries received a lot of political attention, resulting in these markets being highly regulated. In 1999, the Global Sugar Alliance was established with the objective of achieving meaningful liberalization of the world sugar market. The members of this group (Australia, Brazil, Canada, Chile, Colombia, India, Guatemala, South Africa and Thailand), representing over 50% of world sugar production and more than 85% of world raw sugar exports, signed a communiqué calling for the World Trade Organization (WTO) to liberate the sugar trade from distortions through progressive and meaningful trade reforms. In recent years some trade liberalization has taken place, most notably the restructuring of the EU sugar protocol that initiated a 39% price cut over three years, causing a number of marginal producers to exit and resulted in rationalization amongst other producers. Changes in the pattern of trade in this way will affect production of sugarcane in terms of expansion in new areas, which will in turn impact on the ecological and social environment.

1.2.3 Economic development

In terms of the World Bank Global Economic Prospects (2009), the highest average annual economic growth rate over the next decade will be in China followed by India, Brazil, South-East Asia and Africa, which covers the major cane growing areas of the world. In contrast, in the developed world (Europe, USA and Japan), where most of the sugar beet is grown, the demographics will change as populations on average may either decline, or remain the same (Gopinathan et al. 2010). As a consequence, this is expected to lead to a shift in the demand-supply situation of sugar, moving towards the Asian, South East and African countries.

Against this positive background the economic margins derived from sugarcane agriculture are continuing to decrease in real terms, which have resulted in the need for average farm sizes to increase as growers chase the benefits of economies of scale. This is particularly evident on the large commercial plantations in Brazil, where most field practices are highly mechanized, with a substantial reduction in application costs and time to complete the operations. The advantages of economies of scale, which is an important production strategy of the Brazilian sugar industry, is underlined by this industry having one of the the lowest production cost structures relative to other producer countries, mostly due to the advances of agricultural and industrial technologies associated with the expansion of bioethanol production. In countries with mainly smallholder producers, there is a need for average farm size to increase, but in real terms land holding / farm sizes are decreasing due to population pressure. To overcome this issue, there is a drive towards block farming that will at least obtain some benefit from reduced costs due to economies of scale.

For potential entrepreneurs, entry into the sugar industry becomes more difficult because young aspiring farmers are attracted to more ‘rewarding’ industries, causing the number of farmers to decrease whilst the average age of growers is increasing, as evidenced in the Australian industry.
1.2.4 Biofuel and renewable energy

The trend towards biofuels and renewable energy has continued unabated since the oil crisis flared up in the last decade. In 2007, there were 37 countries mandated for blending ethanol as a fuel component, either directly or blending with gasoline or fuel (Gopinathan and Sudhakaran 2009). Sugarcane is ideally positioned to play an increasing role in producing bioethanol. On the back of their successfully integrated sugar/ethanol/cogeneration business models, Brazil has rapidly expanded its cane planting program despite sometimes suppressed world market sugar prices. The generation of surplus electricity from bagasse is already well established, and in Mauritius 40% of the country’s electricity is produced in this way. Another benefit is that carbon dioxide emission is reduced where coal is replaced by bagasse/trash as a fuel. Rapidly advancing technologies based on biotechnology and bioprocess engineering has converted bagasse into a wide range of other products (Allen et al. 1997; Rogers et al. 2001).

From an economic standpoint, the prices paid to bioethanol manufacturers in Brazil relative to gasoline, have been highly attractive and reinforces the importance of promoting it on a competitive basis. The commercialization of second generation technologies capable of better utilizing the cellulosic component of sugarcane are expected to further speed up this trend.

The successful Brazilian model provides an important lesson to prospective developers, that the State must assume important responsibilities, such as establishing an equitable tariff structure in the fuels market and setting standards and minimum levels for bioethanol in gasoline blends. Likewise, competitive pricing of bioenergy also stimulates cogeneration investment. Developing ‘home grown’ energy also stimulates job creation and rural development, which are particularly important government responsibilities for developing countries.

1.2.5 Technological change

Research remains a key element of a successful and sustainable industry, as demonstrated by the Brazilian example that over the last 35 years not only diversified into ethanol but other derivatives of biomass and molasses. At farm level, there is still considerable scope for improved productivity per unit area through the adoption of good management practices. Even on many irrigated sugar estates in Africa, average yields rarely exceed 70% of climatic yield potential, indicating scope for the implementation of improved practices. A number of sugarcane estates in Africa that were taken over by private enterprise following nationalization, have seen average yields doubling from a baseline value of 50 tc/ha, through improved irrigation, drainage, weed control and fertilization practices. In Zambia, a large estate currently averages yields close to 120 tc/ha/y, equivalent to 17 tons sucrose/ha/y.

Conventional breeding continues to be an important source of sugarcane cultivars, although advancements in genetic modification will doubtless play a significant role in the future (Fitzgerald and Bonnett 2007).

1.2.6 Global warming and climate change

There is now widespread acceptance that accelerated global warming is a result of human activities that started with the industrial revolution, and that if it continues unabated there could be serious consequences for the planet. However, there is still considerable debate around the rate and impact of global warming. The Inter-Government Panel on Climate Change (IPCC) in 2007 reported that if the present trend of warming continued, global temperatures could rise by as much as 6°C over the
long term (IPCC 2008). While increased temperatures could benefit irrigated sugarcane agriculture provided the crop water requirements are met, most models predict that many regions will experience more variable rainfall with a possible decrease in the number of rainy days. This implies that both dryland and irrigated cane will experience more frequent moisture stress periods, necessitating the need for water conservation strategies such as green cane harvesting, and replacing surface irrigation with sprinkler and drip to increase water use efficiency.

1.2.7 Environmental issues

Environmental protection is a rapidly growing concern internationally as man’s impact on natural resources is better understood and becomes more pronounced (Kingston et al 2007). The potential for negative off-site impacts by the sugar supply chain, that includes crop establishment, weed control, fertilization, harvesting, transport and processing on the ecology, has led to ever-increasing scrutiny of current sugarcane production systems from regulatory agencies (Everglades For Ever Act (Anon 1994); Reef Water Protection Plan (DEH 2006)), and from community and consumer groups concerned about environmental sustainability. On the other hand, many of these challenges have been met by self-regulated codes of practice initiated by local industries, as well as in more recent times market driven sustainability initiatives organized largely by Non-Government Organizations (NGOs).

Industry driven voluntary codes of practice initiatives

In response to public and increasing market pressures, growing communities in many cane producing countries have adopted self-regulation codes of practice to identify, collate and disseminate the elements of better management practices for sugarcane production (Australia, COMPASS evaluations (Azzopardi 2002); NSW, Industry Code of Practice (McGuire 2005); Brazil, Jalles Machado ISO14001; India, EID Parry (2006); South Africa, Standards and Guidelines for Conservation and Environmental Management System (EMS) (SASRI 2002), Noodsberg Growers EMS (Mayer and Schulz 2003) and SuSFarMS EMS (Maher 2007).

Since 2001, various stakeholders in the Australian sugar industry have developed the COMPASS (COMbining Profitability and Sustainability in Sugar) code of practice. Ten years later it continues to be a useful tool for sugarcane growers to assess the economic and environmental sustainability of their farms. It uses a straightforward, easy to use workbook that helps growers identify more sustainable farming practices. Current farming practices can be assessed in a wide range of areas, from fertilizer application to harvesting, riparian management to business management, and everything in between.

In South Africa the local growing community responded to public pressures by establishing Local Environment Committees (LECs) for the various extension areas. The Noodsberg, Darnall and Umhlali/Umvoti LECs have introduced the concept of environmental auditing to their growers, hoping to improve their awareness of the standards that have to be attained. Every aspect of environmental management on cane farms is rated on a 0 to 4 point scale to measure progress towards compliance with the required environmental management standards for indigenous vegetation, wetlands, waterways, terraces, cane extraction roads, loading zones, tillage, planting, use of chemicals, irrigation, cane burning, harvesting and a long list of other factors that can impact on the environment and the welfare of workers (Maher 2000).

Recently, a more comprehensive set of revised guidelines known as SuSFarMS (Sustainable Sugarcane Farm Management System) was introduced (Maher 2007). The guidelines emphasize the need for conservation of natural assets and the maintenance of critical ecosystem services as well as focusing on social and economic issues. By auditing each farmer’s compliance to the Principles,
Criteria, Indicators and Verifiers, continuous improvement in sustainable agriculture can be both expected and demonstrated over time. While these developments in self-regulation are extremely commendable, some sugar mills and estates have opted for accreditation of their practices using internationally recognized schemes such as ISO 14000, which makes trade between countries easier and more equitable while safeguarding the consumer.

**Market driven industry sustainability initiatives**

Almost in defiance of self regulatory codes of practice, markets through consumer groups and Non-Government Organizations (NGOs) are promoting social and environmental awareness within industries. As a consequence, ‘triple bottom line’ reporting (Elkington 1998), is gaining momentum, whereby customers, governments and NGOs alike are more aware of and concerned about economic, environmental and social issues in terms of their buying habits and their lobby in reviewing trade policies. The goal for the triple bottom line is for more sustainable practices that comply with:

- Profitable production and maintenance or improvement of quality of production resources.
- Minimizing or avoiding off-site impacts on the environment.
- Production taking place in a socially equitable environment.

International NGOs that are at the forefront of market driven regulation for sugar include the Bonsucro initiative, formerly known the Better Sugar Cane Initiative (BSI) and Fair Trade International, while the Roundtable for Sustainable Biofuels (RSB) was established to set standards for a range of biofuel feedstocks including the sugarcane ethanol value chain. Bonsucro was launched to fill the need for an international set of sustainable sugar standards by which industries, companies and investors could define their sugar purchasing principles. While there have been concerns that developing sugarcane producers might not be able to comply with these standards, even on a voluntary basis, the reality of the situation is that an increasing number of food products that are globally traded, will eventually require certification not only in terms of quality, but also on how the food crop is grown. Sugar is no exception and, as in the case of coffee and other food commodities, sugar producers will need to give Bonsucro serious consideration.

Customer and stakeholder demands, as channeled through these organizations, will become an important part of the future sugarcane value chain which will include the processing of sugar, ethanol and power. (See Section 3, Chapter 1 for a detailed description of market driven industry sustainability initiatives.)

**1.3 The impacts of sugarcane production on the environment**

Given that more than 20 million hectares of land are cropped to sugarcane, mostly as a monoculture, intensive use of agricultural chemicals such as fertilizer, herbicides and ripeners, coupled with greater reliance on heavier mechanical harvesters and infield haulage equipment, it is not surprising that sugarcane production continues to raise concerns about environmental impact issues and sustainability. Sugarcane is listed as one of four crops to be investigated in terms of its impact on biodiversity as part of the IFC’s Biodiversity Agricultural Commodities Program (BACP). It is also widely acknowledged that commercial agriculture has the potential to impose severe hydrological, soil degradation and biodiversity impacts on the natural environment (Clay 2004).

According to Gopinathan and Sudhakaran (2009), “A degraded environment truncates the set of livelihood strategies available to the poorest people and undermines economic growth, particularly where legislation is weak or inadequately enforced.” Although many scientific papers have reported on the impacts of sugarcane production, separately on soil loss, soil degradation and water
pollution, an excellent more recent publication by Cheesman (2004) has reviewed the work more holistically, in terms of the whole range of impacts, including biodiversity, water use and quality, soil quality and air quality. While the impacts of different practices are considered under each of the chapters in this manual, some selected examples of impacts and measures to mitigate these impacts are summarized below.

1.3.1 Biodiversity loss

Loss of natural habitat
The process by which natural ecosystems of endemic tropical and sub tropical plants are cleared and then replaced by artificial ones, such as sugarcane grown as a monoculture, has destroyed much of the natural flora, fauna and soil biota biodiversity, that formed part of the previous ecosystem. In terms of social impact, this loss in habitat in turn would have undermined the lives, livelihoods and cultures of peoples who previously used the ecosystems for hunting, gathering, grazing or shifting cultivation.

Habitat fragmentation
In Australia, Arthington et al. (1997), in a study on the potential impact of sugarcane production on riparian and freshwater environments, concluded that sugarcane cultivation may interfere with and modify the functional linkages between vegetated riparian zones, the surrounding land, streams, riverine flood plains and the adjacent marine environment. They highlighted three consequences of sugarcane production that have been particularly detrimental in coastal catchments as follows:

(i) Extensive vegetation clearing of riparian zones of rivers and flood plain wetlands, (ii) soil erosion and stream sedimentation and (iii) contamination of water bodies with nutrients, pesticides and other discharges from diffuse sources. A report by Johnson et al. (1997) using a Geographic Information System (GIS) to compare the distribution of vegetation species between the 1960 and 1996, concluded that sugarcane lands have increased and that landscape diversity, integrity and quality of these ecosystems have declined.

The impacts of monoculture on diversity
Sugarcane cultivation, particularly under continuous monocropping, can have a serious impact on biodiversity by building up harmful species of organisms. The yield decline syndrome project in the Australian sugar industry was initially linked to a root pathogen called Pachymetra chaunorhiza. Cultivars that were found to be resistant to this pathogen led to yield increases of up to 40% (Egan et al. 1984). Subsequent intensive studies highlighted the importance of a legume fallow, reduced tillage, green cane harvesting, and controlled infield traffic in improving soil health, especially in providing a balanced population of soil biota (Garside and Bell 2006).

The benefits of diverse cultural practices
- In a study conducted in Egypt, Salman et al. (1978) compared sugarcane fields at two localities in Upper Egypt, and found much greater numbers of predacious arthropods (mostly spiders and coccinellid beetles) in the more diversified ecosystem.

- Baliddawa (1985) in his literature review on the effect of plant species diversity on crop pests, concluded that populations of several pests were found to be depressed in situations where crop and/or weed diversity was relatively high.

- In the South African sugar industry, researchers have demonstrated in a number of experiments that using diverse cultural practices can help to reduce the build-up of pathogens and pests such as nematodes, avoiding the need for treatment with toxic chemicals. Apart from using legumes as a fallow crop, or adding organic residues such as manures and composts to soils (Berry et al. 2005),...
recent work showed that where nematodes were a serious limiting factor, planting a mixture of cultivars (NCo376, N12 and N31 or N39) in the furrow increased yield by about 40% over that of the average of the individual cultivars planted alone (Spaull et al. 2006).

- Reports of similar studies have shown that mixtures of cultivars suffer less from diseases and abiotic stresses and are higher yielding than single cultivars (Garrett and Mundt 1999; Newton et al. 1997; Wolfe 1985, 2000).

- A more recent study to determine the reasons for better cane growth on soils associated with former termite mounds showed that, in addition to improved physical and chemical properties due to a build-up in clay by termites, the number of nematode species was greatly enhanced. In particular, there was a greater presence of the species *Helicotylenchus dihystera*, a beneficial nematode that in previous studies was found to be associated with better sugarcane growth (Cadet et al. 2002).

- In Australia, in studying the impact of farming systems on soil biology and soil borne diseases, Stirling (2008) concluded that the integration of sugarcane and vegetable production led to a more diverse population of soil biota species.

1.3.2 Water resource use

- It has been reported that at the global level, the agricultural sector is responsible for about 70% of all freshwater withdrawal, more than twice the amount of industrial, municipal and all other users combined, and this consumption can threaten downstream ecosystems or those that share aquifers with crops. Where evaporation rates are high relative to rainfall, irrigation can also cause salt contamination of surface soils (Clay 2004).

- Most reports indicate that approximately 100 mm of water (effective rainfall or irrigation) is needed to produce 10 tc/ha (1 ML/ha/10 tc) (Isobe 1968; Humbert 1971; Scott 1971; Thompson and Boyce 1971). If one assumes that rainfall is only 70% effective then the water requirement translates into about 14 ML for a 100 t/ha crop of sugarcane. Other reports quoted by Cheesman (2004) provide estimates ranging from 15 to 54 ML/ha for irrigated cane growing in parts of northwest Australia (Wood et al. 1998). A subsequent study reported an allocation of 17ML/ha and a budgeted value of 22ML/ha (Gosnell 2002). Despite their importance to the industry, sugarcane irrigation systems have often been found to be inefficient, leading to wastage of water.

- Groundwater withdrawals are reported to exceed natural recharge rates of aquifers, leading to the lowering of water tables, potential salinization and land subsidence in many parts of the world (Gopinathan and Sudhakaran 2009). There are not enough water sources further that can be diverted for increased sugarcane production.

- In countries such as India the current water development and management system is considered unsustainable, due in some countries a highly seasonal rainfall pattern with 50% of annual rain falling in just 15 days and over 90% of river flows occurring in just four months. It is also reported that India’s dams can store only 200 m$^3$ water/person, which translates to 30 days of rainfall, compared to 900 days in the major river basins of the world (World Bank 2005; IPCC 2007).
1.3.3 Pollution of water sources

Watercourses and aquatic habitats can be polluted by agrochemicals and sediments due to both sugarcane cultivation and downstream sugarcane processing. Groundwater can be contaminated by leaching of nutrients from fertilizers especially when applied to sandy soils that can extend to downstream coastal zone ecosystems (WWF 2003). With regard to pesticides and herbicides, while there is still considerable concern about the potential for pollution, it would appear from recent reports that the better management practices being employed by commercial agriculture are having increased benefits. In Australia for example, it has been reported that the long term threat of pesticide impacts has been contained in recent years, as less persistent chemicals have replaced older formulations of the lethal organochlorine pesticides, which in earlier times were widely used in the Australian sugarcane industry (Cavanagh et al. 1999). However, in the case of fertilizers and other amendments, there appears to be mounting evidence for increased levels of contamination by nitrogen and phosphorus. Further examples of research outcomes from various countries include:

**Mauritius:** A research study covering 40 ha of land, conducted in an environment that experiences more than 3,500 mm rainfall each year, revealed that mean herbicide concentrations in run-off waters were low and did not exceed existing drinking water guidelines (Umrit and Ng Kee Kwong 1999). The total mass of herbicide lost by runoff from the 40 ha catchment over one growing season represented very low proportions of the quantities applied (not more than 0.02% atrazine, 0.32% hexazinone, 0.07% diuron and 0.19% acetochlor).

**USA, Everglades:** Regular monitoring of groundwater quality has revealed increased levels of nitrate and phosphate despite the fact that on the peat soils no N fertilizer is used. Here cultivation methods that disturb the soil together with the lowering of water tables, has released levels of nitrate through mineralization of nitrogen from the native organic N pool in the soil. Research has been carried out to develop Best Management Practices for sugar cultivation to reduce these impacts (Anderson and Rosendahl, 1998).

**Brazil:** Chemical water quality and macroinvertebrate fauna of two streams in the Piracicaba river basin in south-east Brazil were related to land use (including sugarcane cultivation) in their respective catchments (Ometto et al. 2000). This was confirmed in another study that showed sugarcane cultivation could be a contributory factor in increased levels of dissolved nitrogen and phosphorus in the lower portion of the Paraiba do Sul river, Brazil (Silva et al. 2001).

**Hawaii:** Investigations indicated that elevated loads of nutrients and sediments in the coastal waters of West Maui, Hawaii, were due to sewage effluent impacts as well as some contribution from sugarcane and pineapple cultivation (Soicher and Peterson 1997).

**Australia:** Increased application of N fertilizers in Australia has led to soil acidification, contamination of ground and surface water and enhanced greenhouse gas emission (Keating et al. 1997). Thorburn et al. (2003) confirmed elevated levels of nitrate in some boreholes located in the north-eastern parts of Queensland. In the Tully river catchment (North Queensland) alone, the area under sugarcane and bananas doubled and fertilizer N use/ha increased by 130% between 1987 and 1999, suggesting that elevated levels of nitrate were due to higher N usage as well as inefficient use of N fertilizer (Mitchell and Larsen 2000).

**South Africa:** A comprehensive survey of ten years of river water quality data covering 12 selected rivers in the sugar industry showed small increases in concentrations of ammonium and nitrate forms of nitrogen, as well as phosphate and potassium. With the exception of the Crocodile River in Mpumalanga, the peak concentrations of these nutrients were well below accepted world standards.
for drinking water. The survey revealed that water quality for irrigation was deteriorating in some of the rivers, with the Mkuze River moderately saline with a fairly high sodicity hazard, and that salinity levels in the lower Crocodile River have more than doubled since the last assessment was made in 1976. Of the other rivers, the Pongola, Umfolozi and Mhlatuze showed a moderate sodicity hazard, implying that use for irrigation in the long term could lead to soil degradation and eventual yield decline on sensitive soils (Meyer and van Antwerpen 1995).

Judging from the literature that has been reviewed by Cheesman (2004) and recently updated, the impacts of sugarcane processing on water quality are mainly due to high Biological Oxygen Demand (BOD) levels from organic matter and carbohydrates. Principal sources of mill effluent include those derived from cane washing, barometric condenser cooling water, spillages, and cleaning operations. Other sources include oil and grease, heavy metals and cleaning agents. The pH and temperature of discharged effluent can also influence the potential pollution hazard. Selected examples cited by Cheesman of potential cane processing impacts on water quality and aquatic ecosystems are given in the Box 1.1 below.

**Box 1.1 Examples of some impacts of sugarcane processing on water quality and aquatic ecosystems**

- **India:** Pollution of rivers by mill effluent has in the past been a major problem at some mills in India. For example, in the Abu drainage area at Meerut in Uttar Pradesh (Rajendra Singh 2000). They examined soil and water pollution levels and identified indiscriminate discharge of effluents from a wide range of industries (including sugar mills) resulting in serious effects on the local flora and fauna, and water was found to be unsuitable for human consumption, domestic use and irrigation purposes.

- **Nepal:** Discharge of water from two sugar factories and a distillery into a stream without proper treatment in the Gorakhpur district in Nepal had rendered the water unfit for drinking, bathing or irrigation (Srivastava 1998).

- **Kenya:** Pollution from effluents emanating from sugar and other industries in the Kenyan part of the drainage basin that feeds Lake Victoria is reported to be having an effect on downstream water quality (Thuresson 2001).

- **Trinidad:** Wastewater monitoring at the Sainte Madeleine cane sugar mill led to major expenditure on wastewater treatment to further prevent serious pollution of the Cipero River.

Most large sugar industries are very conscious of pollution and are usually policed by local authorities. There has also been considerable progress in the management of solid and liquid wastes and effluents at most large mills, considerably minimizing the risk of environmental pollution. Some examples that were observed during the field trip include composting of filterpress mud and other wastes, anaerobic ponds, ash-packed anaerobic filters, aeration systems, maturation ponds, re-use of effluents. Even in the case of vinasse, the law in Brazil now requires that a K balance is required to assess how much vinasse can be returned to the fields. The canals conveying vinasse are lined with plastic to prevent seepage and groundwater contamination. Since the temperature of the vinasse ex the factory is around 50 °C, a vinasse cooler is used to prevent damage to the plastic.

### 1.3.4 Soil loss impacts

Where planting and production practices take place under conditions of high rainfall and steep terrain, the potential for soil loss through erosion and loss of nutrients is high, as well as the loss of diverse communities of soil organisms, and material that is washed away into rivers to damage...
downstream ecosystems (such as coral reefs) and economic infrastructures (such as dams). Some examples of investigations in different countries follow:

**Brazil**: Soil loss from sugarcane fields in a study in Brazil has been estimated by Weill and Sparovek (2008) using the Universal Soil Loss Equation (USLE) at 58 t/ha/an. In this study the influence of topography, soil erodibility, crop use and management and erosion control practices were evaluated. It was found that under similar weather conditions, crop management and erosion control practices had the greatest influence on soil loss. When crop management and erosion control practices were kept constant, topography had the greatest impact. The erodibility factor thus showed less influence in this case. Also using USLE calculated estimates, Prado and Nóbrega (2005) estimated soil loss of greater than 20 t/ha/y for sugarcane cropping in Parana state in Brazil.

**South Africa**: Erodibility ratings of some South African sugar industry soils were determined by Platford (1982) using runoff plot measurements. The results of both laboratory and field experiments with rainfall simulators conducted on grey Plinthisol soil (Longlands form), showed that surface crusts do not form under a trash mulch. Average results from five trials conducted with a rainfall simulator over a five-year period showed that trash saved 89% of the soil and 58% of the water lost from plots where tops from burnt cane had been spread (Platford 1982). As a consequence of this research, trashing (mulching) is recommended on slopes greater than 15% during the wet season, to reduce the impact of raindrop action, if insufficient crop cover has developed.

Benefits to minimum tillage were quantified by Haywood and Mitchell (1987) and results showed a 60% reduction in soil loss and 34% reduction in runoff. Further investigations by Platford (1987) showed soil losses and runoff percentages as in Table 1.1.

**Table 1.1. Summary of soil losses and runoff from rainfall simulator trials comparing conventional tillage and chemical minimum tillage (from Platford 1987).**

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil</th>
<th>Slope (%)</th>
<th>Tillage</th>
<th>Loss (t/ha/y)</th>
<th>Runoff (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Mercy</td>
<td>Waldene</td>
<td>6</td>
<td>Conventional</td>
<td>4.4</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum tillage</td>
<td>0.8</td>
<td>67</td>
</tr>
<tr>
<td>La Mercy</td>
<td>Waldene</td>
<td>8</td>
<td>Conventional</td>
<td>8.6</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum tillage</td>
<td>3.4</td>
<td>69</td>
</tr>
<tr>
<td>Darnall</td>
<td>Williamson</td>
<td>17</td>
<td>Conventional</td>
<td>15.7</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum tillage</td>
<td>4.1</td>
<td>22</td>
</tr>
<tr>
<td>Cornubia</td>
<td>Clansthal</td>
<td>15</td>
<td>Conventional</td>
<td>16.4</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum tillage</td>
<td>0.1</td>
<td>4</td>
</tr>
</tbody>
</table>

Additional examples of important research outcomes include:

- **Australia**: Soil losses of 42-227 t/ha/y were recorded on conventionally cultivated slopes of up to 8% (Sallaway 1979a, 1980), and 47-505 t/ha/y (average 148 t/ha/y) on conventionally cultivated slopes of 5-18% (Prove et al. 1995).
- **Mauritius**: Soil loss from bare plots of 37.6, 14.3, 9.5, 4.1 and 0.5 t/ha/y were obtained on five soils in Mauritius on various slopes. Sugarcane was shown to reduce erosion by 80 to 99% compared to a bare fallow (Seeruttun et al. 2007).
- **Fiji**: Research into soil loss through erosion showed a soil loss of 16 t/ha/y from cane planted up and down the slope on an 8°, slope but only 220 kg/ha/y in trashed ratoons planted across the slope (Ram et al. 2007).
- **Argentina**: Scandaliaris et al. (2002) considered the use of cover crops in cane cultivation. As well as reducing superficial erosion, cover crops reduced evaporation rates, provided a physical barrier to weed growth, and generated improvements in soil quality.

Quite clearly, there is the potential for substantial soil loss from conventionally cultivated lands depending on the slope and stage of crop, but with some management practices such as trashing and minimum tillage, combined with strip cropping the risk of soil loss is considerably reduced. It should be noted that the sugarcane crop once it has canopied and when the crop root systems have been established, provides a very stable erosion control mechanism. According to Platford (1987), 85-90% of soil loss from sugarcane fields occurs at the time of replanting. New land developments would be subject to the same or greater risk of soil erosion and this would be a critical time for careful choice of systems and care in implementation (see Chapter 3).

### 1.3.5 Soil degradation

The soil is a living, dynamic system made up of different mineral particles, organic matter and an extremely diverse community of living and interacting microorganisms that is referred to as the soil ecosystem or the soil food web. Soil not only provides mankind with food and renewable energy sources, but also produces living space and food for billions of microorganisms. Conservation of this ecosystem is seen as vital for maintaining the physical, chemical and biological integrity of the soil and the sustainable cultivation of sugar crops (e.g. Morgan 1986; Meyer and Wood (2000).

Sugarcane cultivation, particularly when grown as a continuous monoculture, can contribute to soil degradation and yield decline (Henry 1995, Meyer 1995, Garside et al 1997, Haynes and Hamilton, 1999). It is the use of intensive agricultural practices such as ripping and deep ploughing, over-fertilization, no recycling of organic residues, no legume breaks, uncontrolled field traffic that lead to soil compaction, which in general represents a threat to soils in tropical areas (Meyer and van Antwerpen 2001).

Soil quality is a complex concept, involving a wide range of biological, chemical and physical variables. Haynes (1997) considers that soil quality can be broadly defined as, “the sustained capability of a soil to accept, store and recycle nutrients and water, maintain economic yields and maintain environmental quality.” Soil quality has been shown in studies in South Africa and elsewhere to be adversely affected by the wrong management practices. In a paper covering the results of paired site survey of virgin and adjoining land, reductions in soil organic matter, increased acidification, compaction and sometimes increased salinity were all found in cultivated fields compared to the adjoining virgin sites (Dominy et al 2001).

Meyer et al (1996) carried out a review of soil degradation and management research under intensive sugarcane cropping, soil factors limiting yield potential that were identified for the grey soil group, were low intake rates due to crusting, soil loss through erosion, low available moisture capacity, soil organic matter loss, acidification and waterlogging during wet seasons. A number of ratoon management practices currently in use, such as interrow ripping, burning of crop residues at harvest, harvesting under wet conditions and using heavy infield transport, were found to be incompatible with the physical, chemical and biological properties of these soils.

Practices that conserve soil organic matter such as green manuring, minimum tillage, the use of organic nutrient carriers such as filtercake, chicken and cattle manure, and trashling of cane at harvest (Kingston et al 2005) have greatly increased in the industry as there is a need to sustain the all-important functions of the soil food web by maintaining soil humus (van Antwerpen et al 2003).
Further practices that improve soil quality and health based on soil specific guidelines are explored in Chapters 2 and 3.

1.3.6 Air quality impacts

Impact of burning
The cultivation of cane can result in air pollution where the crop is burnt prior to harvesting. Many industries have established codes of burning practice to limit the nuisance value and danger of smoke on highways. A Green Protocol was recently sponsored between UNICA and the State of São Paulo that provides for the elimination of sugarcane burning by 2014 for areas that can be mechanized and 2017 for the other areas (UNICA 2008). All new sugarcane areas must be harvested mechanically. Specified prohibition areas are near urban perimeters, highways, railways, airports, forest reserves and preservation units, among others. The elimination of sugarcane burning must be gradual since mechanization will inevitably provoke unemployment of former cane cutters. The sugarcane industry is working together with international organizations, NGOs and the State government to requalify the 200 000 sugarcane cutters of the São Paulo State.

On the industrial side, stricter enforcement, new emission standards for bagasse-fired boilers and substitution of old boilers for more efficient units have been contributing to a progressive reduction in stack emissions, principally particulates.

The impact of nitrous oxide emission
The cultivation of sugarcane results in varying levels of air pollution in the form of nitrogenous emissions from soils, arising from the use of nitrogenous fertilizers which release nitrous oxide from either the nitrification of ammonium or the denitrification of nitrate in wet environments. In sugar industries with high rainfall (> 2 000 mm/y) or over-irrigation, the potential for nitrous oxide release is very high, especially where the soils are not well drained (Keating et al. 1997). Nitrous oxide is a potent greenhouse gas (GHG) that can add significantly to the carbon footprint of sugar or ethanol production. It is problematic not only because it is 298 times more absorptive than carbon dioxide, but can also linger in the atmosphere for over a hundred years. In GHG balance studies, calculating the global warming contribution from N fertilizer is uncertain and dependent on the fate of applied N. Nitrous oxide emissions can vary by more than two orders of magnitude, depending on the combination of soil composition, climate, crop and farming practices present (Rein 2010). Following the IPCC recommendations, the assumption is made that 1.325 % of N in nitrogen fertilizer is converted to N in N₂O through nitrification and denitrification. However, this is very general and should be based on at least the soil type and crop potential. N fertilizer use efficiency by the crop will vary widely from 25 to 60 % and will depend on soil type, application methods, cultivar and system of irrigation (Meyer et al. 2007). With drip irrigation and fertigation, N fertilizer use efficiency can be greatly improved and the downside risk of N loss through denitrification will be greatly diminished.

On the other hand, various studies in Australia have focused on GHG emissions, and how they are affected by soil type, moisture conditions and trash blanketing. The findings suggest that the emission factor of 1.325 % recommended by the IPCC could be too low (Allen et al. 2008; Denmead et al. 2008). Follow-up work will be needed to develop a set of ratios that could in practice cover a range of soil types and cropping conditions.

Use of Life Cycle Analysis
Climate change has promoted great interest in GHG emissions, otherwise referred to as the carbon footprint. The GHGs that are listed in the Kyoto protocol are CO₂, N₂O, CH₄, SF₆, perfluorinated compounds, methylene chloride, certain ethers, and hydrofluorocarbons. As far as the cane industry is concerned, only the first three are applicable in terms of assessing the carbon equivalent emission.
Life Cycle Analysis is increasingly being used to quantify the likely impact of production processes on carbon emissions. The approach has received wide attention in the biofuel industry, but less attention in the production of sugar. In a hypothetical example to illustrate the methodology using a set of base case values for the various inputs, the total GHG emissions were calculated as 0.43 g CO$_2$eq/g sugar, but when the credit for molasses production and power export was applied, this emission improved to 0.31 g CO$_2$ eq/g sugar (Rein 2010). The emissions from the use of nitrogen fertilizers and lime in the fields accounted for almost half the emissions, but the author cautioned that the uncertainty introduced by the use of these fertilizers has a significant bearing on the reliability of the emission estimates. Burning of cane in the fields also has a significant effect, comprising 10 to 15 % of agricultural emissions when the total crop is burnt. The EU Renewable Energy Directive states that ethanol produced from sugarcane has the best default value of 71 % emission saving relative to fossil fuels, compared to 16 to 52 % variation for corn, wheat or sugar beet.

British Sugar Corporation and Tate and Lyle recently employed a life cycle approach to evaluate the carbon footprint of sugar. In Australia, Renouf and Wegener (2007) have calculated the carbon footprint for raw sugar production under three different Queensland scenarios.

In a study conducted in the Mauritius sugar industry, using a Life Cycle Analysis, Ramjeawon (2004) estimated that cane cultivation and harvesting accounted for the largest environmental impact of 44 % of GHG emissions, followed by fertilizer and herbicide manufacture (22 %), sugar processing and electricity generation (20 %), transportation (13 %) and cane burning (1 %).

In terms of the future international consumer market it is anticipated that the carbon footprint of sugar producers in any cane growing area of the world will have to be specified in accordance with a standardized system that will still need to be agreed on by various certification bodies.

**Box 1.2 Strategies to reduce carbon emissions (after Rein 2010)**

In the sugarcane industry, particular improvements can be achieved by focusing on the following, in roughly the following order of importance:

- Cogenerate and export power to the maximum extent possible
- Maximize cane yield and factory recovery
- Reduce the amount of fertilizer and chemical inputs, particularly N fertiliser
- Reduce the extent of cane burning to zero
- Reduce the quantities of any supplementary fuels purchased.
- Minimize irrigation power input.
- Reduce cane transport distances
- Recycle water to reduce water intake.

Other avenues to explore could involve the generation of biogas from wastes. Vinasse from 1 m$^3$ of ethanol treated anaerobically produces 115 m$^3$ of biogas, which in turn can generate 169 kWh of power, after deducting the power used in the process (BNDES 2008).

**1.3.7 Social and community impacts**

It was apparent from recent visits to estates in a number of countries that companies are becoming more socially responsible, and are seeing the benefits of investing in the welfare of their staff as well as complying with stricter labor laws and codes of conduct that their Governments have set.
Communities are being involved in the value chain to a greater extent and there is tangible evidence of improved worker conditions and ongoing training programs for staff, not only to reduce farm and factory accidents but also to raise levels of technological, environmental and computer literacy amongst workers as well as outgrowers. Further examples of good management practices as contained in the report covering visits to various countries (Meyer et al. 2011) are summarized below.

- The Brazilian government is signatory to a whole host of international treaties ranging from agreements on forms of child labor to conventions concerning equal remuneration for men and women workers for work of equal value. These have consequently resulted in very strict government regulations about social and labor conditions for workers so minimum standards are high and many companies do not need to exceed minimum standards.
- In conformity with Brazilian law, all sugarcane workers must receive at least the minimum salary in force in Brazil. They also receive extra compensations based on productivity. This additional payment allows sugarcane cutters to almost triple their revenues and be the best paid among rural workers.
- Brazil has generous working conditions for employees such as one months’ annual leave, a vacation bonus of 33% for that month, a thirteenth cheque, and an employer contribution of 70% towards employees’ pensions funds and in-house medical facilities.
- Two mills in Brazil have developed comprehensive environmental resource centers at their factories. Particularly impressive is the new purpose built centre at the Boa Vista mill, built entirely out of recycled material.
- UNICA has implemented retraining programs, to provide alternative skills and opportunities for cane cutters and others whose functions have been replaced by mechanized planters and harvesters.
- With the support of the World Bank Institute, UNICA set up a Socio-Environmental and Responsibility Unit, to implement various programs within the industry and build on best practices for corporate, social and sustainable competitiveness among current and future workers in the industry. The Unit also works with industry suppliers, media, NGOs and executives to encourage sustainable practices.
- In India, the EID Parry mills have developed a progressive system for interaction with farmers, recognizing that farmers are both investors and partners. They provide significant support services on a sustainable basis to ensure that cane supply to the factory remains stable and sustainable.
- EID provides a prime case study model of how cane supply and smallholder farmers can be maximized through strong partnerships. Farmer demonstration plots are used as training grounds to identify lead farmers to demonstrate techniques and sustainable management practices.
- EID in India and RSSC in Swaziland provide comprehensive employee welfare programs with incentive and attendance schemes, social services including counseling and life balance improvement classes, group savings initiatives, canteen services, dispensary, clubs, sports and cultural events, and PPE and uniforms.

1.3.8 Summary of Good Management Practices

Agricultural impacts

Environmental impacts of production practices can largely be reduced by the adoption of general good management practices. In the case of agriculture this might involve the adoption of alternative cultivation systems (e.g. integrated or precision methods) that provide more efficient use of chemicals, and subsurface drip irrigation to save on water and chemicals such as N fertilizer. Many of the impacts of the cultivation of sugarcane are significantly influenced by local conditions, such as
soil type and climatic factors, so appropriate planning as well as management is an important factor in the reduction of cultivation impacts. Possession of good quality soil maps is essential in adopting soil specific management guidelines (see Chapters 2 and 3). The challenge to the grower community is to protect biodiversity through the maintenance of natural habitat fragments within the farmed landscape, and the adoption of more diverse cropping systems that include legumes to break the monoculture of sugarcane. A number of good management practice guides are available such as the Australian CANEGROWERS’ Code of Practice for Sustainable Cane Growing in Queensland (CANEGROWERS, 1998) and in South Africa, the South African Sugar Association’s Manual of standards and guidelines for conservation and environmental management in the South African sugar industry (SASRI, 2002). Further generic recommendations of good management practices are summarized below.

**Box 1.3 Summary of selected generic recommendations to minimize cane cultivation impacts**

**Land use planning and zoning:** Biodiversity conservation and maintenance of ecosystems need to be addressed on a landscape level, as well as on individual fields. Without effective conservation measures, farms can quickly consume a dry region’s water supplies, impacting specific species and critical habitat as well as biodiversity more generally (see Chapter 3).

**Crop establishment:** Soil specific guidelines need to be followed when planting, and production practices must protect soil ecology and fragility, particularly under conditions of high rainfall and steep terrain. The potential on steep terrain is high for loss of nutrients and soil structure, diverse communities of soil organisms and contamination of downstream ecosystems (see Chapter 2).

**Planting on former cultivated lands:** Planting on previously cultivated agricultural or pasture land involves less labor, machinery, pesticides and clearing than planting in natural habitat. Such areas are arguably more expendable from a conservation point of view, and in Brazil this policy will be followed in their expansion of sugarcane areas.

**Maintaining soil fertility:** Fertilizer recommendations based on soil tests and soil specific advice should be adhered to at all times, followed by regular leaf sampling; recycling of mill organic wastes such as filterpress mud (for phosphorus), fly or boiler ash (for silicon) and vinasse (for potassium)(see Chapter 2).

**Reduced use of inputs:** Integrated Pest Management (IPM), precision application methods, spot applications as needed and the elimination of prophylactic use of agrochemicals are all ways to reduce inputs.

**Reduction in water use:** Reducing excessive water consumption by adoption of more appropriate irrigation practices; improved scheduling of irrigation to enhance water use efficiency; adoption of water-saving irrigation methods, recycling of drainage water, mulching or trashing to reduce evaporation.

**Improving soil quality:** Controlled infield traffic practices to reduce soil compaction and stool damage and the use of ‘Low Ground Pressure (LGP) running gear’ to control tyre pressure while the vehicle is moving , as well as the use of GPS on both harvesters and infield transport to prevent inadvertent ‘straying’ of machinery onto crop growing areas.

**Reducing air pollution from pre-harvest burning of cane:** Continued adoption of green cane harvesting/trash blanketing, already widely used in parts of the industry, this technique yields a wide range of environmental benefits in terms of water saving and improved biodiversity.
**Processing impacts**

Two areas where good progress has been made in recent years are the recycling of water used in cane mills and the treatment of effluents. Available effluent treatment techniques include simple screening and settling of solid wastes, and more sophisticated (aerobic and anaerobic) methods for biological treatment. Further examples of practices where environmental impacts can be reduced are summarized below.

### Box 1.4 Summary of selected practices to minimize processing impacts (see Section 2)

**Water conservation:** Many older mills still indulge in cane washing which contributes greatly to inefficient water use. This is gradually being phased out in Brazil because of the high water usage. Historically, the water use benchmark was 22 m$^3$/t cane, this has been drastically reduced to 2 m$^3$/t cane in 2005, and is projected by CTC to go to 0.5 m$^3$/t cane. At the La Union mill in Guatemala, water usage has been greatly reduced to a level of 1.4 m$^3$/t cane.

Recommended practices include:
- Replacing cane washing with dry cleaning to remove sand and leaves,
- Recycling used condenser cooling water for irrigation,
- Managing the factory water balance, aim to use less than 1 m$^3$/t cane.

**Air quality:** Reduction of stack emissions of mainly particulates on the industrial side, through stricter enforcement of new emission standards for bagasse-fired boilers and substitution of old boilers for more efficient units. Greater use of Life Cycle techniques to establish the carbon footprint of both factory and agricultural operations, and to develop strategies for lowering the footprint based on reforestation of fragile areas with indigenous trees, recycling organic mill wastes back to fields as added value compost, implementation of environment Education Centers for staff and the community, use of sustainability metrics for meeting all the requirements of sustainable production.

**Energy conservation:** Measures adopted by various mills include:
- Energy generation from bagasse must be measured and controlled for optimization.
- Replacing old boilers with more efficient high pressure boilers.
- Use of renewable supplementary fuels such as woodchips instead of coal.
- Attention given to factory steam and energy balance.
- The use of cane leaves and tops as fuel is receiving widespread attention.
- Utilization of waste heat.
- Potential for biogas generation and use.

**Soil and economic sustainability:** Evaporation of vinasse to Condensed Molasses Solubles (CMS) is gaining wider acceptance in terms of adding value as a K fertilizer while biogas fermenters on vinasse are also fairly widely evident in Brazil, India and Argentina.
Social and community impacts (see Section 3).

**Box 1.5 Summary of selected generic good management practices**

**Social welfare: provision of comprehensive employee welfare program**
- Compliance with local government labor and social regulations concerning minimum standards for workers.
- Provision of incentive and attendance schemes, group savings initiatives, insurance, canteen services, dispensary, clubs, sports and cultural events and PPE and uniforms.
- Provision of schooling and crèche facilities.
- Provision of psychological, economical, health and environmental wellbeing of the employees and their families.
- Encouraging participation in exercise regimes throughout companies where trainers take employees through a series of exercises in the morning aimed at focusing the employees to reduce accidents and promote alertness.

**Labor management and working conditions**
- Maximum daily and weekly working hours for each employee, fixed period of leave and thirteenth check or bonus related to company performance.
- Introduction of retraining programs for employees who have been retrenched, and provide alternative skills and opportunities for cane cutters and others whose functions have been replaced by mechanized planters and harvesters.

**Land and resource management**
- Provision of environmental resource centers at each factory.
- Allocation of 20% of farm land to natural resources in ecologically sensitive areas (e.g. Amazon), the split is reversed.
- Legislation against burning.

**Community Health, Safety and Security**
- Reporting of safety incidents.
- Risk assessment and mitigation policy and management: Enable environmental, health and safety performance results to be made available to all employees and company officials to see.
- Training and re-training of all employees on a regular basis; general and job specific, and needs be conducted continuously.
- Provision of safety equipment
- Hazards in the workplace: Good housekeeping is an essential part of reducing risks in the workplace.
- Measurement of lost time due to safety incidents.

**Outgrower and contract farming**
- Smallholder developments can work provided a holistic approach is applied to outgrower development, which involves the ongoing involvement and partnership between the host company, donors, banks and farmers, instead of just taking a technical approach which is unsustainable.
- Farmer demonstration plots provided by the host company are essential as training grounds, to demonstrate techniques and sustainable management practices.
- Case study models of successful smallholder farming developments need to be written up and published, as a large part of future cane supplies will be generated by smallholder farmers in places like Africa.
1.4 The soil-plant-climate continuum

The main requirements for a high yielding sugarcane crop are water, heat, sunlight and adequate nutrition, and given the right combination, together with deep soils and good management practices, biomass yields in excess of 130 tonnes per hectare per annum are achievable on a commercial basis. The best climate for growing dryland sugarcane is one with two distinct seasons: one warm and wet, for encouraging germination and vegetative development, followed by a cool, dry season to promote ripening and consequent accumulation of sucrose in the stalks.

Moisture supply from the soil to the sugarcane plant through the root system is continually in sync with moisture demand through transpiration losses through the stomata in the leaves to the atmosphere. In many ways a sugarcane plant can be compared to a continuous column of water with a control mechanism at each end, the bottom end being the root/soil interface and the top end representing the stomata/atmosphere interface. Scientists refer to this highly dependent relationship between all three components as the ‘soil-plant-atmosphere continuum’ or SPAC. Further important points include:

- The atmosphere, comprising the combined effects of temperature, solar radiation and evaporation, can be considered the primary driving force controlling the rate at which moisture is absorbed through the root system into the plant and transpired through the leaf stomata of the crop.
- Under good growing conditions the amount of moisture taken up through the roots from the soil is almost equal to the amount lost through transpiration from the leaf canopy (±98%).
- The rate of transpiration can be controlled by closing the stomata, but this will reduce growth and development of the crop.
- Moisture uptake through the roots is reduced when the soil is unable to supply sufficient moisture to meet atmospheric demand.
- The soil moisture supply to the sugarcane plant must meet the demand for moisture from the atmosphere to ensure maximum growth rate.

1.4.1 Climate

Temperature

Sugarcane requires high temperatures for growth, with optimum temperatures of between 20 and 30 °C, although cultivar differences and cultural practices can modify this range slightly. The optimum temperature range for the germination of cuttings varies from 26 to 33 °C. In the south of Brazil, critical temperatures were found by Bachi (1977) to be 19-20 °C (not irrigated) and 18-19 °C (irrigated). This difference is due to soil temperature, which is considered to have a great impact on root growth (Mongelard and Mimura 1971). Temperatures below 20 °C affect both the length of the growing season and the extent of ripening. Low temperatures are the most effective way to ripen cane. Although fluctuations in temperature may have a positive effect on sucrose accumulation, a temperature of less than 5 °C is potentially damaging to growth even for the coldest tolerant cultivars.

Box 1.6 The ideal climate for a one year old crop of sugarcane

According to Blackburn (1984), “The growing season of four to five months should be warm with mean day temperatures around 30 °C and with fully adequate moisture and high incident solar radiation. The ripening and harvesting season of six to eight months should be cool, with mean day temperatures between 10 and 20 °C, but frost free, dry and with high incident radiation.”
There are not many areas in the world that have such ideal conditions. Areas that come close to achieving this include the southern parts of Brazil, inland areas of Columbia, parts of Zambia and Malawi and the northern parts of India. In some of these areas actively growing ratoon cane receives adequate moisture through irrigation. Cane is grown in deep, well aggregated, uniformly textured, sandy clay loam soils to enable deep rooting and provide dynamic nutrient cycling.

**Solar radiation**

Solar radiation drives photosynthesis which results in sugarcane growth, provided temperatures and moisture are above the minimum threshold. A fully developed crop canopy ensures full utilization of incoming radiation. According to Oliverio *et al* (2004), the sugarcane plant is one of the most efficient converters of sunlight into chemical energy stored in sugars, fiber and straw. These three products can yield $1.718 \times 10^3$ Kcal from one tonne of cane harvested from field, which is equivalent to 1.2 barrels of oil.

When these conditions are not limiting, solar radiation determines potential yield. The number of hours of sunshine has a significant effect on transpiration rate and cane development. A cloudy day can halve the rate of transpiration and impacts on water requirement. Some plant breeders are looking at the merits of leaf geometry, as a potential criterion for selecting highly efficient photosynthetic sugarcane cultivars.

**Evaporation**

- The maximum moisture requirements of a crop are referred to as potential evaporation ($E_t$). Researchers have shown that this consumptive moisture use by the crop is closely related to the evaporation from an open Class `A` pan (Thompson 1976).
- For a fully canopied sugarcane crop, a ratio of 1:1 can be accepted for all practical purposes, between consumptive moisture use and evaporation from a Class A pan.
- Potential evaporation can be influenced by a number of factors such as the amount of green leaf canopy (e.g. leaf area index), which can vary widely during a season. In the incomplete canopy stage of ratoon crops, it can also be influenced by the amount of trash covering the soil.
- Potential evaporation can also be governed by the intensity of solar radiation, the dryness and temperature of the air and the amount of wind.
- For irrigation purposes actual crop evapotranspiration ($ET_c$) is the main factor in irrigation planning and scheduling (See Chapter 6) and is determined from the relationship below:

$$ET_c = k_c \times Eto$$

where

- $Eto$ is the Reference Evapotranspiration obtained from a reference surface of an actively growing extensive surface of green grass of uniform height, completely shading the ground and with adequate water.
- $k_c$ refers to the crop factor which can range from 0.4 to 1.25 depending on the stage of the season.

- In addition to the traditional evaporation pan, a number of other techniques are available to estimate $ET_c$. Examples are APSIM, CANEGRO and DSSAT, which are climate based simulation models using the Penman-Monteith equation (see Chapter 14).

**Rainfall and moisture**

Moisture is important for sugarcane growth whilst a dry season benefits ripening and harvesting of the crop. If the dry season is too short, the economics of producing either sugar or ethanol becomes unsustainable due to a high capital investment in the factory and the cost of harvesting and
transport. If the dry season is too long, which in many areas is the case, expensive irrigation systems have to be installed and maintained.

The distribution of wet and dry seasons is largely determined by proximity to the equator. The equatorial zone, which has no dry season, extends 2° north and south of the equator while the zone with two wet and dry seasons extends from 2 to 15° north and south of the equator and beyond the 15° latitude. The seasons are replaced by a relatively short wet season of four to five months followed by a long dry season of six to seven months.

The bimodal variation of average estate sucrose content shown in Fig. 1.1 highlights variations with latitude. Peak sucrose occurs between 18° to 22° north and south of the equator (Shaw 1954). The plot for the northern hemisphere is almost a mirror image of the curve for the southern hemisphere, except that average sucrose contents tend to be about 3 percentage units higher at 30° S compared with 30° N. This could reflect advances in the plant breeding and selection programs in the southern hemisphere.

![Figure 1.1. The effect of latitude on sucrose content of cane at harvest (after Shaw 1954).](image)

Annual crop water use can range from around 1 000 mm in the rainfed areas of South Africa to nearly 2 000 mm in extremely hot irrigated areas (e.g. the Ord in Australia and Mali in Africa). Crop water use is highly dependent on potential evaporation (E), solar radiation, the amount and distribution of rainfall, season and soil type.

A number of researchers have reported on the strong correlation between cane yield and evapotranspiration. Most reports indicate that approximately 100 mm of water (effective rainfall or irrigation) is needed to produce 10 tc/ha (1 ML/ha/10 tc) (Isobe 1969; Humbert 1971; Scott 1971; Thompson and Boyce 1971).

The relation holds for the plant and first ratoon crops but reduces by an average of 10 % for subsequent ratoons (Thompson 1976). Using this relationship, the achievable potential yield for plant or first ratoon crops can be determined from the equation:
\[ Y = \frac{E_t}{100} \times 9.8 \times 0.8 \]  
\hspace{1cm} (1.2)

where

\begin{align*}
Y &= \text{Yield (tc/ha/y)}, \ E_t = (E_o \times 0.8) \\
E_o &= \text{Class A pan evaporation/y in mm fully replenished by rainfall and irrigation.} \\
0.8 &= \text{a factor that allows for incomplete canopy, fallow periods and drying off periods.} \\
9.8 &= \text{represents the target yield of 9.8 tc/ha per 100 mm} \\
E_t &= \text{has been obtained experimentally.}
\end{align*}

With GMP’s, which include selecting a high potential cultivar, good weed control, well timed and properly placed N, P and K fertilizer treatment, timely harvesting and controlled infield traffic, the same amount of water can potentially produce 12 to 15 tc/ha/100 mm water.

1.4.2 Soils

Soils play an important role in influencing the SPA through modifying the effect of climate by influencing the amount of runoff and the portion of rainfall retained in the root zone and released to the plant. Other important properties include:

- Acts as a medium for plant and root growth by providing stored moisture and nutrients and physical support for the plant by keeping it upright
- Deeper and lighter textured soils tend to support deeper root systems. In general the amount of roots below ground may be as large as the amount of biomass above ground.
- Is a principal factor in the hydrologic cycle system
- Provides a habitat for organisms
- Soils also determine the rate of fertiliser application due to their different nutrient supplying and immobilising characteristics

The properties of soils, that impact on SPAC as well as soil forming factors, how to describe and classify soils are comprehensively dealt with in Chapter 2, the nutritional properties in Chapter 5 and the importance of a knowledge of soils is emphasized in the irrigation (Chapter 6) and drainage chapters (Chapter 7).

1.5 Physiology of the sugarcane plant

This section briefly reviews the physiological processes that are involved in the growth of sugarcane.

1.5.1 Brief overview

Sugarcane grows by means of photosynthesis, a process in which the sun’s energy is stored as photosynthate. The green leaf contains cells with chlorophyll that regulates the photosynthetic reactions whereby light energy is used to combine water (and nutrients) with carbon dioxide from the air into carbohydrate (sugars). These sugars are then loaded into phloem cells and transported to various parts of the plant (Fig 1.2). Sugarcane plants have a unique ability to store these sugars as sucrose in their stems.
Figure 1.2. Diagrammatic representation of sucrose production by sugarcane.

Box 1.7 The link between photosynthesis and transpiration

Three processes characterize the movement of moisture through the cane plant:
- Absorption of water from the soil through the root system;
- Translocation of water and nutrients in the plant;
- Loss of water through transpiration through the leaf stomata to the atmosphere.

In a plant the process functions as follows:
- During daytime the stomata of the leaf will open and CO\textsubscript{2} will be taken up for photosynthesis. Open stomata will also allow water to be lost from the leaves (high water potential) to the atmosphere (low water potential). This loss of water is called transpiration.
- The loss of water from the leaf causes the water potential in the leaves to drop which in turn causes water and nutrients that are at a higher potential in the soil, to move through the root vascular bundle and continue through the plant stem to the leaves into the atmosphere.
- If evaporation from the leaf exceeds the rate of water supply from the soil to the leaves, the stomata will close until equilibrium is re-established. At night the stomata will also close to reduce water loss as photosynthesis cannot take place.
- Due to the fact that photosynthesis and transpiration only take place if the stomata are open, it is clear that a close link exists between photosynthesis and transpiration. The rate of transpiration can therefore be used as an indication of the rate of photosynthesis.

Characteristics of sugarcane which make it a commercially viable crop:
- Sugarcane is very responsive to high solar radiation, high temperatures and water.
- Sugarcane is a high yielding vegetative crop producing a high content of sucrose.
• Sugarcane plants are vigorous and produce a number of crops before plough out (up to 30 ratoon crops of NCo376 in Swaziland).
• Sugarcane has valuable fiber, which is utilized for power in the milling process and ethanol as an ideal source of biofuel (twice as much as corn).
• Sugarcane produces a complete ground cover with tops and trash which help control weeds and prevent erosion.
• The crop requires very little management once it has canopied, an exception being irrigation.
• Harvesting takes place over a long period of the year.
• Sugarcane production is versatile as it can utilize labor or machinery depending on the scale of the operation and costs.
• Most pests and diseases can be controlled.
• An ideal smallholder crop as it can perform with low inputs in ideal situations and there is no necessary marketing of the product by the smallholder.

The harvested part of the plant is the stem which grows continuously, usually for about 10 to 18 months (Hawaii up to two years), provided temperature, moisture and sunshine hours are not limiting. In large crops approximately 50-60 % of the stalk dry weight (11 to 16 % stalk fresh weight) is sucrose, and this is about 25 % of the total dry matter produced. The climatic yield potential of the crop depends on age, weather conditions, and whether rainfed or irrigated. Achievable yields under commercial conditions depend on soil potential, cultivar choice, good weed control, adequate fertilizer and other crop husbandry practices. Typical yields are 100 to 140 tc/ha/an (irrigated) and with a 12 % sucrose content, sucrose yield may vary from 12 to 17 ts/ha/an under commercial conditions. Under ideal conditions yields in excess of 20 ts/ha/an are possible especially where artificial ripeners are used. Achievable dryland cane yields are much lower and more variable due to variability in rainfall and the length of the wet season (Table 1.2).

Table 1.2. Likely impact of climate, management and soil potential on differences in cane yield performance (t/ha) for a 12-month irrigated crop and an 18-month rainfed crop.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Irrigated 12 month crop</th>
<th>Rainfed 18 month crop*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate potential (solar energy)</td>
<td>170</td>
<td>140</td>
</tr>
<tr>
<td>Management achievable potential</td>
<td>100 – 135</td>
<td>75 – 115</td>
</tr>
<tr>
<td>(commercial yields good soils)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil potential limited by low water holding capacity poor soils.</td>
<td>70 – 90</td>
<td>48 – 70</td>
</tr>
</tbody>
</table>

*assuming a well distributed rainfall of between 1 500 to 2 000 mm/an

The various parts of the cane plant are interdependent and damage to one may affect the growth of another. For example, a single defoliation by trash grub at two months of age can reduce cane yield at 16 months of age by over 10%, and nematode damage to roots can reduce cane yields in sandy soils by as much as 50%.

1.5.2 Main growth stages in sugarcane

Gascho and Shih (1982) divided sugarcane vegetative growth into four stages:

• Propagation (germination and emergence)
• Tillering and canopy establishment
• Grand growth or full canopy phase
• Crop maturation or ripening.

Duration of the stages is highly dependent on climate. Low temperatures or drought stress can delay germination, emergence, tillering and canopy development. In subtropical climates, the first two stages may last up to 20 weeks. Warm temperatures and plentiful water and nutrients can promote vegetative growth and delay maturation. In addition, where cane is grown for two years the grand growth period can be extended by providing adequate water and nutrients until the crop is 80 to 88 weeks old.

1.5.3 Plant characteristics that impact on cultivar performance

There are many different characteristics of the plant that impact on the performance of cultivars. The main characteristics are described below.

Morphology
The morphology of sugarcane has been extensively reviewed by Moore and Nuss (1987) and Bakker (1999). True seed (fuzz used only for breeding) germinates under certain conditions to produce roots and shoots, and each seedling is effectively a potential new cultivar.

Propagation
Sugarcane is propagated vegetatively usually from setts (pieces of stalk which can be planted as single setts, three-budded or ‘three-eyed’ setts or as full stalk) which is then cut into setts in the furrow. The method chosen is a management choice determined by the equipment and amount of material available, but can also depend on cultivar and the impact on apical dominance. More recently speedlings and tissue culture (plantlets) are being used to propagate sugarcane. Tissue culture provides disease free seedcane to new projects or for quick multiplication of elite cultivars with specific advantages. Speedlings are often produced by specialist nurseries to provide material to growers who do not have the resources to produce clean seedcane.

Sett germination varies with season, cultivar and treatment. In some cultivars roots develop first and in others shoots. Germination can be expected to be about 80 % under normal conditions and to drop to about 60 % following Hot Water Treatment (HWT), but varies considerably with cultivar.

Cool winter temperatures can slow down emergence from setts considerably. Some cultivars may not germinate at all when mean daily temperatures are below 16 °C. A heavy trash blanket can reduce emergence of ratoon cane. Under hotter summer conditions emergence can occur in about 10 days. However, very hot conditions will also reduce germination. If planting is done during hot summer days pre-irrigation and shading of setts is recommended, particularly when using young seedcane.

Well grown, healthy setts from 9 to 10 month old cane provided with adequate nutrition are an ideal source of seedcane. Buds at the top of the stalk tend to germinate faster than buds arising from the more mature lower parts of the stalk.

Root growth
The sugarcane root system is fibrous and shallow but develops buttress roots that serve to anchor the plant. Under rainfed conditions in deep sand clay loam soils, buttress roots have the potential to penetrate to depths of 5 to 7 m, allowing for water absorption under stress (Moore and Nuss 1987). The below ground shoot and root from a single node develops over time into a stool (conglomeration of roots and shoots). It is important that the stool remains intact and is not damaged by mechanical harvesting or cultivation. At the end of the crop cycle the stool must be
killed by tillage or chemical control (e.g. glyphosate) at least three months before the next crop is planted to reduce carry-over of RSD.

**Tillering**
The build-up in the shoot population during the early establishment phase is referred to as tillering. The germinating buds produce primary tillers, which are the oldest shoots. The secondary tillers grow from the primary and the tertiary from the secondary shoots. At full canopy, when full leaf ground cover is achieved, shading out of the smaller tillers occurs and they start dying.

Tillering is a cultivar characteristic, and as many as 350 000 tillers per hectare have been recorded in South Africa on ratoon NCo376 before full canopy. However, only about 155 000 tillers survive to harvest in NCo376, whereas other cultivars with higher sucrose tend to have a lower stalk population at harvest of 90 000 to 120 000. Final stalk population varies with cultivar, climatic conditions, and stage of ratoon (smaller stalk weight and a higher population with successive ratoons).

High light intensity and an increase in temperature to 30 °C tend to favor tiller development. Water stress reduces tillering. Side shoots may occur when irrigation is resumed. Damage to the growing point (e.g. from hail, frost or chemical ripeners) reduces apical dominance and increases the development of lower order tillers and side shoots.

**Stalk elongation**
Rapid stalk elongation occurs when daily mean temperatures reach about 18.5 °C and will continue to grow rapidly under warmer conditions at between 1 to 2 cm/day, and then can almost cease when temperatures drop in the cool winter months. Any stress reduces growth rate and this is manifested in a decrease in the distance between successive nodes (reduced internode length). Under conditions of continuous growth, more than 30 nodes may be produced in a year and stalk length can reach over 3.5 m.

**Sugar production**
Sugar production increases with age to maturity, which, depending on cultivar and climate, may vary between 12 to 15 months (hot irrigated areas) and 14 to 22 months (under rainfed conditions with carry-over cane). Drying off, winter and chemical ripeners all slow down growth and increase the sugar concentration. The tons sugar per hectare per annum or any other component of value (e.g. TCH per annum) is used to determine cultivar production efficiency. Adaptive efficiency is also important.

**Maturity**
Maturity is a function of age, season and cultivar and can be influenced by management. Juice purity (%) determines the level of maturity, and for mature cane is generally in the range 85-90%. The most mature part of the stalk is the base and the most immature the top. Cane above the natural breaking point, which comprises the growing point, is considered too immature for sugar milling. For ethanol (Cackett and Rampf 1981a,b) and cogeneration, a greater proportion of the top may prove suitable for milling, particularly at the start of the season. The plant crop takes longer to establish than a ratoon crop and consequently it matures a couple of months later than the ratoon crop. Lodging and excessive side shooting, particularly under extremely wet conditions, can cause a loss of maturity and an increase in deterioration.

Cut or borer damaged cane deteriorates rapidly and it is essential to ensure that this cane is milled as soon as possible.
Maturity is a critical aspect as it determines the optimum age and time of harvest for any cultivar. The level of maturity (juice purity) also determines the likelihood of a response to chemical ripeners. Under the hotter irrigated conditions, harvesting tends to be on an annual basis with limited carry-over cane. In contrast, rainfed cane tends to be harvested on a 14 to 18 month or longer cutting cycle. Irrigated cultivars need to mature earlier and often respond to chemical ripeners and a programmed drying-off, whereas rainfed cultivars tend to be later maturing and must be able to withstand water stress.

Lecler and Tweddle (2010) propose a farming system based on controlled traffic, zero-till, irrigation and break crops that would impact favorably on the environment. Although this system appears promising and has the potential to become a good management practice, it will need to be tested commercially under a wide range of conditions. Also, where there is a change in the system of management, there is also the need to test cultivars for this change.

Tops and trash
Good management practices must consider the value of tops and trash for soil conservation as well as a source for co-generation and food security in times of drought. In rural areas, tops can help keep stock alive in times of drought.

Lodging
Lodging is associated with good yields, but does reduce sucrose accumulation in the wet and dry tropics (Singh et al. 2002). Lodging is common in high yielding cultivars. New basal and side shoots are produced and can cause the main shoot to deteriorate. Lodged cane is not suited to ripener application as side shoots are encouraged to develop. In general, higher fiber well rooted cultivars are less inclined to lodge. Lodging reduces harvesting efficiency of both manual and mechanical harvesting.

Flowering
Flowering signifies the change from the vegetative to the reproductive phase. When flowering occurs, no further leaves or internodes are produced on the flowered stalk.

Once the young developing internodes below the flower have fully expanded, growth of the stalk ceases. Fiber accumulation is greater in flowered than non-flowered cane stalks, particularly in the upper internodes. This can lead to the development of pithiness. Quality improves after flower emergence, but subsequently declines following the emergence and growth of side shoots. Heavy flowering is frequently a serious problem in cane growing in low latitudes.

Flower emergence requires a day length of 12.5 h declining and minimum temperatures above 18 °C during the critical period when day length is around 12.5h. A minimum light intensity is necessary, but this is seldom the most limiting factor. A high soil moisture status especially due to the presence of a water table or along the field edges, near feeder canals and drains, and below storage dams, promotes flowering. In a study conducted in Zimbabwe, it was demonstrated that Nitrogen deficiency increased flowering substantially, with urea producing more flowers than ammonium nitrate, and phosphate application appeared to reduce flowering. Where the previous crop had been burnt there appeared to be more flowering than where the previous crop was trashed (Gosnell 1973).

Cane has to reach a certain physiological stage of development before flower initiation can take place. This varies with cultivar and NCo376 can be used as a guide. This cultivar must be older than 2.5 months at the start of the inductive period and should have produced at least three fully elongated internodes. Soil type and fertility can impact on flowering.
Late season and carry-over cultivars need to have a low rating for flowering and produce limited side shoots, which should develop slowly.

Chemicals can be used to suppress flower initiation (paraquat and diquat) or to ripen cane and control flowering (ethephon). However, the most cost effective way is to grow the appropriate low flowering cultivars.

**Cane quality**
The plant chemical composition varies considerably depending on age, early, middle or late harvesting in the milling season, and rate of maturity of the cultivar. Individual cultivar characteristics are also important. Mills carry out cane sampling for quality on arrival at the mill (front end). The actual payment can be based on the front end sample only, or may include milling factors influencing the recovery of sugar or production of ethanol.

The following terms are used to describe cane quality of cultivars:

- **Dry weight**: Sample shredded cane dried for one hour at 105 °C in a forced draught oven.
- **Pol**: The apparent sucrose content in cane or juice expressed as a percentage by mass.
- **Brix**: The total dissolved solids content in the cane or juice expressed as percentage by mass.
- **Non-pol**: Brix minus pol.
- **Fiber**: Dry, water-insoluble matter in cane.
- **Reducing sugars**: Reducing substances calculated as invert sugars (mainly glucose and fructose).
- **Juice purity**: Pol % x 100/Brix %.
- **Total fermentable sugars**: Percentage pol converted to equivalent reducing sugars plus percentage reducing sugars combined (see Chapter 13).

**Basis of payment (see also Section 2)**
This varies, normally with the country. With payment based on cane yield there is no allowance for quality or milling efficiency; based on pol % cane there is no allowance for milling losses or efficiency. There is a growing trend to include milling losses and efficiency of sugar production in the payment formula. Some examples are Commercial Cane Sugar (CCS) in Australia, Estimated Recoverable Crystal (ERC%) in Zimbabwe, and Relative Value (RV%) in South Africa. A mill balance is done on a regular basis for calculating grower payments.

The key aspects of a cultivar are high pol and high juice purity and low fiber content. Higher fiber is favored for cogeneration and high total fermentables for ethanol production.

Industries need to have a practical mill delivery schedule and payment system. For smallholders, cognizance must be taken of the seasonal milling curve and their deliveries, which might be restricted to only one week in the season. Cane payment needs to be adjusted for this and a premium provided for superior quality cultivars. In general, industries are moving to reward milling efficiency and payment on the basis of saleable co-products and losses.

All mills and many industries combine this information for industry performance comparisons, which often includes performance of individual cultivars per mill and for the industry.
1.6 Sugarcane cultivars

1.6.1 Cultivars the key to economic sustainability

Good Management Practice (GMP) is influenced by cultivar which is the central component to the sugarcane production system (Fig. 1.2.). Cultivar performance and selection varies based on the interaction of the climate, soil and management (Table 1.1.) and impacts on social, environmental and economic factors. Sugarcane originated in the wet tropics and responds well to adequate water and high temperatures, and as a result it is irrigated when rainfall is inadequate (Ham et al. 2000). Although sugar has been the major trait selected for, ethanol and biomass are now also major considerations (Zuurber and van de Vooeren 2008; BNDES 2008).

It is not the intention in this section of the chapter to evaluate cultivars but the objective is to provide broad principles that impact on cultivars and enable rational choices on cultivar selection based on GMP and the available information.

1.6.2 New emerging developments

Biotechnology or genetic engineering is one of the most exciting new developments in recent years for many crops and sugarcane is no exception. Australia, Brazil, South Africa and USA have been in the forefront of this development of producing glyphosate resistant cane and more recently eldana resistant cane has been tested in the South African Sugar Industry while research has been initiated to investigate the engineering of complex agronomic characteristics, such as improved nitrogen-use efficiency and drought tolerance of cane, that if successful, would provide favorable impacts on the environment of reduced nitrogen and water use (Watt and Snyman 2011).

In Brazil, a genetically modified (GM) sucrose enhanced sugarcane is expected to enter the local market through the cooperation of CTC (Centro de Tecnologia Canavieira), a progressive Brazilian research institute and a large agricultural chemical producer in Germany. However, continuing negative consumer perceptions about health and environmental concerns in the Euro zone and elsewhere, as well as issues surrounding ownership of intellectual property, are factors that will delay commercialization of GM cane in the foreseeable future.

A recent Breeding and Germplasm Workshop held by the International Society of Sugar Cane Technologists (ISSCT) (Castello et al. 2010) recommended the need for traditional plant breeding and biotechnology tools to work together for progress in increasing not only sugar but also bioenergy. It reported on Brazil’s bio-energy program, BIOEN, which includes research on sugarcane breeding, ethanol production and its impacts. Caribbean research is aimed at developing combined high sugar and fiber cultivars. Work is being done to increase water and phosphorus use efficiency.

Singels et al. (2005) evaluated the Canegro crop model and found that there was a need to distinguish between respiration and photosynthesis, and the strong dependence of both on temperature. Also the sinks for leaf, stalk structure and sucrose need to be considered separately. Models such as Canegro help one get a better understanding of what attributes to look for to increase production and cultivar selection and performance.

Over the years new cultivars have resulted in the expansion of the sugar industry into areas that were previously considered unsuitable for sugarcane production. This was because the original noble canes (Saccharum officinarum) had poor ratooning characteristics, were not hardy and were prone to diseases. These undesirable traits were corrected by producing new cultivars from interspecific hybridization between S. officinarum (the cultivated species) with S. spontaneum (a wild
species) with high levels of disease resistance, adaptability and stress tolerance (Screenivasan et al. 1987).

All the main sugar producing countries have embarked on sophisticated sugarcane breeding, selection and evaluation programs. The time from making an initial cross to commercialization is more than ten years in Australia (Cox et al. 2000) and between 11 and 16 years in South Africa (Meyer et al. 2010) and involves considerable human and financial resources.

Development of new cultivars involves two important stages. The first is the generation of variability and genetic combination for the important traits to be incorporated into a new cultivar. The second stage is the identification of genotype that combines the important traits required for commercial cultivars. After this the selected genotypes are tested to determine the expression of the genes that control these traits.

The considerable investment in breeding and selection programs is protected by Plant Breeders Rights (PBR). In some instances there is a requirement to pay royalties for new cultivars that are grown commercially. Contracts between the grower and the research institute are sometimes required to allow for the commercial use of certain cultivars.

Diseases that threatened the viability of the sugar industry resulted in many of the governments legislating for both control of production and cultivar use.

Sugar production is largely under government control and the Sugar Act and Regulations determine how industries are regulated and operated. It is normal for the Sugar Act to be more general and for the Regulations to apply the operating procedures. However, in some countries (e.g. Kenya) the Sugar Act is very detailed and specific in laying down what can and cannot be done. In addition governments are responsible for plant quarantine and phytosanitary requirements as well as controls over import and export of cultivars.

The main industries are developing programs to help select the most profitable cultivars for use based on the classification of the most desirable traits (e.g. Inman-Bamber and Stead 1990). There is also broader based research (Bezuidenhout et al. 2007) to look at agroclimatic and hydrological responses, which help support regional decision making strategies on cultivar, etc. Landell et al. (2009) developed a model for central-south Brazil for selecting cultivars on the basis of production, soil type, time of harvest and stage of cultivar testing. Batistini Brunoro and Moreira Leite (1999) used linear programming of production versus costs, including transport, to design sugarcane production policy based on cultivar choice. Ramburan et al. (2010) have developed a cultivar selection decision support system based on genotype x environment analysis and system evaluation.

Most major producing countries publish literature on cultivar selection, performance and management. The 26 sugarcane cultivars in Brazil are described by Zimback and Figueiredo (1990) and cover the cultivars produced by the Institute of Agronomy of Campinas (IAC) and for SP and RB cultivars used by Planalsucar. Ramburan et al. (2007) provided an overview of the released cultivars in South Africa. Manuals (e.g. India, Srivastava et al. (1998)) or Information Sheets (South Africa, SASRI) and the internet (Queensland cultivars) provide specific information to the growers they serve.

1.6.3 Sugarcane taxonomy

Sugarcane belongs to the genus Saccharum L of the tribe Andropogoneae in the grass family Poaceae, which includes Sorghum and Zea. The Saccharum genus comprises six species, S. spontaneum, S.
officinarum, S. robustum, S. edule, S. barbari and S. sinense (D’Hont et al. 1996). The taxonomy and phylogeny of the five interbreeding genera share common characteristics and are known as the Saccharum complex (Daniels and Roach 1987). There are high levels of polyploidy and frequently unbalanced numbers of chromosomes (aneuploidy) making it difficult to determine taxonomy (Daniels and Roach 1987; Screenivasan et al. 1987).

1.6.4 Centers of origin

New Guinea 6 000 BC is the first record of S. officinarum, a cultivated species not known in the wild (Screenivasan et al. 1987), which resulted from complex introgression between S. spontaneum, Eriathus arundinaceus and Miscanthus sinensis. (Daniels and Roach 1987). This noble cane was spread along human migration routes throughout Southeast Asia, India and the Pacific, hybridizing with wild sugarcanes, and ultimately producing ‘thin’ canes. Sugarcane reached the Mediterranean between 600 and 1 400 AD, spreading into Egypt, Syria, Crete, Greece and Spain; then down into West Africa and subsequently across into Central and South America. The centre of origin of S. officinarum is probably Polynesia with modern central diversity in Papua New Guinea and Irian Jaya (Indonesia).

S. spontaneum probably evolved in southern Asia. This cultivar accumulates no sugar and is a highly polymorphic species with high levels of disease resistance, adaptability and stress tolerance (Screenivasan 1987). It is widely grown from 8° S to 40° N and extends across three vast geographical zones (Pursglove 1972; Daniels and Roach 1987; Tai and Miller (2001).

1.6.5 Hybridization

Modern cultivars are based on 20 S. officinarum and less than 10 S. spontaneum derivatives (Roach 1995). Genome in situ hybridization (GISH) showed approximately 15 to 20 % S. spontaneum chromosomes and less than 5 % translocated or recombinant chromosomes (D’Hont et al. 1996; Cuadrado et al. 2004). In Australia most cultivars can be traced to POJ 2878 (the ‘Java Wonderclone’).

The modern cultivars have many different and often specific traits, which give them advantage over the older cultivars. Primarily, the cultivar must be high yielding with good ratooning ability. The cultivar must also have desirable agronomic traits, tolerance to diseases and insect pests and fit into the management system. The cultivar must also be adapted to the local climate and soil environment.

A cultivar might start out well but suddenly succumb to a change in insect pest or disease pressure or to a new pest or disease. The cultivar is part of a diverse changing biological system, and climate change could well have a direct impact on cultivar performance as well as on insect pest and disease pressure in the future.

1.6.6 Diseases

Changes in cultivar due to diseases are well illustrated by Bailey (1995) in South Africa. Cultivars were subject to smut, which was identified in 1877 followed by Mosaic in 1910 to 1920s. Streak occurred in the 1930s and rust and RSD in the 1940s. Leaf scald became a threat in the 1970s and RSD was widespread in the 1980s. In the 1990s two new viruses (SCBV and SCMMV, a retrovirus) emerged.
RSD in the 1940s resulted in Co281 being replaced by NCo310, which later succumbed to high levels of smut, and NCo376 was the next victim to succumb to smut in the hotter northern areas. NCo376 and NCo293 were both infected with mosaic in the cooler areas. The proportion of NCo376, once the major cultivar, has fallen to 3.9% in South Africa, 11% on Triangle Estate in Zimbabwe and 24% on the two estates in Tanzania.

The diseases of sugarcane that cause yield losses in Australia (Frison and Putter 1993; McLeod et al. 1999; Croft et al. 2000) have impacted on cultivar choice. The most widely grown cultivar, Q124, was severely damaged by orange rust (Apan et al. 2003). This led to the development of more resistant cultivars. Risk and productivity were assessed and a matrix was produced to assist growers reduce risk in the future (Wilcox and Croft 2004). Other cultivars (e.g. Q173 and Q182) have also since succumbed to the disease (Anon 2005a). Smut was first recorded in Australia in 1998 in the Ord river area of Western Australia. The outbreak was first controlled, but in 2006 it spread to Childers in Queensland and has continued to spread. Control of smut has been based on growing resistant cultivars (e.g. Q177, Q200, Q208, KQ228 and QS94-2329). Soil type interacts with both yield and resistance (Watson 2007).

1.6.7 Pests

Pests have also caused havoc in different parts of the world. Cane grubs are a major pest affecting the Australian sugar industry and cost the industry millions of dollars per year in yield loss and control costs. Control measures are unsatisfactory, and reliance is being placed on breeding with some success (Allsopp et al. 2003). Recently genetic engineering of sugarcane for resistance to cane grubs has been initiated (CRC SIIB 2006).

Samson et al. (2004) reported evidence of an effect of cultivar on soldier fly. Cultivar Q138 produced lower pupations of smaller larvae, which also took longer to mature compared with the same pest on Q135.

Agnew (1997) lists 28 pests affecting sugarcane in Australia. Many are rare or sporadic pests not requiring control. Leslie (2004) provides a comprehensive overview of sugarcane pests worldwide and control involving the use of resistant cultivars.

The major pest affecting sugarcane in South Africa is the stalk borer Eldana saccharina Walker (Lepidoptera: Pyralidae) (eldana), which has largely been addressed by field hygiene, reduced carry-over and resistant cultivars.

Nematodes cause yield loss, particularly on poor sandy soils when the crop is under stress and moisture is limiting. There are a wide range of nematodes and control is based on cultural and chemical control methods as well as cultivar resistance (Cadet and Spaul 2005).

The use of resistant cultivars is particularly useful, as it reduces the use of harmful chemicals which can disturb the balance of nature and result in other pests becoming a problem. Integrated Pest Management (IPM) strategies are continuously being developed on the basis of holistic agroecosystem interactions (e.g. Conglong and Rutherford 2009) and are wide ranging, from habitat management to specific high technology such as Sterile Insect Technology (SIT). IPM requires a full understanding of all the pest, predator, habitat, climate and management interactions as well as an understanding of available modern technology such as SIT.

Cultivar adoption patterns have been studied in the Australian sugar industry (Mordocco et al. 2007), and showed generally good adoption of new cultivars.
1.7 Cultivar management

A cultivar on release is described on the basis of origin by normally one to three capital letters at the start and this is followed sometimes by the year, or just given a sequence number or some other number which has meaning to the institution that produced it (e.g. SP, SR - Brazil; Co - Coimbatore, India; CP - Canal Point, Florida, USA; N - Natal, South Africa; Q - Queensland; NCo - Natal crossing Coimbatore material; ZN - Zimbabwe selection with Natal crosses; POJ - Java).

Some cultivars, for example POJ 2878 (Cox et al. 2000) in Australia and NCo376 (Nuss 2001) in South Africa have had a large impact not only on production but also for producing superior offspring.

1.7.1 Identification

It is important to be able to identify cultivars particularly in seedcane so that one is only bulking up the required cultivar. This is particularly critical at the early stages of bulking up when any rogue would continue to increase exponentially as bulking up progresses. Habit and general appearance of the leaf canopy are important and differs between cultivars. Final confirmation is often based on examination of the following:

- Leaf (blade, sheath, collar and auricle);
- Stalk (internode, wax band and bud furrow);
- Node (growth ring, root band, sheath scar, bud and flange).

The presence or absence of one of the above components, for example the auricle and bud furrow, and differences in color, size, shape and form of these characters may vary considerably between cultivars. SASRI publishes an Information Sheet for each cultivar bred in South Africa, which gives details of characters and traits as well as a visual representation of a typical stalk.

In additional to physical identification, larger research organizations use DNA fingerprinting and molecular markers to track traits in the crossing program.

1.7.2 Agronomic characteristics

The key requirements considered for selection are rapid and reliable germination, good ratooning ability, rapid canopy formation, sufficient population to achieve good ground cover, and yield. Stalk height and mass must be within reasonable limits to achieve the required yields, bundle sizes and weights. Stalks must not be too brittle. In the case of mechanical harvesting erect stalks with limited trash at the base and uniform height are ideal. Low flowering and therefore fewer suckers and limited lodging are required for end of season cultivars.

The cultivar must have a degree of tolerance and preferably resistance to the following pests and diseases, particularly where the threats from them are greatest: Smut, mosaic, RSD, rust, leaf scald, red rot, nematodes and eldana. Under rainfed conditions the plant ideally must be able to withstand water stress during growth, recover from stress rapidly and ratoon well after drought. Drought predisposes the plant to eldana attack (and other pests) and very wet conditions and waterlogging can impact on the disease situation. Under certain conditions plants need to be able to withstand a degree of sodicity, salinity or aluminum toxicity and survive on sandy, heavy, duplex or shallow soils.
Recovery from frost is also important in lower lying valley bottoms. van Heerden et al. (2009) tested two Louisiana cultivars (LCP 85-384 and HOCP 96-540) against two South African cultivars (N21 and N36). LCP 85-384 and N36 were better able to cope with frost than N21 and produced 30% more sucrose.

It is often only after a cultivar has been commercially grown for a number of years that one has a real understanding of potential under the wide set of conditions that are a reality in commercial production.

1.7.3 Main components of yield

When selecting cultivars for yield it is important to appreciate the impact of the three main components of yield (population, stalk mass and cane quality) on management and performance. Stalk population and mean stalk mass multiplied together equals cane yield. In general, high populations have lower stalk mass and vice versa. Cane quality is determined in the mill laboratory, mainly as pol % cane, brix % cane and fiber % cane and, when multiplied by cane yield, provides the mass of pol, brix and fiber produced. Each component interacts on GMP. High populations would tend to protect the soil, add more trash and result in more cutting strokes at harvest, and have more fiber and tend not to lodge as much. In contrast, heavy stalks tend to produce more sugar and less fiber, and may be inclined to lodge more easily, but have lower transport costs per tonne sugar delivered to the mill.

The growing demand for power has increased the importance of cogeneration to supply the local grid. This has increased the value of bagasse (fiber) and will in the future impact on cultivar choice.

1.7.4 Harvesting and transport

Cultivars with hairy stalks meet with cutter resistance, especially in seedcane and green cane. When cane is burnt before harvest, hairiness is not as significant. Brittle cane and lodged cane does not form good tight bundles and can produce low payloads and increased losses in the field. Uniformity in height helps with both manual topping and mechanical harvesting.

When there is a choice, mechanical harvesting should be restricted to ratoon crops and to when the weather is dry and limits compaction. It is important to ensure that the cane is planted on the correct gradient for the soil type and that contour planting is used on slopes. There is a move to precision planting and the use of fixed beds. For cultivars and machinery to perform well, it is essential that beds should be uniform with good surface runoff and good infield drainage.

Bella et al (2009) found that the disadvantages of an early start to the milling season far outweighed a late finish and that there is a cultivar x time of harvest interaction that needs to be exploited more fully.

Transport is a major cost particularly when long distances are involved. The further from the mill the more important it is to select cultivars with good bundle weights and high sugar, total fermentables (ethanol) and fiber for cogeneration (see Chapters 12 and 13).

1.7.5 Milling quality characteristics (see also Section 2).

The mill balance and efficiency in milling also impacts on cultivar. Some cultivars (e.g. N25) are not suited to the diffuser process as they are not suited to cane preparation processes and this impacts on performance. Cultivars should be tested for milling before final large scale commercial release.
The mill balance determines what proportion of sugar coming in at the front end is available after processing at the back end. Milling efficiency is used in many of the calculations to determine payment for sugar (e.g. RV % in South Africa, CCS in Australia and ERC % cane in Zimbabwe, whilst some industries still pay on the basis of pol % cane or cane yield). The mill balance for a cultivar is important as it often impacts on grower payout and on its economic performance.

1.7.6 Plant breeding and selection

There is a wide exchange of material between the major breeding centers in an effort to increase the chance of crossing to produce superior cultivars. Breeding, selection and cultivar release is a long term process as can be seen from an example given in Table 1.3.

Table 1.3. Summary of 10 years of selection, bulking-up, testing and release in Zimbabwe (1976 to 1986).

<table>
<thead>
<tr>
<th>Stage of program</th>
<th>Total number of cultivars tested</th>
<th>Percentage selected at each stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single stools</td>
<td>516 457</td>
<td>5.91</td>
</tr>
<tr>
<td>Single lines</td>
<td>30 507</td>
<td>8.99</td>
</tr>
<tr>
<td>Cultivar observation trials</td>
<td>2 742</td>
<td>7.11</td>
</tr>
<tr>
<td>Advanced cultivar trials</td>
<td>195</td>
<td>26.15</td>
</tr>
<tr>
<td>Pre-release cultivar trials</td>
<td>51</td>
<td>15.69</td>
</tr>
<tr>
<td>Pre-release bulking</td>
<td>8</td>
<td>37.50</td>
</tr>
<tr>
<td>Limited release</td>
<td>3</td>
<td>–</td>
</tr>
<tr>
<td>General release</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

1.7.7 Field and planting hygiene

A fallow period of three months without any plant debris including stools is required for RSD control. A break crop with any non-gramminaceous plant (e.g. soybean and other beans) also improves soil fertility and promotes sustainable production. In addition there is a need to prevent plant-to-plant spread of disease, particularly RSD by continuously disinfecting cane knives particularly in the nursery stage. Mechanical harvesters should be chemically treated to prevent cutter blades spreading RSD between fields. Regular inspection and roguing form part of the hygiene practices recommended, particularly for nurseries, but also in the commercial crop where warranted.

The time of planting impacts on pest and disease pressure. This is most intense in the wet season. Planting late predisposes plants to increased pest and disease attacks (e.g. from Black Maize Beetles and mosaic disease). Resistant cultivars are particularly valuable for late-planted cane.

Ensuring that the stalks are cut cleanly at ground level with sharp cane knives or cutter blades, with the use of recommended disinfectants, applied correctly, facilitates ratooning and helps keep insect pests and diseases in check. Burning, although not recommended, can be used to help control a serious outbreak of a pest or disease that lives on plant residues.

1.7.8 Seedcane management important requirements

The success of any cultivar commercially is as dependent on the cultivar as it is on the management of the seedcane, which requires clean land and regular inspection, and often roguing and HWT. A
cultivar can only perform to its potential if the seedcane is well grown and is pest and disease free. This is often the greatest limitation on new projects and provides potential for the use of plantlets from tissue culture or speedlings from single setts.

The production of seedcane has to be linked into the bulking-up and commercial planting program, and cognizance must be taken of the time of planting – which must relate to milling in the early, mid or late season. Each part of the milling season has cultivars suited to it. For example early season cultivars are early maturing; mid-season cultivars are more versatile and late season low flowering cultivars have greater pest and disease resistance.

Seedcane schemes help to bulk up new cultivars for release at the correct time for planting out. Schemes can be organized at different levels, from country (Swaziland and Zimbabwe) to regions (e.g. Felixton in South Africa (Fortmann et al. 2006)).

**Bulking-up nurseries**
Cultivars are often bulked up in two stages. The first stage follows HWT to control RSD, and germination may be reduced as a result of this treatment. The next stage is to further bulk-up in a nursery without HWT and then use this material for commercial planting, and some to HWT to establish another first stage nursery. It is normal to grow cane for about 8 to 10 months before using it as seedcane but this can vary depending on the cultivar and its vigor. Seedcane is not dried off and is preferably irrigated and not burnt. Inspection and roguing for trueness to type, for abnormal growth and for pests and diseases is essential for the production of good seedcane.

**Chemical protection of setts**
Setts of cultivars susceptible to smut are cold water dipped for at least three minutes in a suitable fungicide.

An approved and recommended insecticide should be sprayed on setts in areas susceptible to insect pests, such as termites, cane grubs, stalk borers and false wireworms. Some insecticides and nematicides need soil incorporation and may be banded and covered.

It is important to use only those chemicals that are approved and which comply with health, safety and environment considerations and regulations.

**Certification of nurseries and commercial fields**
Diseases and pests must be below set thresholds in nurseries and commercial fields where susceptible cultivars are under pest or disease pressure. Each industry should determine suitable thresholds and control cultivar use and distribution as well as time of planting. This helps protect cultivars in use, particularly in areas vulnerable to pests (e.g. eldana) and diseases (e.g. smut in hotter areas and mosaic in cooler areas).

It is common to use lower thresholds for nurseries than for commercial crops. Zimbabwe and Swaziland managed to continue growing NCo376 for many years despite the threat from smut and mosaic because of rigorous roguing, inspection and certification of nurseries, as well as plough out, by order, of commercial fields with higher than acceptable smut levels. The high cost of roguing and the level of management required for effective roguing have resulted in rapid adoption of resistant cultivars.

Industries often set up independent pest and disease teams to monitor the situation and an industry committee to carry out the withdrawal of nurseries and implement field plough-out orders.
**Breeding centers**
All major producing countries have breeding stations that are central to their research programs. There is often linkage to other institutions with sophisticated molecular and analytical equipment necessary for advancing the industry. There is good collaboration between the major producers, and breeding material is regularly exchanged to mutual benefit. It is important for smaller industries to realize this and to ensure that they obtain material from these institutions for comparison with their own local selections.

**Mitigating risk**
The selection of cultivar should be based on optimizing production with minimal chemical or other inputs and should be able to withstand any perceived risks from pests or diseases.

The payment system should ensure that better cultivars are rewarded for quality. This can even be done on the basis of cane payment by giving these cultivars a higher cane price. There needs to be a good tracking system on cultivar use.

A cultivar can only perform to the level of management it is given and the production system needs to be sustainable. Zero till and controlled traffic systems are under investigation and the inclusion of a fallow or break crop is becoming more common.

The main threat is climate change and lack of adequate water. Therefore drought tolerant cultivars are particularly necessary under monoculture where soil conditions are deteriorating, particularly in the more marginal areas.

The best start one can have is to use the best cultivars, free of pests and diseases, and to establish them under the best conditions.

Tissue culture offers the advantage of providing a sufficient quantity of disease free material to new green fields projects. However, the project must have the levels of expertise to manage the material properly. Plantlets should be established in the field under favorable climatic conditions (not too hot or cold) and well before the rains. This will help limit the threat from the main sugarcane pests and diseases but control of other factors may become important (e.g. animal grazing).

Surface and subsurface drainage are essential under many of the more marginal conditions where cane is being planted. An excellent topographical and soil survey is required as a basis for a sound conservation layout.

Monitoring and control (e.g. leaf and soil analyses and irrigation scheduling) and good record keeping can all help improve cultivar selection, performance and management.

Doing the simple things properly and on time will determines the potential of a cultivar.

At industry level there is a need to continuously evaluate cultivar performance and determine areas with shortcomings. A spread in the mix of cultivars is recommended, but this must take cognizance of the opportunity cost of not using the best cultivars.

Risks must be evaluated and strategies worked out well in advance. Having a surplus of good material to plant is recommended for all sectors of the industry.

Smallholders are often at greatest risk and the choice of resistant cultivars is particularly important for them. They also need to have a financial plan to allow replanting and to change cultivar in time.

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1.8 Conclusions

Research and development into producing high yielding, disease free material is an investment not a cost, but it becomes a cost if benefits are not realized by the industry (Burnquist et al 2010).

Clean, well grown seedcane (speedlings or tissue culture plantlets) form a sound foundation to any development. The importance of this is often not realized. The real potential for the future is resistant or tolerant, more efficient cultivars for the situation where they are to be used.

The greatest threat to cultivar performance is from the impact of climate change on ensuring adequate water. In a global context water is supply limited. This threatens rainfed and irrigated cane.

There is a need to realize cultivar potential by improving soil conditions. GMP must rely on the use of pest and disease resistant cultivars, improving water and nutrient use efficiency and soil conservation practices.

The payment system must take account of cane quality and milling efficiency and reward superior performing cultivars.

Sugarcane is a most forgiving crop as it grows or accumulates sugar unless conditions are desperate. It has the ability to survive under very poor conditions. However, when a serious outbreak of pest, disease or mismanagement occurs, it takes a complete crop cycle of at least four crops (plant crop and three ratoons) to correct the situation. This is costly and all efforts should be made to avoid this. If this does happen it is a good time to re-evaluate cultivar use. Reassessment should take place before the field is due to be ploughed out.

Box 1.8 Summary of good management practices for cultivar selection

- Select cultivar on the basis of proven performance (sugar, fiber or ethanol), which are suited to the specific soil, climate, harvesting, management and milling conditions. Ensure that they are obtained legitimately and comply with phytosanitary requirements, import regulations and any Sugar Act and Regulations that might apply.
- Priority must be given to selecting the cultivar with the required agronomic and milling characteristics and with pest and disease resistance/tolerance.
- Source in advance: clean, certified, pest and disease free material (setts, plantlets or speedlings) from a reputable source.
- Check on material before delivery if this is at all possible.
- Soil sample land to be used before final land preparation and planting, and obtain fertilizer recommendations from an approved laboratory. It must be able to give recommendations for sugarcane. Apply the recommendations.
- Plant new cultivar for bulking-up into virgin land if possible.
- Plant into well drained and prepared soil corrected with lime and phosphate as required.
- Plant into soil free of weeds, pests and diseases or treat accordingly. Make use of broadleaf break crops to achieve this.
- Land must be free of volunteers for at least three months for control of RSD.
- Ensure that fertilizer application for the crop cycle is based on soil and leaf analysis.
- Plant when rains are reliable for rainfed cane and conserve moisture. Plant only after irrigation has been installed for irrigated cane. Schedule irrigations on the basis of need.
- There must be regular monitoring and control of weeds, pests and diseases.
• Harvest commercial cane after drying-off (do not dry off seedcane), or after application of chemical ripener (do not apply ripeners to seedcane). Harvest at the recommended time of milling season for the variety being harvested (early, middle or late).
• Preferable to harvest by hand and as green cane, but mechanical harvesting is becoming more appropriate.
• Do not harvest when soil conditions are too wet and when there will be a long term negative effect on soils and cane performance. If lands are likely to be harvested in the rains select well drained areas and lighter soils and grow robust varieties with good ratooning characteristics.
• Harvest cleanly at ground level to ensure good ratoonability and reduce incidence of pests and diseases.
• Use tops and trash to conserve the soil environment and to improve plant performance. Burning or removing trash and tops may be appropriate under certain conditions.
• It is preferable to have a mix of varieties. The predominant variety should not exceed 30 to 40 % of the total area planted. This will depend on the balance between risk and performance.
• It is important to monitor variety performance and to continuously introduce new varieties.
• The performance of a variety is dependent on its genetic potential, quality and the cleanliness of the planting material (pest and disease free), climate suitability for growth, time of milling and most importantly on the level of management provided. These must all be considered as part of GMP, which integrates all aspects of production.

1.9 References


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2. THE SOIL AND ITS ENVIRONMENT

In this chapter the reader is provided with the necessary tools to know and understand his or her soils better; what they look like, how they were formed and where they may be found in the landscape. In time the successful implementation of the ‘Triple Bottom Line’ (TBL) approach will be affected by how well a manager knows his soils and it is therefore important to consider what soil types there are, where they occur and what their main physical and chemical limitations are. Selected examples are provided, illustrating how soil specific guidelines can be used for managing a range of agricultural operations and inputs on a particular sugarcane estate or outgrower farm.

2.1 Why is knowledge of soil important?

Many of the decisions a manager makes are affected by the soils that occur on the farm or estate. Good management practices must be economically and environmentally sustainable, and include systems of land preparation for re-establishing cane, cultivar selection, nutrition, weed control, the use of agricultural chemicals, irrigation planning and control, the optimum time to harvest, and trash management. A key philosophy for all to follow to ensure long term sustainability is:

*Man is dependent on good soils and good soils are in turn dependent on man and the use he makes of them.*

While the global sugar industry is characterized by a wide range of climates, the soils in the industry show even greater variation, differing widely in their physical and chemical properties, their ability to produce crops and their management requirements. It is also not uncommon to find a number of soils differing in these characteristics on the same estate.

2.2 Origin of soils and their distribution

2.2.1 Soil composition and functions

Soil is composed of a mixture of mineral particles of varying sizes which are derived from rock fragments (< 2 mm in cross-section), finely weathered minerals (particularly clay), organic matter, humus, soluble nutrients, live bacteria, fungi, algae, air spaces and water. Soil forms part of the thin porous mantel covering most of the terrestrial parts of the globe. Main functions of soil:

- Acts as a medium for plant and root growth by providing stored moisture and nutrients, and physical support for the plant to remain upright.
- Deeper and lighter textured soils tend to support deeper root systems. In general the amount of roots below ground may be as large as the amount of biomass above the ground.
- Soil modifies the effect of climate by influencing the amount of runoff and the portion of rainfall retained in the root zone and released to the plant.
- A principal factor in the hydrologic cycle system.
- Provides a habitat for organisms.
- Soils also determine the rates of fertilizer application due to their different nutrient supplying and immobilizing characteristics.
2.2.2 Weathering agents contributing to soil formation

Weathering refers to the physical and chemical disintegration and decomposition of rocks, aided by biological agents, under varying temperature, pressure and moisture conditions on the earth’s surface. Initially, weathering precedes soil formation, particularly in fresh rocks creating the parent material from which soil formation takes place. Physical agents tend to be more important than chemical agents in dry and/or very cold climates.

Box 2.1 Principal agents of physical weathering

- Temperature changes causing differential expansion and contraction resulting in exfoliation or ‘onion skin’ weathering of rocks.
- Raindrop splash can be very destructive on an unprotected soil surface, causing dispersion and capping.
- Water from heavy rains and flowing waters rupture weakened rocks, exposing the inner portion to weathering as well as transporting materials.
- Wind exerts abrasive action, and acts as a carrying agent.
- Alternate wetting and drying results in downward leaching or an upward movement of soluble salts due to capillary water movement and evaporation.
- Lichens and mosses growing on bare rocks are capable of gradually disintegrating rock material. Grasses, shrubs and trees growing in rock crevices extend the cracks by the growth of their roots.

Chemical weathering is more important in hot and wet climates. Where this takes place in the soil profile the weathering is termed pedochemical, whereas weathering in the deeper underlying rocks may be termed geochemical. The chemical decomposition of rocks is brought about by solution, hydration, hydrolysis, carbonation, oxidation and reduction reactions.

Box 2.2 Principal processes of chemical weathering

1. **SOLUTION:** Through the solvent action of water dissolving soluble salts, accelerated by carbon dioxide and organic acids released during the decomposition of organic matter.
2. **HYDRATION:** Hydration involves the slow conversion of certain compounds by water molecules to more easily decomposable compounds. For example, yellow ochre has more water attached to the molecule than red ochre and is less stable.
3. **HYDROLYSIS:** This is the most important process of chemical weathering, whereby weatherable minerals are converted into hydroxides of potassium, iron, magnesium or calcium in the presence of water and elevated temperatures.
4. **CARBONATION:** The hydroxides produced during hydrolysis react with the dissolved carbon dioxide to form carbonates which may either leach out or accumulate according to drainage or weather conditions.
5. **OXIDATION:** Oxidation is an important reaction in well-aerated rocks and soil material where oxygen supply is high and biological demand is low, and it is the dominant process for soil groups such as Nitosols and Ferralsols to have red or chromic colors due to the oxidation of ferrous to ferric iron.
6. **REDUCTION:** During reduction, particularly under prolonged waterlogging, the reverse of oxidation occurs. When biological oxygen demand is high and the supply of oxygen is low, the ferric ion is reduced to the ferrous ion, causing the red color to disappear.
2.2.3 Soil development

Soils form part of a landscape which itself is the result of the operation of present and past geomorphic regimes, dominated by the weathering processes just described. These processes are largely driven by climate, which is one of the major soil forming factors, along with parent material, topography, biological conditions and geological time. Throughout geologic time, wide variations in climatic conditions, and thus geomorphic regimes, have affected regions to different extents worldwide, resulting in a diverse range of landscapes and even more diverse range of soils that can often result in up to three or more different soil types occurring in a field.

The character of the soil profile itself, in terms of the individual layers called horizons, is fashioned by a number of soil development factors that include:

- Climate
- Parent material
- Topography or drainage
- Biological conditions
- Geological time.

**Climate**
Mainly through temperature and moisture acting over thousands of years, climate has had a major effect on soil development and distribution, and the sequence of soils on a regional scale. The following are some examples of climatic influence on soil development.

- Tropical moist climates speed up the rate of chemical weathering and cause the development of deep, porous, leached, acid soils. In general, the rate of chemical reactions described earlier doubles for every 10 °C rise in temperature.

- Dry climates, resulting in evaporation in excess of precipitation, cause soluble salts and nutrients to accumulate in surface soils, often to the extent of causing saline sodic conditions (see Chapter 7). Chemical weathering is slow in deserts but physical weathering, particularly exfoliation and sand blasting or wind erosion, is common. Soils are less weathered and often contain a higher proportion of 2:1 lattice clay minerals that can provide an excellent source of potassium as well as other cations.

- Cold climates slow down the rate of chemical weathering, restricting soil development and causing shallower soils, but generally with above average cation and organic matter contents.

Climate and soil age are therefore often associated, as well as climate and natural vegetation, and these resulted in the zonal concept of soil classification (White 1979).

**Parent material**
This is essentially the underlying geological material from which the soil is derived. Geological materials can range from common igneous rocks such as high silica or quartz content granites, granodiorites and rhyolites to low silica rocks such as dolerite, diabase and basalt, to sedimentary rocks such as sandstone, shale, conglomerate, siltstone and limestone to metamorphic rocks such as gneiss, schist, amphibolite and marble. In general the high silica containing rocks such as granite, gneiss and sandstone containing minerals such as quartz, mica and feldspars weather to form mainly light textured, grey sandy to sandy loam soils that have coarse texture, are friable with a low base status, are acid and are poorly supplied with nutrients. In contrast, the low silica parent materials such as dolerite and basalt that contain some feldspar clay forming minerals and iron containing
minerals such as Hornblend, Augite and Olivine, tend to produce heavier sandy clay loam to clay soils, often red or black in color, and generally well supplied with nutrients, except phosphorus. These soils tend to be neutral to basic in reaction at low elevations, but at high elevations the red soils are older and more highly leached, often containing toxic levels of aluminum in the profile.

Topography and aspect
Topography or relief has a dramatic impact on soil development and in determining the pattern or toposquence of soils in a particular landscape. This pattern of soils is closely linked to the water balance at every site, and drainage can play an enormous role in changing the nature or characteristics of soil over relatively short distances. An example of this sort of change is given in Fig. 2.1 for a toposquence on granite in Mpumalanga, South Africa.

![Figure 2.1. Cross-section of soils along a toposquence on granite.](image)

Soils on the crest position have the highest rate of soil loss through erosion, resulting in a very shallow soil which progressively becomes deeper with descent, reaching a maximum depth in the bottomland position with the accumulation of eroded material. Soil in and around the valley floor not only receives moisture from rainfall, but also from deep percolation and seepage from the well drained soils above. The term ‘hydromorphic’ (water loving) is used to describe this bottomland soil, also known as a ‘Gleysol’ in terms of the World Record Base (WRB) of soil classification, as it is frequently waterlogged in the wet season, with a mottled, clay subsoil (G-horizon). The footslope soil just above the gleyed subsoil is associated with an eluviated (bleached or washed out) layer, called an ‘E’ or ‘Albic’ horizon overlying a gleyed subsoil. This is usually caused by water moving laterally through the soil above the impervious subsurface layer. This horizon usually contains very little clay, organic matter and nutrients and is not a good environment for plant roots. The soil profile is classified as a ‘Planosol’ in terms of the WRB soil classification. This horizon disappears further upslope into a better drained but much shallower profile comprising a shallow grey loamy sand topsoil merging smoothly into a denser subsoil with prominent clay tongues penetrating the soft granite saprolite. In the above example the soil qualifies as a ‘Cambisol’ in terms of the WRB.

The soils in a large part of the Herbert Valley sugarcane areas in Queensland, Australia, have been mapped in this way and at least seven toposquences have been identified, covering 24 soil types (Wood et al. 2003).
Aspect is also an important factor in soil development. In the southern hemisphere, northerly and westerly aspects are hotter than southerly and easterly aspects, and northerly and westerly aspects are often in a rain shadow, compared to south-easterly slopes that face the cool rain bearing winds. In South Africa, the northerly aspects tend to develop shallower soils, black or red in color, and have greater structural development, whereas southerly slopes are often deeper soils, brown or yellow in color with apedal structure on the same parent material.

**Time**

This soil forming factor has been referred to as the ‘age effect’ or the ‘geological erosion effect’ (Maud 1965). Throughout geologic time wide variations in climatic conditions, and thus geomorphic regimes, have affected regions to different extents worldwide. Generally warm prevailing climatic conditions have been operative only for the past 10 000 years or so, known as the geological period of the Holocene (or Recent). Prior to this, during what is known as the ‘Last Glacial’ period, which began about 120 000 years ago but which had its maximum effect only about 18 000 years ago, climatic conditions were generally significantly cooler and drier than those of the present, with consequent changes in the prevailing geomorphic regime that prevailed at that time. Of significance in the presently warmer and moister sugarcane growing regions of the world, the ‘Last Glacial’ period was one of enhanced erosion and deposition. As a result, most of the present-day soils in these regions are ‘young’ and have formed during the Holocene. However, this is not to say that some older soils, or remnants of older soils, have not survived in some situations conducive to their preservation (Dr R.Maud personal communication 2011). Examples of this are the survival of older elevated alluvial river terraces, but more notably the survival of remnants of ancient petro-plinthite (laterite) profiles which had their origin in the geological Cretaceous period, more than 60 million years ago, and which occur widely in the warmer portions of the former Gondwana remnant continents of Africa, South America, Australia and India (Fig. 2.2).

![Figure 2.2. Highly weathered soils (Ferrosols) developed on an ancient remnant of the African surface in the background, 240 m above the Quaternary erosional surface in the foreground with young soils.](image)

Indeed, soils reflecting more recent climatic and geomorphic regimes have been, and are currently being, developed on these ancient soil profiles in many places, with the modern soils inheriting many characteristics (mainly unfavorable) of these earlier soils. Examples of this can be found in Africa in the sugarcane growing areas of Uganda on the northern shore of Lake Victoria, and in the northern part of the Ivory Coast.
Living organisms
These include microorganisms, insects, plants, animals and human beings that can influence soil development in a positive and negative way. Selected agents of biological weathering include the following:

- Plant roots can assist in decomposing parent material and reduce soil erosion losses and once they have died will facilitate water and air movement through the decayed skeletal remains that act as channels.
- The soil food web, which is a highly evolved biological community of tens of thousands of interacting species of organisms, consists of the tiniest of one-celled bacteria, algae, fungi and protozoa, to the more complex nematodes and microarthropods, to visible earthworms, insects and small vertebrates. All of these play a big role in decomposing plant residues, releasing plant available nitrogen and producing substances that may dissolve or help to translocate other minerals. Topsoil is often stained a dark color by humus from decomposed organic matter that improves physical properties such as soil structure, and promotes better water infiltration and eventually greater crop yield.
- Soil macro-organisms such as earthworms, termites and moles also redistribute recycled material, either within the soil profile or over short distances on the land surface. Termite mounds are a feature in a number of industries and have transformed many natural soil profiles by greatly increasing the clay content as well as large increases in base status compared with soils adjacent to the termite mound.

Examples of important global soil differences in relation to soil forming factors
In general, ‘dryland’ sugarcane production takes place worldwide in regions of some significant erosional topographic relief where the general youthfulness of the soils reflects fairly strongly the characteristics of their specific parent material origins. For example, the acid red clayey Luvisol soils developed so extensively on the Parana Basalt of Brazil, the grey sandy loam Cambisols derived from Basement Granite and sandy Arenosols derived from Cape System Sediments in the South African sugar industry. In some places, due to very high rainfall conditions, as in places in Hawaii, the derived Ferralsols, also derived from basalt, show the extent of the extensive weathering and leaching they have undergone during their formation. Along the Queensland coast in Australia, most soils have formed on Alluvial deposits and are known as Fluvisols. For example in the Herbert River Valley a complex soil pattern has developed with mainly sandier soils found closest to the river along its levees and a trend towards finer heavier textured soils away from the river when flooding occurs (Wood et al. 2003).

Irrigated sugarcane production in the drier regions normally takes place on soils derived from Alluvial deposits (Fluvisols) on river flood plains, their terraces, and lake shores in areas of minimal relief, close to the main water source. An excellent example is the Vertisolic black clay soil of the Gezira region of the Sudan, which is located between the Blue and White Nile Rivers above their confluence. However, as mentioned, young irrigated Fluvisol soils are sandy, reflecting their alluvial origin. Alluvial soils to be irrigated in very low rainfall areas are frequently characterized by a natural accumulation of sodicity and salinity in their adverse Solonetzic soil profile.

2.3 Recognizing important soil properties

Soil properties
Soil properties are the most important parameters that affect a whole range of agronomic decisions in the field, such as what implements to use in land preparation, what type of irrigation system to use, water application rates, irrigation intervals, and whether subsurface drains are needed. The most effective way to understand soils and their properties is to expose the soil profile in the field by
clearing a soil face in an adjacent road cutting or ditch or, better still, by digging a pit. This provides the opportunity to describe the basic pedological properties such as color, texture, structure and effective rooting depth, and to look for horizontal horizons or layers in the profile.

**Box 2.3 Summary of steps to follow in a simple profile description**

1. **Step 1:** Expose a fresh profile of the soil to be identified.
2. **Step 2:** Mark off and identify the master soil horizons or layers (Fig. 2.3). There are normally three layers, designated ‘A’ for the topsoil, ‘B’ for the subsoil and ‘C’ for the underlying horizon (Fig. 2.3).
3. **Step 3:** Record the depth, color, texture and structure for each horizon.
4. **Step 4:** Obtain an estimate of the effective rooting depth in the pit. This depth is defined as the depth of soil (excluding gravel, stones and rocks) in which about 85 to 90% of the crop roots are found.
5. **Step 5:** Classifying the soil and giving it a name would require knowledge of the naming of diagnostic horizons using the National Soil Classification System in a particular country. If this is not available, then the WRB could be considered.

Each horizon has its own color, texture and structure that distinguishes it from the horizons above and below. The changes in these properties between horizons can be smooth to abrupt and will vary with the type of underlying parent material and the position of the profile in the landscape.

**Soil color**

The most important soil colors are red, brown, dark brown-black, light grey, dark grey and yellow. Soil color is affected mainly by the amount of organic matter present, the dominant clay mineral present, the presence of iron oxide contents and the degree of reduction if drainage is a factor. Dark colored soils generally contain more organic matter than lighter colored soils. Well drained soils tend to be red in color whereas more poorly drained soils have paler grey and yellow colors. Very badly drained soils range in color from grey to blue. Mottles indicate cyclic processes of periodic wetting and drying. Bleached horizons indicate that organic matter has been leached from the horizon.
When describing the color of a horizon it is important to state whether it has a single uniform color and whether transition from A to B is gradual or abrupt (Table 2.1). Soils with abrupt horizons are difficult to manage under irrigation as downward percolating water tends to accumulate at the abrupt interface, leading to runoff when the topsoil is filled with water.

Table 2.1 Summary of agronomic implications of different soil colors.

<table>
<thead>
<tr>
<th>Soil color</th>
<th>Interpretation</th>
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<tbody>
<tr>
<td>Uniform</td>
<td>Uniform colors tend to indicate that stable, almost equilibrium conditions have persisted for a long time, e.g. in mature soils on old landscapes. Ferrosols and Nitosols are two examples.</td>
</tr>
<tr>
<td>Red and brown</td>
<td>Indicate good drainage and aeration with a high capacity to store moisture. They normally occur in upland positions and are regarded as high potential soils, well suited to high potential cultivars and irrigation. The chromic Luvisol derived from Parana Basalt is a prime example.</td>
</tr>
<tr>
<td>Yellow</td>
<td>Yellow color is caused mainly by hydrated iron oxides and generally indicates a moister and less well aerated soil than does a red. Tends to occur in the lower part of the toposequence and is also widespread under the cooler conditions of the Midlands Mistbelt in South Africa.</td>
</tr>
<tr>
<td>Black/dark brown</td>
<td>Indicates high organic matter or smectite clay. Black is a common feature of most Vertisols and Mollisols. Surface irrigation is the preferred system, given the variable intake rates under wetting and drying cycles.</td>
</tr>
<tr>
<td>Grey</td>
<td>Grey colors indicate bleached soils due to intensive leaching or removal of clay minerals, e.g. E, or Albic horizon. Grey is also indicative of low fertility, particularly low organic matter levels, as well as a high risk of surface crusting. Not recommended for irrigation especially where water quality is a problem. Irrigation should not be attempted without proper drainage.</td>
</tr>
<tr>
<td>Mottling and blue/grey</td>
<td>Mottles are indicative of fluctuating water table levels leading to periodic saturation in bottomland soils, with usually anaerobic (without oxygen), followed by aerobic (with oxygen) conditions due to wetting and drying. The mottles usually form around soil pores and root channels where oxygen is present. Not recommended for irrigation especially where water quality is a problem.</td>
</tr>
<tr>
<td>Variegated</td>
<td>Variegated colors indicate presence of dark clay skins, or due to the decomposition of different colored minerals. Very common in alluvial soils, also referred to as Fluvisols.</td>
</tr>
</tbody>
</table>

Soil texture

Texture refers to the relative proportions of different sized mineral particles in the soil. The largest particle size diameter according to USDA standards includes gravel (> 2.0 mm), coarse sand (2.0-0.5 mm), medium sand (0.5-0.25 mm), fine sand (0.25-0.05 mm), silt (0.05-0.002 mm) and clay < 0.02 mm in diameter. The scale in the difference in particle size can only be appreciated in terms of the relative number of particles in one gram of coarse sand amounting to about 650, compared to 6 million particles in a gram of silt and 90 million particles in a gram of clay. The important fact is that a gram of colloidal clay has an external surface area well over one thousand times that of a gram of coarse sand. Some silicate clays have extensive internal surface areas as well and the combined total surface area can range from 10 m²/g to more than 800 m²/g for clays with extensive internal surfaces. It is for this reason that clay is such a vital property of soil, as it affects the cation exchange capacity (see Chapter 5), the water infiltration rate and the capacity of the soil to hold water (see Chapter 6). Clay also
impacts on management issues such as the erodibility of soils, root development, drainage and resistance to compaction.

Once the amounts of sand, silt and clay have been determined from a laboratory physical analysis, the actual textural class of the soil (which refers to the ratio of sand, silt and clay fractions) can be interpolated from the textural triangle shown in Fig. 2.4. Note that the results of all three fractions should add up to 100%. However, only two of the fractions are needed to determine the soil texture. For example, a soil with 30% clay and 60% sand is classified as a sandy clay loam, whereas a soil with 10% clay and 70% sand would qualify as a sandy loam.

![Figure 2.4. Soil textural classification triangle.](image)

**Estimating soil texture in the field by feel**

The sand, silt and clay fractions in a particular soil can be distinguished by feel when the soil is moistened with water to the consistency of a thick friable paste or mud. Sand tends to have a distinct gritty feel when rubbed between two fingers and makes a grinding noise when the rubbing takes place close to the ear. Clay on the other hand has a greasy, slippery feel and will stick to the palm of the hand. Silt has more of a silky feel, not unlike plasticine, but does not stick to the hand. The relative amounts of the different fractions (i.e. the textural classification of the soil) can, with training and experience, be fairly accurately estimated. Start by manipulating a heaped teaspoonful of soil with sufficient water to a state of maximum stickiness and plasticity, working out all of the lumps before applying the following tests.
TEXTURAL ASSESSMENT: BY FEEL

<table>
<thead>
<tr>
<th>Texture Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAND:</td>
<td>Sand is loose when dry, cannot be molded when wet and is not at all sticky when wet. When rubbed between the fingers a grinding noise can be detected and it leaves no film on the fingers.</td>
</tr>
<tr>
<td>LOAMY SAND:</td>
<td>Has sufficient clay to give it slight plasticity and cohesion when moist and leaves a light film of fine material on the fingers when rubbed. The grinding noise with rubbing between the fingers is still there but not as audible.</td>
</tr>
<tr>
<td>SANDY CLAY LOAM</td>
<td>Has sufficient clay to be distinctly sticky when moist, but still unable to form a ball; the sand fraction is still an obvious feature.</td>
</tr>
<tr>
<td>CLAY LOAM:</td>
<td>The soil is distinctly sticky and greasy when sufficiently moist, and sand fractions can only be detected with care. There should be sufficient silt to provide a smooth, soapy feel.</td>
</tr>
<tr>
<td>SANDY CLAY:</td>
<td>The soil is plastic and sticky when moistened sufficiently and can be molded into a ball. A slight gritty feel still indicates the presence of sand.</td>
</tr>
<tr>
<td>CLAY:</td>
<td>The soil is strongly plastic and sticky when moistened and gives a polished surface on rubbing. When moist, the soil can be rolled into a ball which in turn can be rolled into threads or molded into any shape and takes clear fingerprints.</td>
</tr>
</tbody>
</table>

TEXTURAL ASSESSMENT: VISUAL

Take a handful of moist soil, knead it and roll it between the palms of the hands to form a ‘sausage’. The relationship between this ‘sausage’ and soil texture is as follows:

1. If no ‘sausage’ can be formed, the soil is a sand (< 10 % clay).
2. If a ‘sausage’ can just be formed but it cracks upon slight bending, it is a loamy sand (10-15 % clay).
3. If the sausage can bend a little, it is a sandy loam (15-20 % clay).
4. If it will bend readily before cracking, it is a sandy clay loam (20-30 % clay).
5. If it will bend round nearly into a circle, it is a sandy clay (35-55 % clay).
6. If it will bend into a circle it is a clay soil (> 55 % clay).

The following schematic is a guide to estimating texture in the field:

![Figure 2.5. Visual assessment of soil texture.](image-url)
2.4 Impact of clay content on agronomic management

Like organic matter, clay is strongly correlated with a number of physical and chemical properties which in turn have strong implications for a number of agronomic practices such as irrigation, drainage and plant nutrition. Comparative impacts of sandy and clay soils on selected chemical and physical properties are summarized below.

Table 2.2. Chemical and physical properties of sandy vs. clayey soil types.

<table>
<thead>
<tr>
<th>Main property</th>
<th>Properties of sandy soils</th>
<th>Properties of clayey soils</th>
</tr>
</thead>
</table>

Soil structure

A network of solid particles distributed to form a system of channels and pores, introduces the concept of aggregation and structure in soils. Aggregation is the arrangement of primary soil particles (sand, silt and clay) and organic matter into secondary units called aggregates, crumbs or granules. Structure on the other hand is the arrangement of primary and secondary aggregates to form visible structural units called peds.

Structure may be classified as weak, moderate or strong. In the case of weak structured soils, the peds can be easily ruptured between the fingers whereas with strong structure the cohesion within the peds makes it very difficult to break a clod of soil into the individual peds. When one is successful, the dislodged peds can be easily fitted back into clod, much in the same way as fitting a missing piece into a puzzle. Soils that are without any form of structure are described as structureless, such as beach sand. Aapedal structure indicates mainly a micro-crumble structure that is not visible to the naked eye. This structure characterizes some of the highly weathered red clay soils that occur on old erosion land surfaces such as Ferralsols in South Africa and Australia, Latisols in Brazil and Oxisols in Hawaii.

A soil may be highly structured but poorly aggregated and as such is often not suited to irrigation and agricultural development (Its massive nature impedes root growth and has a low water availability). Conversely, soils such as some alluvial derived clay loams (Fluvisols) are not structured, but may be strongly aggregated to form small aggregates that rank as some of the best soils for irrigation and crop production. Soil structure affects growth of plants through its influence on soil air, soil water, mechanical impedance to roots, and soil temperature.
Structured particles are categorized according to their nature (type, size and degree).

Type: angular, apedal, blocky, columnar, crumb, granular, platy, prismatic
Size: fine, medium, coarse
Degree: strong, moderate, weak, structureless.

Types of structure and their descriptions as well as relationship to selected soil and plant development are summarized in Table 2.3.

**Table 2.3. Examples of different types of soil structure and impact on selected soil properties.**

<table>
<thead>
<tr>
<th>Structure type</th>
<th>Structure shape</th>
<th>Description</th>
<th>Plant available water</th>
<th>Root penetration</th>
<th>Internal drainage</th>
<th>Erodibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single grains (none)</td>
<td></td>
<td>No observable aggregation, no natural lines of weakness, but non-coherent.</td>
<td>Very low</td>
<td>Usually very deep</td>
<td>Very rapid</td>
<td>High</td>
</tr>
<tr>
<td>Apedal (weak)</td>
<td></td>
<td>Moderately aggregated forms a micro-crumble structure. Common to sesquioxic Ferralsols and Oxisols.</td>
<td>Low to medium</td>
<td>Deep</td>
<td>Very rapid</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Crumb (moderate)</td>
<td></td>
<td>More or less small rounded peds and relatively porous.</td>
<td>Medium</td>
<td>Deep</td>
<td>Rapid</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Blocky (strong)</td>
<td></td>
<td>Flat or less rounded peds and relatively non-porous. Common in Chromic Luvisols.</td>
<td>High</td>
<td>Moderately deep</td>
<td>Moderate</td>
<td>Medium</td>
</tr>
<tr>
<td>Prismatic and columnar (strong)</td>
<td></td>
<td>Vertical dimension exceeds horizontal dimension. Common to dry climate soils, e.g. Vertisols.</td>
<td>Medium</td>
<td>Shallow, poor roots</td>
<td>Slow</td>
<td>Medium to low</td>
</tr>
<tr>
<td>Platy (strong)</td>
<td></td>
<td>Horizontal dimension exceeds vertical dimension. Can be caused by heavy infield compaction under wet conditions.</td>
<td>Low</td>
<td>Very shallow, poor roots</td>
<td>Very slow</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Organic matter**

Organic matter is any material that is part of or originated from living organisms. Organic matter may be divided into three fractions, the living, the dead (active fraction) and the very dead (stable fraction). The living soil organic matter fraction includes microorganisms, soil-dwelling insects, microarthropods, animals and plants. The dead fraction consists primarily of fresh residues from crops, recently dead microorganisms and insects, sloughed-off root cells, leaf litter, manure, etc. This fraction is considered active. The sugars, proteins, cellulose and other simple compounds are quickly broken down (degraded) by soil microbes and used as a food source which fuels the soil microbial population. The exudates (sticky substances) produced by the microbes (and roots) as well as the microbes themselves (e.g. fungi) help bind the mineral particles together to form soil aggregates. Good soil aggregation is important for maintaining good (crumbly) soil structure and enabling
adequate air exchange and water drainage. The very dead organic matter fraction is also called humus. Humus is very stable and resists further degradation. Although it is not an important food source for microbes, it is important for storing nutrients and water, binding toxic chemicals and contributing to improved aggregate stability.

Soil depth
Knowledge of the underlying chemical and physical condition of the soil is important in understanding root development, as factors will dictate the quality of the root system in terms of distribution and depth. For example, in a uniformly deep red sandy clay loam (Chromic Luvisol), cane distribution reached a depth of 3 m (Fig. 2.6). In soils with subsurface barriers such as plinthic horizons, heavy prismatic B horizons or wet gleys, the potential depth for rooting is considerably reduced and may be as low as 500 mm. The effective rooting depth (ERD) refers to the depth of soil within which the root system can freely exploit its moisture and nutrient requirements without any other factors limiting root development (Fig. 2.7). In a freely draining soil without subsurface hindrances, it is assumed to be 70% of the total depth exploited by roots. In the example of the red sandy clay loam below the ERD was estimated to be 2100 mm (70% of 3000 mm). The ERD will in turn impact on the water extraction efficiency and will also determine the total available moisture (TAM) capacity of the soil once the available moisture capacity is known (see Chapter 6).

Other properties
Other physical properties such as available water capacity, total available water, infiltration rate and permeability that are important for irrigation and drainage are dealt with in Chapters 6 and 7. Major chemical properties such as pH, organic matter content, cation exchange capacity, the primary, secondary and micronutrients are dealt with in Chapter 5.

2.5 Classifying Soils
Thus far the basic soil forming processes and main physical properties have been presented which will enable the wide range of soils that occur in global sugar industries to be simply classified through a description of color, texture, structure, depth and other features as follows:
Red and grey medium-grained sands
Black, heaving clays which are occasionally saline
Shallow grey sandy loams on steeply sloping land in parts of the coastal hinterland
Dark alluvial soils
Neutral red clays
Wet gley soils, clayey and sandy
Moderate to very acid, porous, red and yellow soils, some aluminous and/or humic.

It has also been shown that differences between these types of soils can be attributed to various soil forming factors such as the parent material, rainfall, temperature, topography, drainage and biological conditions. The length of time that the parent materials have been exposed to the combined actions of these environmental factors or weathering processes is also important. While using a string of words to describe a soil or groups of soils in terms of color and other properties appears to be a simple and easy way to classify soils, using a description such as ‘a black, blocky structured, heavy clay soil, rather shallow, overlying shale rock’, is far too cumbersome and subjective to describe the soil to another person. The many permutations that can be made up from the four properties described and varied deductions one can make about a soil from a description is the main reason for wanting to classify soils into easily recognizable groups.

**Systems of soil classification**
Unlike plants and animals that can be classified as separate entities, the global soil mantle is a continuum. Soil is a three dimensional system with properties that mirror the influence of climate, flora and fauna, and the topography formed from the underlying parent material over a variable period of time. Grouping and naming of soils has developed and changed considerably over the years. Historically, the Russian school classified soils on the basis of climate as climate is the dominant soil forming factor in that country. However, grouping soils of sugarcane areas located mainly in the tropics and subtropics into podsols (soils of the coniferous forests), pedalfers (soils rich in aluminum and iron), pedocals (soils rich in calcium and magnesium) and desert soils, simply did not work out. A number of further soil classification systems were developed and reviewed by Butler (1980), such as the map of Africa (D’Hoore 1964), for former French colonies Duchaufour 1982), but they all ended up being mainly of academic value.

Only two systems of soil classification enjoy international recognition and are used in soil surveys needed in feasibility studies of new green fields sugar cane related projects. These are **Soil Taxonomy**, originally developed in the USA in 1938 and now in its 11th edition (USDA Soil Taxonomy) and the **World Reference Base** (WRB) system of classification, which is a revision of the FAO soil classification system (FAO 1974). A number of countries such as Australia, Brazil, India, Argentina and South Africa have developed their own national systems of classification that are best suited to their environmental conditions. Selected examples covering the principles and relative merits of some of these classification systems for sugarcane production are briefly discussed.

**Soil taxonomy**
Since 1938, when soil taxonomy was first conceived by soil survey staff of the US Department of Agriculture to group many thousands of soil series into meaningful, exclusive groups, the classification has evolved though a number of stages or approximations, to the extent that the 11th edition of Soil Taxonomy was published in 2010. The system has changed from being a classification that between 1938 and 1960 was based mainly on soil forming factors as criteria for identification, to becoming almost totally generic, focusing on soil morphology in the form of topsoil and subsoil diagnostic horizons as criteria for classification.
Soil Taxonomy can be considered a hierarchical system which classifies soils into six levels of detail, from the most detailed level, soil series, to the broadest category, soil orders. The 12 Soil Orders at the broadest level are summarized in Box 2.4. Further details may be found in USDA (1975, 1982), and the system is very well documented on the website http://soils.cals.uidaho.edu/soilorders/orders.htm.

Box 2.4 Soil Taxonomy’s 12 soil orders are listed in the sequence in which they key out

| Gelisols – soils with permafrost within 2 m of the surface. |
| Histosols – contain a high organic matter content. |
| Spodosols – acid forest soils with accumulation of metal-humus complexes in subsoil. |
| Andisols – formed from volcanic ash. |
| Oxisols – highly weathered subtropical and tropical soils. |
| Vertisols – usually black cracking clays with high shrink/swell potential. |
| Aridisols – lime containing soils of arid environments. |
| Ultisols – strongly leached soils with clay accumulation in the subsoil with < 35 % base saturation. |
| Mollisols – grassland soils with high base status. |
| Alfisols – moderately leached soils with a subsurface accumulation of clay with > 35 % base saturation. |
| Inceptisols – soils with weakly developed subsoils. |
| Entisols – soils with little or no morphological development. |

World Reference Base (WRB) soil classification
This system was developed with international collaboration coordinated by the International Soil Reference and Information Centre (ISRIC) and sponsored by the International Union of Soil Science (IUSS) and the FAO via its Land and Water Development division. It is essentially a follow-up to the FAO Legend for the Soil Map of the World. The classification is based mainly on soil properties defined in terms of diagnostic horizons and characteristics which should be observable and measurable as best as possible in the field. The WRB is a two-level classification system (FAO 1998):

- The first level contains 30 Reference Soil Groups, e.g. Histols, Fluvisols, Luvisols.
- The second level is based on the use of one or more qualifiers or adjectives, from a range of 121, that are used to subdivide a Reference Group. The qualifier may relate to color, chemical conditions or a number of other properties, e.g. Leptic Umbrisols (weakly developed), Chromo-Vertic Luvisols (red colored with vertic properties). The subdivisions do not generally take into account factors such as climate, parent material, vegetation, depth of water table or drainage, and physiographic features such as slope, geomorphology or erosion, with the exception where they have affected soil morphology. These features can be used locally to define mapping phases, but they are not considered soil properties to be classified as such.

Driessen (1991) has gone a step further and simplified the 30 reference groups into nine sets using identifiers that incorporate the soil forming factors. The nine sets are shown Table 2.4 with examples of Reference Soil Groups that are likely to be encountered in sugar industries worldwide.
Table 2.4. Major WRB Reference Soil Groups simplified in nine sets.

<table>
<thead>
<tr>
<th>Sets</th>
<th>Dominant identifiers</th>
<th>Reference soil group</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organic soils</td>
<td>Histosols</td>
<td>Soils containing more than 20% soil organic matter (SOM).</td>
</tr>
<tr>
<td>2</td>
<td>Mineral formation due to human influence</td>
<td>Anthrosols</td>
<td>Soils conditioned by human influence.</td>
</tr>
<tr>
<td>3</td>
<td>Mineral soils conditioned by parent material</td>
<td>Andosols Arenosols Vertisols</td>
<td>Young soils from volcanic deposits. Sandy soils with weak profile development. Dark cracking and swelling clays.</td>
</tr>
<tr>
<td>4</td>
<td>Mineral soils conditioned by topography – lowlands/high elevations</td>
<td>Fluvisols Gleysols Leptosols Regosols</td>
<td>Young alluvial derived soils. Permanently or temporarily wet soil. Shallow soil on hard rock or gravel. Very limited profile development.</td>
</tr>
<tr>
<td>5</td>
<td>Mineral soils conditioned by limited age</td>
<td>Cambisols</td>
<td>Weak to moderate profile development.</td>
</tr>
<tr>
<td>8</td>
<td>Mineral soils conditioned by climate in steppes and steppe regions</td>
<td>Kastonozems Chernozems Phaeozems</td>
<td>Soils rich in SOM but with lime/gypsum in subsoil. Black topsoil rich in SOM over subsoil with lime. Dark topsoil rich in SOM, and leached subsoil.</td>
</tr>
<tr>
<td>9</td>
<td>Mineral soils conditioned by climate in sub-humid forest and grassland regions</td>
<td>Luvisols Planosols Podzols</td>
<td>Soils with subsurface high activity clays. Topsoil over a bleached layer on impermeable gley. Acid soil over with a back/brown/red subsoil.</td>
</tr>
</tbody>
</table>

(after Driessen 1991)

According to Rossiter (2001), the WRB has borrowed heavily from modern soil classification concepts, including Soil Taxonomy, the legend for the FAO Soil Map of the World 1988, the Référentiel Pédologique, and Russian concepts. He further recommends that the WRB is not intended to be used in detailed mapping, as many detailed soil properties that are important for land use and soil behavior are not specified in sufficient detail in the two levels of the WRB. For detailed mapping and site characterization, locally-defined soil series would need to be integrated into the system.

**Australia**

According to Bruce (1999), there are at least three common soil classifications used in the Queensland sugar industry: (i) the official Australian Soil Classification System (Isbell 1996), (ii) the Great Soil Group and (iii) the Factual Key. In addition, there appears to be a fourth classification that is used by CSR in the lower Herbert River, Stone River, Lannercost and Seymour districts of Queensland that is based mainly on color, texture, structure and depth (Wood et al. 2003). It is a more user friendly system for growers to follow as it is not based on the national hierarchical system consisting of five levels, ranging from the most general to the most specific level as shown by the following sequence: order, suborder, great group, subgroup, family. There are 14 orders at the top level: Anthroposols, Organosols, Podosols, Vertosols, Hydrosols, Kurosol, Sodosols, Chromosols, Calcarosols, Ferralsols, Dermosols, Kandosols, Rudosols and Tenosols. At the next level there are five suborder color categories: Red, Brown, Yellow, Grey and Black. The remaining soil orders have suborder categories that reflect unique characteristics of the given order (Isbell 1996).
While the philosophy that soils should form the basis for making decisions on good management practices is very strongly followed in the Australian sugar industry and implemented through a number of courses to growers through extension services, there appears to be little reference to using the national system of soil classification in pursuing soil-specific management guidelines.

South Africa
In KwaZulu-Natal, early soil scientists working on the soils of the South African sugar belt found a very strong similarity between the underlying rocks and the soils that were weathered from them. Many soil profiles were examined, mainly in coastal cane land, and the findings were that dolerite always weathered to form heavy, deep red or shallow black clay; shale produced dark colored base rich clays and granite, and Table Mountain Sandstone produced shallow, coarse grained, loamy sands and somewhat deeper grey medium grained sandy soils respectively. Initially, individual soil series were described and named after the farm or locality at which they were first found, but later it was decided that soil associations, each consisting of soils derived from one parent material, would be the best mapping unit (Beater 1962). The soils were therefore classified according to the rocks from which they had weathered and these were all mapped. Initially, eight major soil parent materials were identified, namely: granite, Table Mountain Sandstone, Dwyka tillite, Ecca sediments, basalt, dolerite, Recent Sands and alluvium. Virtually the entire industry covering close to 400 000 ha has been surveyed in this way to a scale of 1:6 000.

In keeping with the global trend, and stimulated mainly by the publication of the USDA’s 7th Approximation in 1960, soil classification in the South African sugar industry also moved away from using a soil forming factor approach to a generic approach based on the properties of diagnostic horizons. The national Binomial System of Soil Classification that was developed during the late 1960s and early 1970s (MacVicar et al. 1977), was subsequently adopted in the local sugar industry for mapping and use in compiling Land Use Plans. It grouped soils into a general category called ‘soil form’ and a specific category referred to as ‘soil series’. Initially 41 soil forms, each made up of a vertical sequence of diagnostic top and subsoil horizons, were described, but this was extended to 73 forms in the revised edition, published in 1991 (Soil Classification Working Group 1991). The names of the five topsoil and 20 subsoil horizons that regularly occur in the South African sugar industry and most other industries, and their relative positions in the soil profile, are diagrammatically illustrated in Fig. 2.8.

Figure 2.8. Arrangement of master and diagnostic horizons according to the Binomial System (after MacVicar et al. 1977).
The main features of selected top and subsoil diagnostic horizons are summarized in Table 2.5. More detailed definitions of these diagnostic horizons may be found in the main text of ‘Soil Classification: A Taxonomic System for South Africa’ (Soil Classification Working Group 1991).

Table 2.5 Simplified description of main diagnostic horizons used in the Binomial System.

<table>
<thead>
<tr>
<th>HORIZON POSITION</th>
<th>DOMINANT FEATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOPSOILS</strong> (O and A)+</td>
<td>1. ORGANIC O: rich in organic matter, at least 20 %.</td>
</tr>
<tr>
<td></td>
<td>2. HUMIC A: rich in humified organic matter, at least 3.5 %.</td>
</tr>
<tr>
<td></td>
<td>3. VERTIC A: high shrinking swelling clay (&gt; 45 %) with slickensides; strongly blocky structure; wide vertical cracks when dry.</td>
</tr>
<tr>
<td></td>
<td>4. MELANIC: black non-swelling clay; moderate to strong blocky structure.</td>
</tr>
<tr>
<td></td>
<td>5. ORTHIC A: does not qualify as an organic, humic, vertic or melanic topsoil, although it can be darkened by organic matter.</td>
</tr>
<tr>
<td><strong>SUBSOILS</strong> (B, E, G, R and C)</td>
<td>1. HARD PLINTHIC B: ironpan, laterite or ferricrete.</td>
</tr>
<tr>
<td>Hard material or weathering rock</td>
<td>2. HARDROCK B: continuous hard layer of rock that cannot be cut with a spade.</td>
</tr>
<tr>
<td></td>
<td>3. LITHOCUTANIC B: tongues or cones of soil penetrate into the weathering rock.</td>
</tr>
<tr>
<td>Structured</td>
<td>4. RED STRUCTURED B: uniform red blocky clay; red cutans and color variation due to faunal activity may be present.</td>
</tr>
<tr>
<td></td>
<td>5. PEDOCUTANIC B: moderately to strong blocky structure; prominent clayskins on most ped surfaces result in non-uniform or variegated colors.</td>
</tr>
<tr>
<td>Uniformly colored, freely drained</td>
<td>6. PRISMACUTANIC B: prismatic or columnar structure; peds non-uniform color.</td>
</tr>
<tr>
<td>7. RED APEDAL B: mainly uniform red color, but color variation due to faunal activity allowed.</td>
<td></td>
</tr>
<tr>
<td>8. YELLOW-BROWN APEDAL B: mainly uniform yellow and yellow-brown colors.</td>
<td></td>
</tr>
<tr>
<td>Non-uniformly colored, young soils</td>
<td>9. NEOCUTANIC B: has weakly developed structure, variegated colors or clayskins.</td>
</tr>
<tr>
<td>Restricted drainage</td>
<td>10. E HORIZON: is light grey or bleached when dry but is sometimes yellowish or pinkish when moist; may contain mottles due to periodic waterlogging.</td>
</tr>
<tr>
<td></td>
<td>11. G HORIZON: underlies an organic, vertic, melanic, orthic or an E horizon; saturated with water for long periods of time unless drained.</td>
</tr>
<tr>
<td>Material recently transported by water, wind, gravity or man</td>
<td>12. SOFT PLINTHIC B: reddish-brown, yellowish-brown mottles or iron.</td>
</tr>
<tr>
<td>13. STRATIFIED ALLUVIUM: contains stratifications caused by alluvial or colluvial deposition.</td>
<td></td>
</tr>
<tr>
<td>14. REGIC SAND: a recent deposit, usually Aeolian; little development other than a darkening of the topsoil by organic matter.</td>
<td></td>
</tr>
</tbody>
</table>

By determining the presence, sequence and depth of the diagnostic horizons the appropriate soil form may be determined by referring to a special soil form key in which form names are arranged in terms of the defined topsoil and subsoil horizons (see Annexure 1). For example, a soil with an orthic A over a red apedal B horizon will be classified as the Hutton form. Another soil profile with the same topsoil but a red structured B subsoil will be classified as the Shortlands form.
### Box 2.5 Examples of representative forms in each of the main soil color groups using the South African Binomial System.

1. **HUMIC AND ORGANIC SOILS** (about 8% of the cane belt)
   - Champagne: organic / unspecified
   - Inanda: humic A / red apedal B

2. **BLACK STRUCTURED SOILS** (about 13% of the cane belt)
   - Arcadia: vertic A / unspecified
   - Rensburg: vertic A / G
   - Mayo: melanic A / lithocutanic B

3. **RED SOILS** (about 18% of the cane belt)
   - Hutton: orthic A / red apedal B
   - Oakleaf (red): orthic A / red neocutanic B
   - Shortlands: orthic A / red structured B

4. **GREY SOILS** (about 60% of the cane belt)
   - Cartref: orthic A / E / lithocutanic B
   - Glenrosa: orthic A / lithocutanic B
   - Longlands: orthic A / E / soft plinthic B
   - Katspruit: orthic A / G
   - Kroonstad: orthic A / E / G

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In many ways, the Binomial System of classifying soils is analogous to that of classifying plants and animals according to their generic and specific names. Thus soils are classified by being allocated first to the appropriate soil form and then to the series, so a number of soil series belonging to the same soil form is like a family of soils. Full details of this system of classification, which has been adopted by a large part of the cane growing community in Southern Africa, to identify, name and manage soils, is given in the publication 'Identification and Management of Soils of the South African Sugar Industry' (SASRI 1999). Briefly, the five steps that are recommended in this bulletin for using the Binomial System is as follows:

**Step 1:** Expose a profile of the soil to be identified by digging a pit, and mark off the master horizons noting whether the transition from the A to the B horizon is gradual or abrupt.

**Step 2:** Note the main properties of the horizons (color, texture and structure) and also likely rooting depth and quality.

**Step 3:** Identify the relevant diagnostic horizons from the soil properties captured in Step 2 using the definitions given in the bulletin.

**Step 4:** Name the soil form by matching the profile sequence found in the pit with the closest combination sequence shown in the soil form key.

**Step 5:** Use the page number shown in the key to locate the color plate of the identified form and select the appropriate soil series using criteria such as texture, grade of sand, or color. In some instances it will be necessary to have the base status of the soil confirmed by laboratory analysis before the correct series can be chosen.

The classification has proved to be particularly useful in sugar industries in sub Saharan Africa in terms of providing a basis for developing soil specific good management guidelines concerning the whole range of agricultural operations ranging from land preparation right through to harvesting as...
discussed under section 2.6 of this chapter. The advantage of the Binomial System is that the soil key based on diagnostic horizons can be adapted and linked to the local soil classification of a country as well as the International WRB system of classification. Soil keys linking the sequence of diagnostic horizons to local soil names have been developed for a number of countries including Swaziland, Tanzania and Fiji. Eventually, a system based on the Binomial System of diagnostic horizons that has more universal application, could be developed for the International sugarcane community.

2.6 Use of soil-specific management guidelines

Following investigations by scientists at the South African Sugarcane Research Institute (SASRI), the results from research trials and observations over many years was linked to the national system of soil classification (Moberly and Meyer 1984). It was concluded that sugarcane management should differ substantially for the various soil forms with respect to practices such as land preparation, season of harvest, trash management, soil amendments, amounts of fertilizer, the use of agricultural chemicals, choice of cane cultivar and irrigation, to name a few practices. These outcomes formed the basis of the soil-specific guidelines that are given in the aforementioned bulletin. An example of the use of this classification, in timing the seed bed preparation to get the best soil tilth, is shown in Table 2.6. An example of a more complete soil specific management grid for plant cane management is shown in Appendix 3.

Table 2.6. Timing and ease of soil tilth preparation in relation to the Binomial and World Record Base classification systems.

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>DESCRIPTION</th>
<th>SOIL FORM (WRB)</th>
<th>ENVIRONMENTAL RISKS</th>
<th>ABILITY TO OBTAIN GOOD TILTH</th>
<th>PLANTING &amp; TIMING OF SEEDBED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark brown humic clay loam overlying a deep friable red sandy clay loam</td>
<td>INANDA (HUMIC FERRASOLS)</td>
<td>High potential for release of carbon dioxide and nitrous oxide excessive tillage and liming. Prone to acidification and build up of Al and Mn toxicity which could lead to im imbalance in micro-organism biodiversity</td>
<td>Easy</td>
<td>Virtually any time of the year Use required start up P in the furrow and other nutrients according to soil test results</td>
<td></td>
</tr>
<tr>
<td>Dark cracking black to grey cracking clay often self mulching and with silt skins</td>
<td>ARCADIA (VERTISOLS)</td>
<td>With the wrong type of irrigation, very prone to early run off due to surface sealing leading to potential loss of fertilizer and herbicide chemicals</td>
<td>Difficult</td>
<td>Under rainfed conditions usually in Spring Use required start up P in the furrow and other nutrients according to soil test results</td>
<td></td>
</tr>
<tr>
<td>Fairly deep reddish blocky structured clay</td>
<td>SHORTLANDS (CHROMIC LUvisols)</td>
<td>A very stable soil but harvesting under wet conditions can lead to serious compaction. High potential for release of carbon dioxide and nitrous oxide</td>
<td>Easy</td>
<td>Virtually any time of the year Use required start up P in the furrow and other nutrients according to soil test results</td>
<td></td>
</tr>
<tr>
<td>Dark grey brown silty loam overlying stratified layers of sand and clay. Usually found on the first terrace above the floodplain</td>
<td>DUNDEE FLUVISOL</td>
<td>Leaching of chemicals under high rainfall or over irrigation a definite hazard. Situated close to the river flooding is also a hazard Very prone to compaction</td>
<td>Generally easy</td>
<td>Spring and summer Planting on the ridge has proved beneficial Under mechanised harvesting 1.85m dual row beneficial</td>
<td></td>
</tr>
</tbody>
</table>

Similar examples of soil specific guidelines are given for choice of land preparation systems, stool eradication systems, cultivar selection, N fertilizer rates (see Chapter 5), priority rating for trash management, choice of irrigation systems and irrigation scheduling, need for drainage and drain spacing and timing of harvesting operations. These guidelines are tantamount to a form of precision agriculture in that they give the grower an opportunity to match production resource inputs more
effectively with differences in properties of soils on their farms, enabling a savings in costs through less water and energy usage, lower fertilizer costs, and reduced impact on soil health and the environment.

Since 1999, a large number of growers in Southern Africa have adopted the philosophy of using soil specific guidelines in driving good management practices. During 2000 and 2001, nearly 900 cane growers attended 47 one to two day soil identification training meetings throughout the industry with the objective of learning the basic soil properties, recognizing important diagnostic horizons, and visiting a number of soil pits to actually classify soils using the Binomial System key in the Soils Bulletin. This national soil classification system is now widely used in south and central Africa, and since 1975 has had a major impact on the reporting of soil conservation, agronomic, soil fertility and irrigation research outcomes.

2.7 The role of soil mapping

While soil classification enables the grower or manager to identify soil characteristics in the field and to provide an understanding of soil processes, it is important for users to know the location and distribution of soils on a particular farm or estate. Cane grows well on good soils with relatively little management, but greater knowledge is required of the many poor soils in the sugar industry if they are to be conserved and managed in the best way possible.

Also, knowledge of the range of soils, their nature and where they occur in an area, is a prerequisite in any feasibility study that is aimed at determining the yield potential and management of sugarcane, whether it is intended for crystal sugar or biofuel production. Apart from influencing the design and management of irrigation and drainage systems, a knowledge of soils also impacts on the design of field layout, areas to be set aside for conservation, wetland delineation, systems of land preparation for establishing new cane areas and all the other management issues that will be dealt with in this manual related to nutrition, weed control, cultivar selection, the use of agricultural chemicals, pest and disease management, ripener management, trash management and the optimum time to harvest.

2.7.1 Choosing an appropriate classification system

Both the USDA and WRB soil classification systems are accepted by most financial institutions that provide funds for new and established projects. However, for commercial consultancy, the WRB system is preferred by a number of consultants as it is a much simpler and quicker system to follow, and the parameters chosen for class definitions are designed to reflect natural classes. It is also a system that appears to incorporate soil units used all over the world, and most soils can be accommodated in terms of their field descriptions (Landon 1991). Simple correlation tables between main classification systems as they apply to tropical conditions have been reported by Sanchez (1976).

Where the required scale for the mapping exercise is more detailed and below 1:20 000, the WRB system needs to be supplemented with a system developed in the country where the mapping is to take place. For sub-Saharan Africa, the previously described Binomial System of classification is strongly recommended as the running partner. In fact, the WRB and Binomial Systems have been applied jointly on sugar estates in Indonesia, Fiji and Nicaragua. This duo-system could well form the basis of meeting the requirements of environmental impact studies as well as assessing the feasibility of any new green field sugarcane related projects.
2.7.2 Potential benefits of soil survey maps

If your service provider does not provide a soil surveying service, then a number of registered consultants are available in major cane producing areas that specialize in soil surveying and land use planning to produce GIS based maps for an estate (see Fig. 2.9). Depending on the accuracy and scale of the map required by the client and the availability of a GIS database, the following examples are properties that can be included in a soil mapping exercise:

- WRB soil units
- Soil form
- Effective rooting depth
- Total Available Moisture (TAM)
- Monthly irrigation demand
- Soil density
- Texture
- Sodicity and salinity risk profiles
- Nitrogen requirements of the crop
- Risk of urea volatilization loss
- Soil compaction risk
- Drainage requirement
- Suitability for mole drainage

Figure 2.9. Example of a TAM generated GIS map from soil survey data on a 1:20 000 scale.

Maps such as that shown above can be provided in a stand-alone form or in combination with field/contour/slope maps. Existing databases such as the soil salinity, piezometer, climate and other datasets, provided they are sufficiently detailed and representative of the area, can be integrated into the GIS system and linked to either the Canesim or Canegro model to produce advanced level information maps that show the number of days per month that soil moisture content (SMC) is between 0-30 % (severe stress), 30-50 % (mild stress), 50-100 % (good conditions) and above 100 % (of field capacity). Other maps that can be produced include:

- Atmospheric water demand for mature cane.
- Monthly irrigation demand for mature cane.
- Peak demand in the season (number of weeks exceeding certain thresholds).
- Peak demands may be estimated by calculating the number of weeks where the mean weekly demand is above a particular threshold.

### 2.7.3 Range of soil mapping options

The accuracy of the soil map, analytical data and resulting applications is related to the intensity of soil profile descriptions. However, the cost of the soil survey increases with improved mapping accuracy and more soil profile descriptions. Four mapping intensities (square grid) are supplied in Table 2.7 below:

<table>
<thead>
<tr>
<th>Option</th>
<th>Grid spacing (m)</th>
<th>No. pits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000x1000</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>700x700</td>
<td>140</td>
</tr>
<tr>
<td>3</td>
<td>500x500</td>
<td>280</td>
</tr>
<tr>
<td>4</td>
<td>300x300</td>
<td>780</td>
</tr>
</tbody>
</table>

### 2.8 Soil health issues

Factors such as a global warming, decline in genetic diversity, pest and disease problems and soil degradation were identified by the Consultative Group on International Agricultural Research) as the most pervasive threats to sustainable agriculture in the new millennium (Lal and Pierce 1991). In the 20 years that has elapsed since this statement was made, soil health has been very firmly under the spotlight in a number of sugarcane industries, as there have been concerns that monocropping of sugarcane over many decades has in a number of industries resulted in nutrient mining, declining levels of soil organic matter and an increase in soil acidity. For more information see [www//soilhealth.cals.cornell.edu/](http://www.soilhealth.cals.cornell.edu/).

#### 2.8.1 The new emerging view of soil health

The terms ‘soil health’ and ‘soil quality’ are becoming increasingly familiar worldwide. Doran and Parkin (1994) defined soil quality as, “the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health.” In general, soil health and soil quality are considered synonymous and can be used interchangeably. The new emerging view is that soil health is a concept that deals with the integration and optimization of the physical, chemical and biological properties of soil for improved productivity and environmental quality (Haynes 1999).

#### 2.8.2 Yield plateau assessments

Concerns over the possibility that a ‘yield plateau’ has been reached, as demonstrated by the industrial yield data from a number of industries, have led researchers and growers in Australia, South Africa, Swaziland and Zimbabwe to look critically at the way soil is presently being managed. The major focus of the Sugar Yield Decline Joint Venture (SYDJV) has been to study differences in soil chemical, physical and biological properties and their effect on sugarcane growth in paired old (cane grown for at least 20 years) and new land sites, in conjunction with rotation experiments and a rundown experiment (Garside and Nable 1996). Break crops that have been tested include soybean,
peanut, maize, pasture grass, various legumes and bare fallow for different periods of time. Other studies initiated by the group have centered on sugarcane root systems, soil biology, nematodes, soil carbon, silicon nutrition and strategic tillage.

As in the case of the Australian Industry, the South Africans also acknowledged that yield decline would not be overcome by a single or discreet factor approach. For this reason a multi-disciplinary approach was adopted involving input from soil scientists, nematologists and soil microbiologists. The program was comprised of the following steps:

- Assessment of industry yield and sucrose productivity trends.
- Survey of industry wide paired old and new cane sites in order to identify differences in soil chemical, physical and biological properties and crop growth on old and new land sites.
- Green manuring trial program comprising field trials employing a range of green manure crops.
- Compaction trials to quantify yield loss and amelioration from inter-row compaction and stool damage.
- Yield potential trials at sites with a history of yield decline.
- Bioremedial amelioration trials with organic amendments such as filter cake, fly ash, chopped trash and chicken litter using vertical mulching as a means of incorporating organic matter to depth.
- Industry wide soil database assessment. Analyses from over 300,000 soil samples, amounting to nearly two million analyses conducted since 1980, covering over 400,000 ha, were assessed to monitor the rate of soil acidification, soil organic matter decline and other fertility related issues.

2.8.3 Paired site outcomes

Selected key research outcomes to restore degraded soils from both countries are given below.

**South Africa**

South African researchers conducted three surveys in the sugar industry. In the first, soil samples were collected from 29 paired sites in the northern areas of KwaZulu-Natal (van Antwerpen and Meyer 1996). In the second survey, 27 sites on the South Coast were sampled, and in the third survey 38 samples were collected in the Midlands (Qongqo and van Antwerpen 2000). Paired sites consisted of uncultivated (virgin) and adjoining cultivated areas no more than 30 m apart. Virgin areas included natural bush and road reserves with natural grassland. The sites were representative of the main soil forms in the industry. Periods of cultivation ranged from zero years under cultivation (virgin veld) to 30 years in the Midlands, 2-40 years in northern KwaZulu-Natal and more than 50 years on the South Coast. The overall impression from these studies was that chemical properties were more affected by sugarcane cultivation than physical properties (Qongqo and van Antwerpen 2000). In general, the results indicated that the old monocultured land was:

- More acidic. The South Coast pH site declined from an average value of 5.34 to 4.35 after 50 years of cultivation. This decline represented a ten-fold increase in acidification, which was statistically highly significant.
- Lower in organic matter. On the South Coast organic matter levels had declined from 4.7 % to a mean value of 2.4 % at a rate loss equivalent to 0.04 % per year compared to a decline from 6.06 to 5.7 % at a rate of 0.01 % per year in the Midlands.
- Greater compaction. A significant increase in bulk density or compaction was evident after only two years under cane cultivation on the South Coast site. This was probably due to the rapid loss of organic matter, structural breakdown and compaction by infield haulage systems.
- Higher titratable acidity and exchangeable Al.
- Lower cation exchange capacity (ability to hold nutrients).
• Lower K and S reserves.
• Lower air-filled porosity and profile available water capacity (PAWC, 0-10 kPa).
• Lower aggregate stability in cultivated areas compared to virgin soils.

Although changes in soil properties were not consistent across all sites, it was evident from the South African results that there was a strong dependence between history of the cane land (i.e. duration of monocropping) and soil properties such as pH, organic matter, soil aggregate stability (SAS), cation exchange capacity (CEC) and bulk density. Equations were developed to estimate soil degradation from these parameters using the multi linear regression analysis technique. However, the equations still need to be validated for various soil types before they can be used with confidence (Qongqo and van Antwerpen 2000).

Australia
The results from the seven paired sites sampled by SYDJV staff in Tully, Herbert and the Burdekin districts generally paralleled the above outcomes. Additional outcomes associated with the older monocultured land (Garside and Nable 1996) included:

• Less microbial biomass (less soil biological activity)
• Lower infiltration rate
• More root pathogens
• Less trace elements.

Swaziland
Soil degradation due to suspected sugarcane monocropping has been linked to ratoon yield decline on an irrigated estate in Swaziland (Nixon 1992; Henry et al. 1996). A comparative assessment of the chemical, physical and biological properties of a range of soils was conducted to identify soil properties which might affect the performance of ratoon crops (Henry 1995). Results indicated that cane monocropping often resulted in degradation of soil properties such as surface crusting, low infiltration rate, high bulk density (BD), low total available moisture (TAM), low organic matter (OM), available soil potassium (K) and sodicity, particularly at depth. Haynes and Hamilton (1999) provide a concise synthesis of world literature on the impact of sugarcane cultivation on soil quality. They note that much more is known about impacts on chemical properties of soils than on physical and biological properties. The main effects identified are:

• Loss of soil organic matter
• Soil acidification
• Changes in soil nutrient levels
• Soil salinization and sodification
• Compaction of topsoil.

2.8.4 Loss of organic matter

The decline in soil organic matter when virgin land is brought under cultivation is a common feature of agriculture in the tropics and sugarcane should not be an exception. Soil disturbance through ploughing causes a sharp initial decline through the decomposition of organic matter, usually followed by establishment of a new equilibrium level after around 20-50 years (Haynes and Hamilton 1999). Apart from the mineralization of organic matter these authors note that the decline also results from reduced input of organic material. Similar reports have emerged from Australia (Wood 1985), Papua New Guinea (Hartemink 1998), Philippines (Alaban et al. 1990), Cuba (Armas et al. 1991), Fiji (Masilaca et al. 1985), Swaziland (Henry and Ellis 1996) and South Africa (van Antwerpen and Meyer 1996; Qongqo and van Antwerpen 2000; Dominy et al. 2001). Recent studies
have shown that traces of the original (pre-cultivation) organic material remain detectable in soils under sugarcane cultivation for varying periods: over the first 50 years of cultivation according to studies from Brazil), and between 13 and 50 years depending on soil type (Burke et al. 2003).

Biological indicators of soil quality (such as microbial biomass C, soil respiratory rate, soil enzyme activity and soil earthworm communities) are sensitive to changes in soil organic matter content, and can change markedly before any substantial changes in organic matter content itself are detected. Recent years have seen an increasing interest in the use of biological indicators of soil quality such as microbial biomass C, soil respiratory rate, soil enzyme activity and soil earthworm communities, which are very sensitive to changes in organic matter content (Pankhurst et al. 1997). Both soil microbial biomass C and basal respiration declined under continuous sugarcane cultivation in KwaZulu-Natal, due to a decline in soil organic matter. Studies in Papua New Guinea showed that organic C content of soils under sugarcane cultivation declined over a 17 year period from around 5.5 to 3.2 g/kg (Hartemink 1998).

2.8.5 Acidification

The detrimental effects of toxic levels of exchangeable Al levels on cane growth are well documented for sugarcane (Sumner 1970; Sumner and Meyer 1971; Moberly and Meyer 1975; Turner et al. 1992; Schroeder et al. 1994). Traditionally, soil acidity problems have been confined mainly to cane growing in the high altitude areas. More recently, an industry wide survey of soil fertility trends indicated that sandy soils on the south and lower south coast of KwaZulu-Natal have become progressively more acidic during the past decade (Meyer et al. 1998).

The results of a more recent investigation based on the use of a soil profile acidification model have shown increased soil acidification on an estate in Zululand and other areas in South Africa (Schroeder et al. 1994). Accelerated acidification of soils under cultivation is most often due to the combined effect of oxidation of ammoniacal fertilizers to nitric acid, mineralization of organic matter and leaching of basic cations from the soil. In virgin soils in tropical areas such as Sierra Leone, where annual rainfall exceeds 3 500 mm per annum, intensive leaching of basic cations over centuries results in highly weathered acid soils with pH values in the range 4 to 5 and very low activity clays (Acrisols).

A decrease in soil pH of virgin land also occurs when the land is cleared for sugarcane cultivation. This has been specifically recorded in Australia (Wood 1985; Garside et al. 1997), Fiji (Masilaca et al. 1985), Florida (Coale 1995), Papua New Guinea (Hartemink 1998), Puerto Rico (Vicente-Chandler 1967) and South Africa (Schroeder et al. 1994; van Antwerpen and Meyer 1996; Qongqo and van Antwerpen 2000).

Use of the industry wide soil database for the South African sugar industry showed that over the relatively short period of 16 years, average soil pH values in the coastal regions of KwaZulu-Natal declined from 6.2 in 1980-1981 to 5.6 in 1996-1997, and the proportion of soil samples with pH < 5 increased from 18 % in 1980 to 43 % in 1997 (Meyer 1998). A similar outcome was obtained in Papua New Guinea, where the pH of topsoils under sugarcane cultivation decreased from around 6.5 to 5.8 between 1979 and 1996 (Hartemink 1998).

There can be little doubt that the sharp increase in the rate of acidification is mainly caused by the use of acidifying nitrogenous fertilizers such as urea and ammonium sulfate, coupled with nitrate leaching that occurs under the high rainfall conditions that often prevail in cane cultivation areas (Haynes and Hamilton 1999). The drop in pH causes a chain reaction with corresponding declines in exchangeable bases (Ca, Mg, K), cation exchange capacity, increases in exchange acidity, and increases in exchangeable Al (van Antwerpen and Meyer 1996; Qongqo and van Antwerpen 2000).
Sugarcane is more tolerant of acidity than most crops (Hetherington et al. 1986) and unlike the root system of maize which can be severely affected by subsoil acidity, sugarcane roots survive and grow even under the most severely acid conditions, as illustrated in Fig. 2.10 below. The root distribution of sugarcane on the left is compared with maize on the right, growing in adjoining plots in the same observation trial. The soil tested with a water pH of 4.5, 85% acid saturation with high levels of exchange acidity, and potentially toxic Al that yielded an Al saturation index (ASI) of 85%.

![Figure 2.10. Root development of sugarcane (left), and poor, shallow root development of maize in a severely acid soil (right) (soil pH (water) 4.5, Al Saturation Index 85%).](image)

Given that a critical ASI of 20% has been used to determine the lime requirement of sugarcane in the South African sugar industry, the observed response of about 30% to dolomitic limestone was not unexpected given that the soil test results also showed calcium and magnesium to be highly deficient. More formal liming trials with sugarcane on less acid soils but with an ASI of 40 to 60% in the subsoil, have always responded to shallow incorporated lime treatments. Deep lime incorporated treatments using a Nardi plough have to date not shown any additional benefit from applying lime to depth (Moberly and Meyer 1975). Recent advances in research have linked Si deficiency with soil acidification, and in the South African sugar industry liming advice makes provision for using calcium silicate amendments in preference to dolomitic or calcitic limestone in order to supply silicon to the crop as well as raising the pH of the soil (Meyer et al. 2005).

### 2.8.6 Soil salinity and sodicity

The effects of soil salinity and sodicity in the low rainfall regions of the world have been extensively studied in South Africa (von der Meden 1966; Johnston 1977, 1978; Culverwell and Swinford 1985; Wood 1991), Swaziland (Workman 1986), Australia (Ham et al. 1997; Nelson and Ham 1998), Egypt (Nour et al. 1989), India (Tiwari et al. 1997), Iraq (Sehgal et al. 1980), USA (Bernstein et al. 1966) and Venezuela (Wagner et al. 1995b).

A primary cause of soil salinization in these regions is the development of high water tables, which allow capillary rise of saline groundwater into the rooting depth of the crop. Poor quality irrigation water may be another source of salts. Chapter 7 deals more fully with the management of saline sodic soils.
2.8.7 Soil compaction

Extracting cane in wet conditions after harvest is unavoidable in many cane growing areas, and uncontrolled infield traffic will cause soil compaction, sealing/capping and physical damage to cane stools. Heavy mechanized traffic has the potential to cause great inter-row compaction, and also stool damage in the cane rows themselves, which is a greater threat to yields than inter-row compaction.

Compaction problems have been reported from many areas where sugarcane is grown, including Australia (Wood 1985; McGarry et al. 1996), Brazil (Centurion et al. 2000), Colombia (Torres and Villegas 1993), Cuba (Armas et al. 1991), Fiji (Masilaca et al. 1985), Hawaii (Trouse and Humbert 1961), India (Srivastava et al. 1993), Papua New Guinea (Hartemink 1998), Thailand (Grange et al. 2002), South Africa (Johnston and Wood 1971; Swinford and Boevey 1984; van Antwerpen and Meyer 1996) and Venezuela (Wagner et al. 1995).

In South Africa, Maud (1960) showed for most sugar belt soils, the tendency to become compacted is greatest when their moisture content is near field capacity. Swinford and Boevey (1984) and Swinford and Meyer (1985) found that moderate and severe compaction on a grey structureless sandy loam caused an increase in bulk density and soil strength and decreased air-filled porosity. Traffic over the row had a greater effect on yield than compaction of the inter-row. Amelioration through ripping was only slightly beneficial. Tines seem to have a detrimental effect due to root pruning, which affects growth of the subsequent crop. It was concluded that yield decline from infield traffic is as much due to physical damage to stools as to a breakdown in structure and sealing/capping from soil compaction, particularly under critical soil moisture conditions.

More recent research outcomes of a compaction trial conducted on a shallow Chromic Luvisol in Mpumalanga, showed increased soil bulk density, reduced water infiltration rates, increased penetration resistance and reduced root distribution in all compaction treatments (van Antwerpen et al. 2008). The treatments with the higher water content were more susceptible to degradation (Fig. 2.11). It was concluded that even a virgin soil in good physical condition will be degraded over a period of a few years to the physical threshold limits. Permanent traffic lanes should therefore be considered essential in most agricultural systems to protect the productive areas of fields. Proper spacing of inter-rows and the use of low pressure high flotation tires on all axles should be considered as additional measures to achieve this goal.

![Figure 2.11. Impact of radial wheel compaction on a virgin soil showing the variable depth of the compacted zone up to a depth of 30 cm (van Antwerpen 2006).](image-url)
The results of trials conducted on a Mollisol in Colombia have also shown that compaction can have significant effects on cane growth and yield (Torres and Villegas 1993). Highly significant differences in cane yield were found due to the effects of the different infield transporters that were evaluated. Damage induced by conventional wagons and dumpers running over stools resulted in a yield decline of between 21 and 45 %, compared with only 10 % decline where wheel passes were confined to the cane inter-row. Passage of the grab loader passing over either the stool or inter-row did not cause a substantial yield decline. Although significant increases in bulk density were generally not associated with any of the treatments, marked treatment effects on infiltration were measured. Changes in soil surface properties leading to surface crust formation, reduced water infiltration, increased runoff and erosion, have also been measured in the Australian sugar industry. Prove et al. (1986) and Davidson (1956), compared cultivated and virgin soils to determine the effect of compaction on bulk density. For subsoils the virgin area was lower in bulk density compared with the cultivated areas for both soil types studied.

2.9 Management strategies for improving soil health

Meyer and van Antwerpen (1996) concluded that, “soil management systems for sugarcane production in the 21st century will have to incorporate ecological principles to an increasing extent in order to arrest the adverse effects of monocropping on soil degradation and yield decline.” Strategies that are based on the principle of management by soils (MBS) as well as emphasizing crop residue retention, nutrient recycling, row and inter-row management based on minimum tillage, green manuring, vertical mulching with filter cake and green cane harvesting, will help to develop productive, profitable and sustainable production systems.

2.9.1 What constitutes a healthy soil?

Before considering selected good management practices it is important to question what we actually mean by the term ‘a healthy soil’. Unfortunately there are no general recipes that can be applied universally, given the wide range of soils that occur in the global sugar industries, but there are certain visual soil properties in the field that can be used to interpolate some of the physical, chemical and biological characteristics that are normally associated with healthy soils, and that with good management practices and water supply can produce high yielding crops over at least 10 to 12 ratoons. Some of these properties are listed below.

<table>
<thead>
<tr>
<th>Box 2.6 Preferred visual characteristics for a healthy soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A sandy loam to sandy clay loam in texture.</td>
</tr>
<tr>
<td>• A uniform dark colored soil without signs of mottling or plinthite at depth.</td>
</tr>
<tr>
<td>• The darker the color of the topsoil the higher the organic matter status.</td>
</tr>
<tr>
<td>• At least weak to moderate but not excessively strong structure.</td>
</tr>
<tr>
<td>• No abrupt changes in the physical properties between the A and B horizons and free of compacted layers.</td>
</tr>
<tr>
<td>• Good soil tilth, free of clods.</td>
</tr>
<tr>
<td>• No evidence of surface capping or crusting.</td>
</tr>
<tr>
<td>• At least 1.2 m effective rooting depth.</td>
</tr>
<tr>
<td>• Good infiltration and soil drainage.</td>
</tr>
<tr>
<td>• At least an available moisture capacity of 120 mm/m soil depth.</td>
</tr>
<tr>
<td>• Visible macroscopic organism activity such as earthworms and millipedes, and insect activity excluding white and grey grubs.</td>
</tr>
<tr>
<td>• Residual roots from the current or previous crop should be seen to a depth of at least 1 m, have many fine branched root hairs and not be stubby. This suggests that plant pathogens and plant feeding nematodes will not be a problem, nor subsoil acidity a limiting factor.</td>
</tr>
</tbody>
</table>
A more comprehensive field visual assessment guide, produced by Vaderstad, can be downloaded from the internet at http://www.vaderstad.com. This guide makes provision for the scoring of both plant and soil characteristics to produce a final index for soil health.

In a recent publication, van Antwerpen et al. (2009) developed a diagnostic system of rating soil health for growers in the South African Sugar Industry, based on 21 indicators, comprising chemical, physical, biological and nematological parameters from which a soil health index can be computed. All indicators chosen were sensitive to land management, and in most cases significant differences were obtained between soils from burnt cane at harvest and virgin land uses, with trashed fields as intermediate. Although the system is still in the process of being evaluated it is an important advance in topsoil analysis and, benchmarked against the indicator threshold values, will be a better guide to growers in terms of selecting which field practices need to be improved.

2.9.2 Good management practices to improve soil health

The management practices that have been most widely researched in terms of conserving and building up organic matter, and that have been listed by Cheesman (2004) and updated in this chapter, are summarized as follows.

- Crop rotation/green manure fallowing: Hill (1988); Armas et al. (1991); Nixon (1992); van Antwerpen and Meyer (1996); Garside et al. (1996); Schumann (2000); Dominy et al. (2001); Rhodes (2009).
- Reduced tillage: Iggo and Moberley (1976); Turner (1980); Armas et al. (1991); van Antwerpen and Meyer (1996); Blair (2000); Dominy et al. (2001); Hammad and Dawelbeit (2001); Grange et al. (2002).
- Dual rows: Bull (1975); Garside et al. (2009).
- Application of lime to counter acidification: Sumner (1997); Haynes and Hamilton (1999).
- Rational fertilizer use: Lu (1991); Haynes and Hamilton (1999); Grange et al. (2002).
- Organic based soil amendments (including filter cake, blackstrap molasses, rum distillery slops, animal manures, crop residues, green manures and Effective Microorganisms [EM]): Haynes and Hamilton (1999); Meyer and van Antwerpen (2001).
- Controlled infield traffic using high flotation tires (van Antwerpen et al. 2008)

Some of the more important aspects of selected practices are given below.

2.9.3 Green manuring

What yield benefits may be expected?

Long term and short term rotation experiments in Australia that have formed the backbone of the SYDJV approach have yielded the following information (Garside et al., 1996, 1997). In general the best break crops out-yielded plough-out/replant by:

- 14 % in Bundaberg plant crop (112 to 128 t/ha)
- 21 % in Bundaberg first ratoon (121 to 146 t/ha)
- 84 % in Mackay (60 to 114 t/ha)
- 27 % in Burdekin (110 to 140 t/ha)
- 51 % in Ingham (48 to 71 t/ha)
- 58 % in Tully (44 to 75 t/ha).
In Swaziland, the effects of green manuring on mainly irrigated duplex soils both at the trial and commercial field stage was studied by Hill (1988). Mean yields of 13 fallowed and green manured 40ha blocks of land compared with the mean yields of 13 non-fallowed blocks of land, improved by 45 % in the plant crop, with residual effects of 25 % measured in the first and second ratoon crops. By using discounted cash flow analysis over a 30 year period, Hill showed that green manuring was on average 12.4 % more profitable than conventional cropping. Follow-up trial work by Nixon (1992) confirmed large responses to bare fallowing (11-29 %) and green manuring (10-54 %) in the plant crop, with small but non-significant residual responses measured in the subsequent ratoon crops.

What are the main soil benefits associated with the yield responses?
In the Swaziland research yield increases were related to improvements in soil physical properties, particularly air-filled porosity at 10 kPa which increased on average from 11.9 to 16.1%, and the resulting improvement in rooting of subsequent cane crops. Intake rate and resistance to penetration under the green manure treatment also improved significantly due to incorporation of organic matter, with the effects being restricted mainly to the A horizon.

The Australian studies showed that legumes impacted on soils as follows:

- Legume and grass fallows added significant amounts of organic matter to soils. A soybean follow crop produced about 3 t C/ha, and 300 kg Pangola grass produced 4.5 t total C/ha, which was equivalent to about 0.5 % organic matter to a depth of about 200 mm (Garside and Bell 1999).
- Part of the yield response in sugarcane following rotation breaks was associated with changes in soil microbial properties such as the reduction of Pachymetra and lesion nematodes, and an increase in functional organisms such as pseudomonads, acitomycetes and mycorhizal fungi as well as soil invertebrates such as earthworms (Pankhurst et al., 2000).
- In Thailand, results from field trials using a 15N tracer study indicated that incorporation of sesbania (Sesbania rostrata) and sunn hemp (Crotolaria juncea) tended to increase soil organic matter and improve soil physical conditions as a function of bulk density (Prammanee et al. 1995).
- Recent evidence indicates that a whole range of legumes and or cover crops can decrease the numbers of certain plant parasitic nematodes. For example forage peanuts, marigolds and sunn hemp indicated resistance to Meloidogyne javanica (Berry and Wiseman 2003) and velvet beans and serradella showed resistance to Pratylenchus zeae (Berry and Rhodes 2006). Cowpeas, on the other hand, were associated with increases in the plant feeding nematode M. javanica.
- Green manuring has been recommended to farmers in Barbados as part of a strategy to control soil erosion (Cumberbatch 1985).

Selection of legumes
Green manure and cover crops can be used in rotation with sugarcane to promote soil sustainability. Green manure crops are those which return extra nitrogen and/or organic matter to the soil and can be used in rotation with sugarcane. Some of the commonly used legumes include sunn hemp, cowpeas, soya beans, Dolichos beans, Velvet beans and lupins (SASRI 2002).

Sunn hemp (Crotalaria spp)
Sunn hemp was introduced into the world sugar industry during the late 1920s, and was used as a natural source of nitrogen until the advent of artificial sources of N, such as urea, during the 1930s. The plant is extremely hardy and fast growing and can produce 12-14 t dry above-ground biomass/ha in 3-4 months. Sunn hemp has bright yellow flowers and roots that form numerous lobed nodules. It has no special soil requirements, implying that it will grow well in most soils across the textural range but within a pH range of 5.0 to 8.5. Once the old cane stools have been
eradicated, the soil should be disced and the seed may be broadcast at 40-50 kg/ha in the spring cycle prior to the onset of rains.

Sunn hemp can be ploughed under when it is in flower (80-100 days after planting), by which time it will have achieved a height of between 0.7 and 1.0 m (Fig. 2.12). If allowed to continue growing it will reach a height of 1.25 to 1.5 m and can be difficult to turn under. It may be mowed or slashed back and left on the surface. It normally takes 5-6 weeks for the residues to decompose in a warm, moist soil.

![Figure 2.12. Fields of sunn hemp at San Martinho (Brazil) ready for harvesting.](image)

**Figure 2.12. Fields of sunn hemp at San Martinho (Brazil) ready for harvesting.**

**Soya bean (Glycine max)**

This legume is well adapted to hot, humid areas and can be grown as a green manure or cash crop in areas that receive 600 mm or more rainfall per year. Additional N is needed only in soils of low to moderate N mineralizing capacity, where adequate nodulation is not expected. Soya beans prefer fairly deep, well drained sandy clay loams or sandy loams, with above average levels of organic matter. Either shallow plough in winter or apply Glyphosate in summer to eradicate the old cane crop. As a green manure, soya beans may be slashed back when in flower, and the residue left on the surface, usually 70 to 100 days after sowing. As a cash crop, harvest when the beans are in the ‘hard dough’ stage, and most of the leaves have dropped but the stems are still moist.

**Velvet bean (Stizolobium spp) (dryland)**

Velvet beans are a warm season crop and should be planted in early summer and grown through to autumn/winter. The plant develops vigorously with long, intertwining vines to produce a jumbled mass of stems and leaves up to 0.7 m high. Flowering occurs approximately four months after planting and the seed stage for harvesting is reached 6-7 months later. Following a shallow disc ploughing to get a good tilth, plant just before the first expected rains with up to 200 kg beans/ha if the objective is to smother cane volunteers, or 80 kg/ha planted in rows if the crop is to be used specifically as cattle feed. If the purpose is to use the crop as a source of nitrogen from green manure, the crop should be slashed back and left on the surface at flowering. The beans can be used as cattle feed if the crop is forage harvested.

**How long should the green manure fallow period be?**

Conclusions from a recent study (Rhodes 2009) indicated that the green manure fallow duration should be at least six months, as significant soil benefits occur only after this period. Both in Australia and South Africa, leaving green manure residues on the soil surface gave similar results to incorporation and, given the cost benefits in terms of reduced mechanical inputs and soil
disturbance, growers should be encouraged to leave green manure material on the soil surface, rather than incorporating it. These results concurred with those of Garside et al. (2006), who found that surface-retained green manure residue gave similar or improved results.

Overall, research outcomes from both countries point to practices that conserve soil organic matter such as green manuring, minimum tillage, the use of organic nutrient carriers such as filter cake, chicken and kraal manure, and trash ing of cane at harvest, have greatly increased in the industry as there is a need to sustain the all-important functions of the soil food web by maintaining soil humus (van Antwerpen et al. 2003).

Green manures are a valuable source of nitrogen
Green manures and cash crops work wonders in rejuvenating the soil, as they take up considerable quantities of nutrients from the subsoil, and release these nutrients to the topsoil when they are incorporated. Some legumes have a special relationship with soil bacteria which enables the nitrogen in the air to be transformed into nitrogen that can be used by animals and plants, and some green manures increase the populations of soil microbes that fight against the effects of pathogenic bacteria, fungi and nematodes.

Scientists working on the Yield Decline Joint Venture in Australia have provided valuable information on the nitrogen supply of different legumes and the residual effects that can last right into the second ratoon. The quantity of N available to the succeeding sugarcane crop is largely dependent on the type of legume, how well it was grown in terms of biomass and whether the legume was harvested (Garside and Bell, 1999; Bell et al., 2003; Garside et al 2004). A summary of the estimated potential amounts available based on the yield decline trials is given in Table 2.8. This information can be used to adjust the amount of nitrogen fertilizer required for the different soils following different legume fallows.

<table>
<thead>
<tr>
<th>Legume crop</th>
<th>Fallow crop dry mass (t/ha)</th>
<th>N (%)</th>
<th>Total N contribution (kg N/ha)</th>
<th>N contribution if harvested (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>8</td>
<td>3.5</td>
<td>360</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>270</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>180</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>Peanut</td>
<td>8</td>
<td>3</td>
<td>N/A</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Cowpea</td>
<td>8</td>
<td>2.8</td>
<td>290</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td></td>
<td>220</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>145</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>70</td>
<td>25</td>
</tr>
</tbody>
</table>

2.9.4 Bioremedial amelioration with organic amendments

While composting has been practiced at the smallholder level for generations in countries such as India, it is only in recent times that this practice has been implemented on a commercial scale on large estates in Brazil and other countries. For example, vinasse fortified compost is applied at
planting at San Martinho and sister mills to 50% of fields at planting, by banding the compost in the furrow at a rate varying from 10 to 20 t/ha. This provides sufficient N, P and K to meet the nutrient requirements of the plant crop. The composting process uses filterpress mud as the base material with vinasse, lime, gypsum, and chicken litter applied with regular turning over. The compost is turned every seven days with specially made machines and generally matures and is ready after 50 days, when the C/N ratio falls below 18. Vinasse or water is applied to cool the decomposing rows of compost to ensure that temperatures are maintained in the 60 to 65°C range to enable the functioning of the population of thermophilic bacteria.

It is common practice in Brazil to produce compost from mill filter cake, boiler waste and vinasse. This is done on a large scale, but in the case of a very large mill it is generally not able to take care of all vinasse produced. While composting is an example of a good management practice, research conducted in South Africa has indicated that burying the organic carrier has greater advantages for both the crop and soil in terms of longer residual effects on cane yield and soil properties by using a technique called ‘vertical mulching’.

**What do we mean by vertical mulching?**
Vertical mulching can be defined as the incorporation of an ameliorant into a vertical slot in the soil at the time of planting (Fig. 2.13). The implement used is a conventional ripper with wings added in a vertical position to produce the slot. In Australia the technique is referred to as ‘slotting’.

![Figure 2.13. Side and rear view of a single tine vertical mulching implement.](image)

**What are the main yield benefits?**
The results of recent research have shown that decomposed filtermud press in the form of compost can also act as a very effective conditioner of hard-setting duplex soils, as well as Vertisols which swell up on wetting causing a rapid decline in the infiltration rate. Trials have shown that vertical mulching with filterpress mud to a depth of 450 mm in the planting row following minimum tillage, resulted in significantly higher yields and an increased number of ratoon crops (Meyer et al. 1992). In a trial conducted at Mtunzini, the cumulative response to vertical mulching after a plant and eight ratoon crops amounted to 98.1 t cane/ha or 11.1 t sucrose/ha. In a further five trials covering 28 crops the ameliorant that has consistently performed the best was the vertically mulched filterpress mud treatment (Table 2.9).
Table 2.9. Average response to deep placement of filterpress mud in trials at six locations in South Africa and Swaziland.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Soil form</th>
<th>No. of crops</th>
<th>Cumulative response</th>
<th>Mean response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>tc/ha/y</td>
<td>ts/ha/y</td>
</tr>
<tr>
<td>Mtunzini</td>
<td>Longlands</td>
<td>11</td>
<td>105</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Simunye</td>
<td>Arcadia</td>
<td>5</td>
<td>70</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.3</td>
</tr>
<tr>
<td>Ubombo</td>
<td>Bonheim</td>
<td>5</td>
<td>11</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Mount Elias</td>
<td>Glenrosa</td>
<td>3</td>
<td>16</td>
<td>5.3</td>
</tr>
<tr>
<td>Renishaw</td>
<td>Glenrosa</td>
<td>2</td>
<td>11</td>
<td>5.6</td>
</tr>
<tr>
<td>Dalton</td>
<td>Glenrosa</td>
<td>2</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td>Overall mean</td>
<td></td>
<td></td>
<td></td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
</tbody>
</table>

What are the main soil benefits of incorporating organic amendments to depth?

The technique was designed to improve the physical properties of dispersed shallow duplex soils as well as soils with a difficult structure such as vertisols. Buried filterpress mud has a much longer residual effect when incorporated into the soil surface, due to a slower rate of decomposition of the organic matter at depth. The technique can also be used with sand as a filler in poorly drained areas, but not with filterpress mud. The benefits of recycling organic materials back to the land are summarized in Box 2.7.

Box 2.7 Effects of organic materials applied to the soil

Improvement of physical soil properties, either directly or by activating living organisms in the soil

- Better soil structure as a result of soil loosening and crumb stabilization.
- Vastly improved infiltration rates.
- Better water-holding capacity and soil aeration.
- Surface protection by mulch layer.

Influence on chemical properties

- Sorption of nutrients by humic acids.
- Supply of nutrients mainly P from decomposition of humus and from dissolving action on soil minerals.
- Fixation of nutrients in organic complexes (mainly a negative influence for a shorter or longer period).
- Effects of growth regulators produced in soil (e.g. growth inhibitors accumulating in monocultures, and antibiotics protecting against some bacterial diseases).

Influence on soil microbiological properties

Provides carbon, nitrogen and phosphorus as well as saprophytic fungi and bacteria which are critically important for supporting the nutrient cycling system and ensuring that the biodiversity of the soil food web community is maintained.

Other organic amendments that have helped to rejuvenate soils include fly ash, boiler ash, CMS, various organic manures (poultry manure, chicken litter, kraal manure, pig manure) and composts. The rate of amendments used must be determined by soil analyses, and must be balanced with mineral N, P and K fertilizers. Further information is supplied in Chapter 5.2.7.7 under organic nitrogen carriers.
2.9.5 Minimum or reduced tillage

In South Africa, research has shown that the minimum tillage system (strip tillage), in which glyphosate is used to kill the old crop, resulted in minimal soil erosion and improved cane yield when compared with the conventional methods of land preparation (Iggo and Moberly 1976). The benefit in terms of cane yield varied according to soil type, being considerable in some instances and negligible in others. Other measured soil benefits included increased soil organic matter content and reduced soil bulk density. A comparison of soil and water losses from conventional and minimum tillage replanting methods on a range of soil forms using the rainfall simulator technique showed that soil and water loss under a minimum tillage system could be reduced by 60% and 30% respectively, provided the crop had grown to the sixth leaf stage at the time of spraying (Haywood and Mitchell 1987). This technique has been widely adopted in other countries such as Australia and Mauritius especially in hilly terrain not only as an important soil conservation measure, but also for preventing the spread of disease by eliminating volunteer plants. Further details are given in Chapter 3.7.3.

2.9.6 Managing soil acidification

Although sugarcane is more tolerant of acid conditions than other crops, yield may be affected because acid conditions can generate toxic levels of Al and Mn and will also affect nutrient availability of both major and minor nutrients. It is desirable to maintain soil pH at or slightly above 5.5 to minimize solubilization of aluminum and subsequent acidification of the subsoil, and to enable the production of break crops that are in general far more susceptible to acid conditions than sugarcane. Liming will assist in reducing aluminum saturation and amend deficiencies in calcium and magnesium. The aim is to maintain soil pH within a range that allows beneficial biological soil processes to proceed unhindered, and also to counter the effects of applying nitrogen. It is important to obtain the correct advice, avoid over-liming, use silicate based liming materials and split large lime applications. Where minimum tillage is practiced, substitute one-third of the application with gypsum.

Tactical liming strategies are based on soil analysis and use an aluminum index (Schroeder et al. 1993) or lime requirement algorithms based on pH and indices of soil buffering capacity such as organic carbon (Aitken et al. 1990). However as a general rule of thumb, 1.5 t calcium carbonate/ha/100 t cane yield are required to neutralize soil acidity generated over a five year period from an annual application of 150 kg N/ha. Further approaches are shown in the box below.

---

**Box 2.8 Lime requirement formulae used in other countries**

**Brazil:** Copersucar recommendations allow for a combined calcium plus magnesium threshold level of 1.8 cmol./kg – 97% relative yield (Anon 1993). Effects of subsoil acidity on calcium status are managed by application of gypsum, if calcium in the 25-50 cm zone is < 0.6 cmol./kg and aluminum saturation is > 40% (Anon 1993). Zambello et al. (1984) showed 40% aluminum saturation corresponded to the 91% relative yield criterion, across a range of Brazilian soils.

**South Africa:** Lime requirement to counter aluminum toxicity in the South African industry is based on an Aluminum Saturation Index (ASI), calculated as 100 x Al/100 g clay/(Ca + Mg + K + Al/100 g clay), where all elements are expressed as cmol(+)/kg (Schroeder et al. 1995). A threshold ASI of 20% applies to most cultivars and an ASI > 40% is likely to be toxic to all varieties grown in the acidic Midlands region. Lime requirement is calculated as 10 x EAl acidity, which must be neutralized to reduce the ASI to 20%. Slight modifications to this formula were made by Schumann (1999) based on a recursive method of calculation. In
terms of soil health, the following modification was made by Nixon et al. (2003) for soils with a pH below 5.0 but not containing toxic levels of Al.

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>&lt; 30 % clay</th>
<th>&gt;30 % clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4.7 to 5.0</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>&lt; 4.7</td>
<td>2</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Australia: Liming recommendations for the Australian sugar industry are not linked to specific aluminum criteria. Lime is primarily recommended on the basis of soil calcium status (kg/ha calcitic lime = (1.5-S_{Ca})*500*BD/(L_{Ca%}*0.85)), where S_{Ca} is calcium (0-25 cm) determined from soil analysis and expressed as cmolc/kg, 500 is a factor incorporating the depth of soil to be treated (cm) and the equivalent weight of calcium, L_{Ca%} is the calcium content of lime, BD is bulk density and 0.85 an efficiency factor for crushed agricultural limestone (Kingston and Lawn 2003).

An alternative to using either calcitic or dolomitic limestone to be applied separately or with gypsum under minimum tillage conditions, is to use a calcium silicate slag which not only has liming properties but is also a source of plant available silicon (see Chapter 5). Most of these slags are by-products from the steel and cement industries. They have a neutralizing value of over 80% (pure lime = 100 %) and are recommended in South Africa where soils are prone to Si deficiency or to improve resistance to Eldana stalk borer damage and general crop health and vigor (Keeping and Meyer 1999). These calcium silicate liming materials are in general comparable to dolomitic lime with the difference that they contain a significant amount of silicon. They typically contain 5-9 % calcium (Ca), 0.1-6.0 % magnesium (Mg) and 5-15 % Si and are more effective in neutralizing soil acidity in a relatively quick change in soil pH in one season as opposed to three or four seasons where conventional crystalline dolomitic lime is used. For full value, Si-lime should be applied as a top-dressing every fourth season to facilitate maintenance of soil pH, Si, Ca and Mg. Using silicate lime in this way can reduce the extra operation of applying both gypsum and lime. General guidelines for taking soil samples from a field for fertilizer or liming advice is given in Appendix 2.

2.9.7 Trash Management

Despite the advantage of improved soil health associated with trashing, this practice has not been generally favored in many industries for both mechanical and manually harvested systems, mainly on economic grounds due to perceived higher costs inputs of trashing. Under dryland conditions the main advantages that have been reported include moisture retention, weed control and increased nitrogen availability from trash (Thompson 1965) and increased soil organic matter, increased soil microbial activity, and improved soil chemical and physical properties such as improved soil structure and reduced soil erosion (van Antwerpen 2008). The agronomic benefits of trashing are more fully dealt with in Chapter 3.2.5.

Production of trash

Trashing or green cane harvesting remains one of the best options for carbon sequestration in the soil and maintaining the carbon balance under a system of monocropping. Results published by Thompson (1966) and Kingston et al. (1984, 2005), showed that the residue dry matter to fresh cane as a percentage varied between 17 and 25 %, depending on cultivar, with an average of around 17 %. This implies that between 14 and 22 t/ha of dry residues can be produced from cane yields between 80 and 130 t/ha. Torres and Villegas (1995) indicate much higher residue yields of 20-40 dry t/ha (40 % dry matter) in Colombia, whereas in Brazil the values obtained were lower with the
trash component varying from 10.7 to 17.4 % of fresh millable stalk yields (Korndorfer 2005). In Argentina Romero et al. (2007) found trash yields varied from 7 to 16 t/ha and the ratio of dry trash to cane yield varied from 12 to 23 %. Differences in cultivar will undoubtedly account for much of the recorded variation.

**Nutrient cycling**

Retention of such relatively large amounts of trash residue in high rainfall and irrigated areas provides an opportunity for recycling of organic matter and nutrients and carbon sequestration in the soil. Data from Brazil indicate that the rate of carbon sequestration that was measured from green cane harvesting over a four year period ranged from 0.24 to 0.78 t carbon/ha/y (Korndorfer 2005). An indication of the potential amount of nutrients that can be conserved in a green cane harvesting system compared to the potential loss of nutrients under a burnt system is shown in Table 2.10 based on data collected by Mitchell and Larson (2000).

<table>
<thead>
<tr>
<th>Component</th>
<th>GCTB system</th>
<th>Green harvest, burnt residues</th>
<th>Fully burnt system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (t/ha)</td>
<td>12.7</td>
<td>2.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Kg/ha</td>
<td></td>
<td>Nutrients (kg/ha)</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>65</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>7</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Potassium</td>
<td>9</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>Calcium</td>
<td>39</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Magnesium</td>
<td>22</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Sulfur</td>
<td>9</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Being water soluble, potassium is readily leached from sugarcane residues and as much as 85 to 95 % is reported to be leached over 12 months (Wagner et al. 2002).

Leaf sampling conducted over a ten-year period from the BT1 trial showed slight improvement in uptake of N, P, K and Mn from trashing, while higher Mg and Fe were found for the burnt treatment. Leaf Si was the only nutrient showing a significant difference with levels being much higher in the unfertilized trashing and burning treatments compared to the fertilized trashing and burning treatments. The lower Si uptake in the fertilized treatments was attributed to the lower soil pH induced by higher acidity generated in the fertilized treatments (van Antwerpen and Meyer 2002).

**Soil carbon-nitrogen balance**

In Brazil and Australia, over 55 and 70 % of the respective industries are on a green cane harvesting system, and these proportions will increase as environmental codes of practice are increasingly adopted and legislation in various countries comes into effect. Provision for trash versus burning treatments was made in some of the SYDJV long term rotational trials and the results confirmed increases in total and labile C in the surface soil relative to burnt cane systems (Moody and Bramley 1999). An interesting development in the Australian approach is the use of the APSIM model to simulate changes in carbon and total N content in soils under different management systems. An exercise conducted by Thorburn et al. (1999), using the results from an Australian burning/trashing trial suggested that modeling could detect the beneficial effects of a trash blanket on soil organic matter levels in the 0-200 mm layer five years after the commencement of trashing.
The APSIM model was also applied to simulating the soil carbon/nitrogen balance using the long term burning and trashing (BT1) trial at Mount Edgecombe in South Africa (van Antwerpen 2006). In a separate investigation spanning 60 years of yield and soil data from the BT1 trial, Graham et al. (1999) concluded that continuous burning of every crop had caused a marked loss of soil organic matter from the topsoil layer when compared with the soils from the surrounding grass breaks which were considered similar to that of undisturbed veld.

**Impact of trashing on soil microbial mass**

The size of the microbial biomass and its respiratory rate, dehydrogenase activity and arginine ammonification rate were also reduced by burning. Differences were most pronounced in the 0-2.5 cm soil layer. By contrast, the trashed treatments showed a significant increase in soil organic matter content and particularly readily mineralizable N, which was higher under trash retention than burning to a depth of 30 cm, and this effect was much enhanced under fertilization (Graham et al. 2001). The findings strongly suggested that soil N availability under green cane harvesting was considerably greater than under burning, and was verified from an analysis of the available leaf analytical data. This can be ascribed to the decaying trash residue feeding the soil carbon and nitrogen cycles which in turn interact with the soil food web as illustrated in Fig. 2.14.

![Diagram](image.png)

**Figure 2.14. Carbon sequestration from trash helps to maintain the functioning of the soil food web through the carbon and nitrogen cycles.**

Crop residue management also resulted in a shift in microbial composition. Not only did green cane harvesting increase the microbial biomass C and total phospholipid fatty acid analysis (PLFA), but it also significantly altered the soil microbial community structure (Graham 2001). As a result of increased biodiversity the PLFA profile of unfertilized trashed sugarcane was very similar to that under undisturbed veld and kikuyu grass. Thus, PLFA analysis proves to be a promising technique to determine the effects of land management on microbial community structure. PLFA can also be used to characterize specific groups of microorganisms, thus providing essential information with regard to a shift in specific functional subsets of the community.

In terms of the impact of burning on soil biodiversity of organisms, Korndorfer (2005) reported a ten-fold decline in the number of organisms from 789 organisms/m² under a trash blanket, to
72 organisms/m². Earthworms declined to zero under burning and the spider and mariapode numbers followed a similar trend.

**Expected yield response benefits**
The average trashed over burnt yield response for the long term BT1 trial over 60 years of cropping is 9 t/ha/an, and this figure is commonly used in the South African sugar industry to represent the response that can be expected from a trashing system (van Antwerpen 2006). However, in a more recent publication as well as past reports at SASRI, responses ranging from 25 to -23 tc/ha/an have been quoted under dryland conditions (van Antwerpen et al. 2008). In certain years of above average rainfall, small responses to trashing were recorded for BT1 and in drier years much higher responses.

It is evident that green cane harvesting with trash retention is an effective way of arresting the loss of soil organic matter that characteristically occurs under conventional sugarcane production where burning is practiced prior to harvest. Not only does the practice increase total soil organic matter content in the surface 10 cm, but it also increases concentrations of various labile organic matter fractions as well as soil microbial activity to a depth of 30 cm. These changes in organic matter content and quality may greatly affect other soil properties such as cation exchange capacity and processes such as aggregation, soil structural condition, and N supply to the crop via mineralization.

**2.9.8 Managing soil compaction**
The use of heavy vehicles in the field will affect soil structure, air-filled porosity, water infiltration and root development. The biggest advance in good management practices in recent times has been the concept of managing zones in the field (Larson and Robert 1990). The principle is to manage the row area differently from the area between the rows. The row area should provide a good soil structure, good rooting depth, and nutrient and moisture availability for plant growth, and the inter-row should be managed to create a surface to maximize intake rate of water, erosion control and be firm for wheel traffic. Tramline and ridge systems for the control of infield traffic have proved very successful in other industries for managing soil compaction (Spoor 1983). This was tested and developed in the Australian sugar industry and is now widely used in an integrated farming system based on a 1.85 m dual rows to avoid stool damage. The system includes minimum tillage, legume breaks and a green cane trash blanket (Garside and Bell 1999; Garside et al. 2009).

Controlled traffic has probably been the greatest impetus to push cane growers into the new system, as they can make major costs savings between cycles. They can maintain their inter-rows and only cultivate the row area (zonal tillage) instead of the whole field. The savings in N fertilizer following legume breaks is also a strong incentive. A further economic benefit is reduced tractor hours, ranging from 20 to 60 %, with improvements in gross margin varying between 10 and 22 %. Further details of this system are given in Chapter 3.8.6. Other measures to minimize damage by compaction are summarized in Box 2.9 below.
Box 2.9 Additional recommended GMPs for managing soil compaction

- Increase organic matter by trashing. Don’t burn tops and trash. Plant legumes or cover crops before replanting to cane.
- Harvest cane on well drained soils in the wet periods. Work in poorly drained soils in the drier periods.
- Improve irrigation scheduling and ensure adequate drying-off before harvesting.
- Improve farm planning and roads to reduce infield travel distances and improve surface water management.
- Keep tire surface contact pressure low. Use large, wide diameter, flexible carcass, low inflation pressure tires. Radial tires are better than cross-ply tires.
- Ensure that the total mass is distributed over all axles. Axle loads should not exceed 10 tonnes. Tandem axles with single wheels are better than single axles with dual wheels. On a single axle, duals are better than a single wheel. Walking beam axles reduce the compactive effect.
- Avoid using non-slewing cane loaders in wet conditions.
- Infield traffic should be restricted to widely spaced traffic paths, and confined to the inter-row.
- Reduce the number of passes by combining operations.
- Operate at maximum speed to keep the duration of pressure to a minimum.
- Use tracked vehicles on soils with a low bearing capacity to reduce sinkage and compaction.

2.9.9 Financial, social and environmental costs of improving soil health

Financial
Once implemented in suitable climatic and soil associations, the financial benefits of healthy soil are enhanced by environmental and social benefits that include reduced use of pre-emergent herbicides, reduced tillage, and less soil erosion. Conservation of soil moisture will improve, with lower irrigation needed up to canopy closure, and air quality will be improved for farm managers and workers. Improvements in soil chemical, physical and biological fertility are associated with the recycling of carbon and nutrients in trash.

Switching over to a minimum tillage system will have important financial benefits as reduced tractor usage results in a savings of 0.2 L diesel/t cane harvested. An estate cutting 25 000 t sugarcane a year would save 5 000 L diesel, which would have not only monetary implications but also global warming benefits in terms of carbon emissions.

The advantages and disadvantages of trashing have been quantified in monetary terms and compared with burning, using a decision support program that accommodated over 500 variables (Wynne and van Antwerpen 2004; van Antwerpen et al. 2008; Purchase et al. 2008). It was shown that in most situations the economics were strongly in favor of trashing due mainly to improved yields through improved plant available water resulting in better growth and vastly reduced herbicide costs. There is also a reduced risk of cane deterioration when burn to crush delay exceeds 12 hours.

Social costs
There are health and environmental risks associated with the use of organic manures resulting from high rates of application of slurry (from cattle or from pigs) in certain areas, and from town compost and sewage sludge which may contain an excess of certain nutrients or be contaminated with heavy
metals or toxic organic substances which attract flies. Organic materials with a low C/N ratio (below 15:1) also have a high potential for nitrification and the generation of soil acidity. International standards for environmental management (such as ISO 14001) would need to be followed, and procedures to achieve the standard would need to be implemented. The requirements of various certification schemes such as Fair Trade and Bonsucro are applicable to sugarcane, the latter being specific to cane. Where amendments are intended for the production of organic sugar, producers will have to be certified and follow strict regulations according to their certification body. A comprehensive list of certification bodies is available in the ‘organic certification directory’ which is available for purchase from www.organicstandard.com. Further details can be found in Part 3, Chapter 2.2.3.

There are risks of accidents associated with manual burnt and green cane harvesting and the use of protective clothing, overalls, gloves boots, safety glasses is a legal requirement in most countries. There are a number of systems covering occupational health and safety standards that can be adopted by organizations to ensure all issues are addressed and the reader is referred to Chapter 12.2 for further information.

Another social impact that has become increasingly important is the retrenchment of cane cutters and other workers with the increased mechanization that is taking place in countries such as Brazil. This has led to the introduction of retraining programs for employees on large estates who face impending retrenchment or who have been retrenched, in order to provide the alternative skills needed for new job opportunities.

**Environmental costs**

Once the system of proposed good management practices based on minimum tillage, legume breaks and a green cane trash blanket is implemented, a better and more efficient farming system with lower production costs will materialize. The carbon footprint of sugarcane will be smaller than with the conventional system, with additional benefits from reduced soil compaction and less damage to the cane stool, and a reduction off-site movement of nutrients, chemicals and sediment from the fields. Trash residue conservation from green cane harvesting, using organic manures and green manure fallow crops will all help to build the organic matter level in the soil that is, after all, the foundation of agro-ecosystem health in terms of biodiversity.

**2.10 Conclusions**

Soil management systems for sugarcane production in the 21st century will have to incorporate ecological principles to an increasing extent in order to arrest the adverse effects of monocropping on soil degradation and yield decline. Strategies that are based on the principle of management by soils (MBS) as well as emphasizing crop residue retention, green manuring, nutrient recycling, minimum tillage, planting with organic manures, green cane harvesting and controlled infield traffic, will help to protect the environment and develop profitable and sustainable sugarcane production systems.
2.11 References


There are several textbooks on soils of the tropics for further reading:
Other major reference books that have their focus on the soils of the tropics by Lal (1987) and van Wambeke (1992).
CHAPTER 3 SUGARCANE CROPPING SYSTEM – PETER TURNER

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3. SUGARCANE CROPPING SYSTEM

This chapter is divided into two sections, the first introduces the land evaluation for new developments and the steps involved in developing the land use plan, AND the second section focuses on the various components of crop establishment and the options available for good management.

3.1 Land use planning and conservation

3.1.1 Introduction

Land in its natural state conserves biodiversity, water and soil, and provides what are termed ‘ecosystem services’ involving flood control, groundwater storage, soil erosion control, and water filtration. The fact that sugarcane production can adversely affect biodiversity, soil, water and air has been reported by Cheesman (2004). This fact, together with knowledge of the difficulty of returning altered land to its natural state, suggests that any future man-made changes from a natural state should be based on a thorough consideration of the costs and benefits in respect of social, economic and environmental sustainability. It is likely that the greatest impact of sugarcane farming is linked to the change in the natural state of the land, therefore for new areas of sugarcane production it is critical to conduct and comply with the results of a credible environmental and social impact assessment before planting. Expansion of existing farms should also undergo evaluation in terms of the same criteria. Existing farms should ideally operate so as to ensure firstly that ecosystem services, which would have been provided by the land in its natural state, are maintained and secondly they should attempt to rehabilitate and conserve as far as possible, the biodiversity which would have existed on the land in its natural state.

This section involves the process from new land evaluation for sugarcane potential and development to the establishment of a detailed land use plan for a farm where the land areas are demarcated for different uses and the conservation requirements are spelt out.

3.1.2 Land evaluation

Initial steps

When proposing a sugarcane project in a new area the first step is selection of the project site. Once the region has been identified, all potential districts should be visited to find the best site. The main criteria are:

Soils
Soil depth minimum 50 cm on heavier soils, 70 cm on sandy soils
Good natural drainage is important, or there should be potential for installation of drains
Texture determines type of irrigation; soils with less than 6% clay normally excluded
Level of nutrition, salinity/sodicity
Sufficient area of reasonable soils for (say) 15 000 ha in one fairly contiguous block.

Climate
Rainfall, adequate length of dry season to allow long crushing season
Sunshine hours, high is desirable
Temperatures, high but best with low night temperatures during the harvest season
Latitude, elevation, effects on flowering and cane quality.
Irrigation water
Overall quantity as well as sufficient flow at the end of the dry season and at periods of crop peak demand; storage capacity available or potential
Water quality
Cost of accessing water from weir/canal
Lift pumping from river
Subsurface water
Flood protection.

Population density
Low density generally preferable as it minimizes problems of access to suitable land, but may cause problems in obtaining sufficient labor and labor housing costs may be high.
Local political issues and means of overcoming, e.g. local human resources expertise.

Location and infrastructure
Cost of moving sugar/ethanol to market
Roads/railway
Power availability.

Topography
Flat to undulating preferable; note drainage in Chapter 2.1.

Availability of materials
Good quality rock for building aggregate
Road gravel
Sand
Coal
Lime
Building timber.

The next steps
When the general site selection has been completed, the next steps are:

- Undertake a full climate suitability assessment to determine likely commercial yield potential (see Chapter 2.1).
- Obtain orthophotos and topographic maps that can be used to delineate the main rivers, topography, land form, vegetation type, existing land use and cover. Create a general map of area boundaries and demarcation of legal entitlement. This could be generated by satellite imagery, aerial photography or land survey and then verified by ground truthing in the case of satellite and aerial photography.
- Unless very detailed maps are available, it will be necessary to download satellite photography, carry out aerial photography or carry out land based surveys with a GPS to obtain contour mapping of at least 5 m (preferably 3 m) vertical interval (VI) which is required for general estate planning and layout.
- Establish rights to use the land (including environmental considerations).
- Visit leaders of local inhabitants and contact representative villagers to discuss the proposals in general terms, stressing employment opportunities in the future and acknowledging existing cultural sites, activities and especially women’s rights and activities. (See also Social section)
- Understand the legal requirements with regard to water usage – complying with all local and regional legal requirements. Obtain national/local regulations pertaining to water usage.
- If the project is to be irrigated it will be necessary to conduct a hydrological survey of the river and/or dam supplying water, assessing dry and wet season flow history and options for construction of off-river storage (refer to Chapter 6.8). For surface irrigation, further detailed topographic surveys will be required (either land based using GPS or aerial photography with LIDAR) to produce a contour map with 1 m VI.

- Conduct a reconnaissance soil survey to identify the main soil types and their distribution as well as their main physical and chemical properties.

- Conduct a pre-feasibility assessment to determine likely cane yield production and projections of costs for irrigation systems, infrastructure development, equipment, bush clearing and crop establishment.

**Box 3.1 Survey and mapping for new irrigation projects**

“A good detailed map is essential in the planning of any new irrigation project. Good drainage is as important as good irrigation, and very often more important. Good drainage of irrigation water is very often more critical in arid and semi-arid areas because of less complete leaching of salts out of the soil. Where overhead irrigation is planned, only enough land leveling needs to be done to ensure good runoff of surface water from the fields, although a master drainage system to take runoff away from the fields is essential. In the case of surface irrigation, i.e. furrow irrigation or, less commonly, flood irrigation, a high degree of accuracy is essential, not only to ensure free flow of water down the furrow, but also to ensure consistent application rates.

The survey and mapping should be carried out with two planning stages and a number of essential criteria in mind. The two planning stages are, first, the overall planning and bankable feasibility cost estimate stage and, second, the later detailed layouts of fields, drains, canals, roads, factory and housing areas. The map for overall planning can be small scale, e.g. 1:10 000, with, say, 2 m contours, but experience has shown that while moderately good detailed planning can be done using 1 m contours, 0.5 m contours allow for estimating cut and fill quantities to a very much higher degree of accuracy, and are also more cost effective in planning of field layouts, especially in the case of furrow irrigation.

Features that should be considered for inclusion in the mapping include:

- Natural drainage patterns.
- Routes for conveyance of water from source to the estate and to individual fields.
- Topography, in combination with the soil survey, whether suitable for furrow irrigation.
- Existing roads, rail, canals, power lines, buildings and other features.
- Suitable water storage areas.
- Density of vegetation.
- Potential factory, office and housing areas.
- In many countries a suitable area must be set aside for timber.

For mapping of large areas an aerial survey has many advantages over ground survey. In recent years Lidar (light detection and ranging) a technology that determines the distance to an object or surface using laser pulses, has increasingly been favored over traditional mapping from aerial photography. Lidar has a number of advantages over traditional photography:

- Because images are digital and the camera is linked to a computerized GPS system in the aircraft, the images are corrected many times per second for the swing, tilt, yaw, bumps and dips of the aircraft flight. The data fed into the databank is what would be obtained from a smooth flight.
• Less ground control survey is needed.
• A bank of tens of thousands of digital images, with accurate x, y and z coordinates is built up which can be electronically thinned out to produce whatever scale and contour interval is required.
• The digital nature of the images allows for a factor to be applied that distinguishes between vegetation height and ground level. In all but the thickest forest, accurate ground contours to a high degree of accuracy can be generated.
• The digital databank results in rapid electronic generation of contours, saving hours of specialist time on traditional air photography plotters.

There are a number of other advantages to using Lidar, and these are developing rapidly in the market. Time spent with the mapping company discussing all the requirements and latest developments is time more than well spent.

Satellite imagery is developing rapidly and should not be dismissed, but at the time of writing the actual accuracies being achieved, especially vertical accuracies, are considerably below the generally perceived levels”

(N. Wilson, Tanzania, 2011, personal communication).

Climate suitability

There are certain climatic limits within which a sugarcane crop can be grown and a first requirement would be to ensure the land and the environment is suitable for cane growing. Ideally, for dryland cane the main growing season of four to five months should be warm with mean day temperatures around 30 °C and high incident solar radiation. The ripening and harvesting season of six to nine months should be cool, with mean day temperatures between 10 and 20 °C, but frost free, dry and with high incident radiation (see Chapter 1.4.1) for further details of climatic requirements). If the project is to be irrigated, lack of rainfall is unimportant; however excessive rainfall may result in a short harvesting season, flooding and associated low sunshine hours.

Reference to a crop atlas which maps the areas on the basis of climatic suitability for sugarcane production is a useful tool. Schulze (2008) has produced such an atlas for sugarcane production in South Africa. For this study, the daily time step conceptual-physical ACRU agrohydrological simulation model, was used to simulate sugarcane yields under dryland conditions for a range of season lengths in order to determine:

• areas suitable for sugarcane growth,
• optimum season lengths at different locations, and
• potential sugarcane yields.

In addition to this, the estimation of yield increments per 100 mm of irrigated water, using various modes of irrigation, can be calculated using the ACRU model.

In Brazil agroecological zoning (ZAE Cana) has been conducted taking into account national biodiversity and environmental conservation considerations (Unica 2010).
Box 3.2 Rules to guide the expansion of sugarcane production in Brazil

“To make the mapping of the national territory, the following guidelines have been set:

▪ **Exclusion of areas with native vegetation**
As the law is approved, it will be prohibited in the entire national territory to remove native vegetation for the expansion of sugarcane cultivation. Areas in which native vegetation is dominant will be protected, as they are considered restricted areas, and sugarcane cultivation will not be permitted.

▪ **Exclusion of areas for cultivation in the Amazon and Pantanal biomes, and in the Upper Paraguay River Basin**
ZAE Cana prohibits the expansion of sugarcane production in the Amazon and Pantanal biomes, and in the Upper Paraguay River Basin. To protect the environment, preserve the biodiversity and make use of the natural resources in a rational manner, the installation of new units of ethanol production will not be permitted on these locations.

▪ **Identification of areas with agricultural potential without need of full irrigation**
ZAE Cana has considered weather and soil conditions, and cultivars of sugarcane to select areas in which sugarcane production uses the lowest volume of water possible.

▪ **Identification of areas with slope below 12 %**
Areas with slope up to 12% allow the use of machinery on the harvesting. Therefore, an expansion of production environmentally adequate can be guaranteed, avoiding new burnings and CO₂ emission. With mechanical harvesting, the expansion will happen with no need for sugarcane manual cutting.

▪ **Respect for food security**
The Bill provides that the Ministry of Agriculture will guide the expansion of sugarcane production so as to avoid any sort of risk to food production or to food security.

▪ **Prioritization of degraded areas or pasture**
ZAE Cana is an important tool to guide public policies and credit policies in a way to give priority to sugarcane expansion in areas already used as pasture. Over 34 million hectares of land currently underutilized or occupied by livestock or degraded pastures are identified in ZAE as suitable for sugarcane production. The increase in the livestock productivity in Brazil (head of cattle per hectare), which today is considered as being low, may provide new areas for sugarcane production”.

### Summary table

<table>
<thead>
<tr>
<th>Description</th>
<th>Area ha (millions)</th>
<th>% of national territory</th>
</tr>
</thead>
<tbody>
<tr>
<td>National territory</td>
<td>851.5</td>
<td>100</td>
</tr>
<tr>
<td>Environmentally restricted areas</td>
<td>694.1</td>
<td>81.5</td>
</tr>
<tr>
<td>Suitable areas currently used for agriculture and livestock</td>
<td>64.7</td>
<td>7.5</td>
</tr>
<tr>
<td>Suitable areas currently used for sugarcane (2008/2009)</td>
<td>7.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Expansion of sugarcane areas projected to 2017</td>
<td>6.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Establish rights to use the land

This would involve permission to conduct pre-feasibility and feasibility assessments of a development and usually will require an Environmental Impact Assessment (EIA)* as well as other conditions to be satisfied before the development will be allowed to proceed.
*Note: it is usual to include social assessments in such evaluations – Environmental and Social Impact Assessment (ESIA) – but in the context of this chapter we are concerned specifically with the environmental aspect, noting that the social aspect is also essential. It is important to involve local consultants in these activities.

National governments usually have some form of legislation which determines the land that can be considered for development and the criteria that require a detailed EIA to be performed. Brazil has developed a national map of agroecological zones, described above, which already precludes possible development in certain areas. South Africa has a National List of Threatened Ecosystems which needs to be taken into account in any EIA. In countries which do not have legislation in place to require EIAs it would still be considered Good Management Practice for a developer to voluntarily conduct sufficient investigation to ensure that no threatened biodiversity was affected. It could be considered good practice to at least adhere to international conventions on environmental issues such as the Convention on Biological Diversity (www.cbd.int) and the Ramsar Convention on Wetlands of International Importance (www.ramsar.org).

**Legal requirements**

All legal requirements for establishment and future management of a sugarcane production system need to be considered in the Land Use Plan (LUP). This includes economic, social and environmental legislation. A full assessment of all relevant national and regional legislation needs to be undertaken or accessed if already available. It is suggested here that all industries should provide a comprehensive set of legal requirements for all participants in the industry. The International Sugar Organization has reported on a survey of all environmental laws affecting sugar production in each member country (ISO 2001). In South Africa a review of relevant international conventions and local legislation is included in the Standards and Guidelines for Conservation and Environmental Management in the South African Sugar Industry (SASRI 2002).

Also relevant are international laws which are usually found in the form of Conventions. In regard to the environment there are laws which relate to assessment of new developments and expansions, and also laws which relate to the ongoing operation of sugarcane farming. This includes the management of impacts on biodiversity, water, soil and air (SASRI 2002; Maher 2007). Of great importance are international agreements on use of river water which flows through different countries, e.g. the Nile River Water Treaty.
Soil survey

Box 3.3 Main types of soil surveys

“There are two main types of soil surveys: reconnaissance and detailed.

A detailed soil survey has an observation intensity of one per four hectares (200 m grid) or less (150 m, 100 m grid, etc.). Any soil survey with an observation intensity of less than one per four hectares is deemed to be reconnaissance.

A reconnaissance soil survey has three main subdivisions: (i) fatal flaws (observation intensity of < one per 100 ha), (ii) pre-feasibility (observation intensity of between one per 30 ha and one per 100 ha) and (iii) feasibility (observation intensity of > one observation per 30 ha). The level of intensity of observations has a direct influence on the accuracy of the maps and resulting recommendations. The greater the number of observations for any given area, and the more accurate the maps and recommendations, the greater the cost to the client.

The above soil surveys can be conducted at any scale, but generally the following applies:

- A detailed soil survey is completed at 1:10 000 or 1:5 000 scale.
- A fatal flaws reconnaissance soil survey is conducted at scales ranging from 1:20 000 to 1:50 000.
- A pre-feasibility reconnaissance soil survey is normally conducted at 1:20 000 to 1:30 000 scale.
- A feasibility reconnaissance soil survey is often conducted at 1:10 000 to 1:20 000 scale.

The scale of mapping is also determined by the type, quality and resolution of the base map, which may be 1:50 000 topographic maps (which can be georeferenced into WGS84 ellipsoid), google earth imagery (this cannot be georeferenced) or georeferenced, contoured (0.5-10 m contours – contour intervals depend on the steepness/relief of the area – steep areas normally have 10 m contours, whereas flat/level areas have 0.5-1.0 m contours to pick up the micro topography), colored imagery that is clear at 1:1 000 scale (high resolution imagery).

Land use plans can be conducted using any of the above soil survey types, type of base map or scale of mapping. The larger the scale, the better/clearer the base map and the higher the imagery resolution and clarity, the more accurate the land use plan.”

(WZ Heathman, Hilton, 2011, personal communication).

The soil survey information is ultimately used in the land use planning process to support delineation of wetlands, watercourses, sacred sites, natural vegetation areas, sites for quarries, buildings, roads, dams, rubbish dumps, waste disposal sites, suitable areas for workshops and chemical stores. Chemical disposal sites, non-crop land, recreational areas, and areas suitable for sugarcane fields should be delineated. Roads, waterways, contours, bridges, sediment traps, and recycling ponds for irrigation water containment should also be identified or sited and demarcated on the map. Knowing the predominant soil type in a particular field also forms the basis of management decisions with regard to the selection of tillage practices, planting techniques, cultivar selection, drainage and irrigation requirements, fertilizer requirements and harvesting schedules (see Chapter 2.7).

Soil development is very much affected by toposequence and an example of soil differences associated with topography is presented in Fig. 3.1.
3.1.3 The Land Use Plan

Having established the legal, social and environmental rights to the use of the land and the climatic suitability in the exploratory and reconnaissance surveys phase, the semi-detailed and detailed soil survey information can be used to develop the LUP. Environmental considerations when establishing the LUP are given below.

Wetlands and watercourses

A wetland can be defined (SASRI 2002) as an area that is flooded for a sufficiently long period for waterlogging to become the dominant factor determining the diagnostic characteristics of the soil, with the presence of mottling or gleyed horizons brought about by the anaerobic conditions. The critical importance of wetlands for the provision of ecosystem services of water filtration, flood control, sediment trap function and water table replenishment makes their management important and a number of countries have regulations in place to ensure this.

Box 3.4 Example of regulations to protect wetlands and watercourses (SASRI 2002)

1. “No land user shall:
   a) Drain or cultivate any marsh or water sponge or a portion thereof.
   b) Cultivate any land on his farm unit within the flood area (10 year flood line) of a watercourse, or within 10 m horizontally outside the flood area of a watercourse.
2. The bed, banks, course or characteristics of a watercourse* may not be altered without permission.
   *watercourse includes a river or spring; a natural channel in which water flows regularly; a wetland, lake or dam into which or from which water flows.
3. Wetlands and watercourses should be identified and mapped, and adequately protected or rehabilitated, e.g. removing alien invaders, encouraging relevant vegetation and removal of any drains.
4. Wetlands, watercourses and riparian areas should be left undisturbed, with no dumping of debris or material.
5. Burning should be undertaken with care in wetlands and watercourses.
6. Access roads should not cross wetlands”. 
Natural areas management

As with wetlands and watercourses, natural vegetation plays a vital role in biodiversity conservation. Recommendations selected from SASRI (2002) are given below.

Box 3.5 Natural areas management

“Identification
All natural and cultural assets and unplanted areas of the farm should be mapped and a management plan developed for them.

Management
Species of flora and fauna should ideally be identified and listed and vegetation types of natural areas classified.
Grasslands may need to be burnt but this should be according to a recognized and accepted code of practice.
Invader plants and animals should be controlled.
Indigenous plants are usually easily maintained by removing invader plants and allowing regrowth or re-infestation from indigenous plants.
Public recreation facilities could be provided where appropriate”.

Conservancies and biodiversity stewardship

Due to the fact that biodiversity is often not adequately conserved in formally protected areas and that private landowners may have substantial natural areas, it makes sense to encourage landowners to increase the areas of conserved land and to manage it sustainably. An example of a program to involve farmers and land owners in biodiversity conservation is the Biodiversity Stewardship program of Ezemvelo KZN Wildlife.

Box 3.6 The Biodiversity Stewardship program of Ezemvelo KZN Wildlife(EKZNW) (http://www.kznwildlife.com/index.php?/About-Stewardship.html)

This recognizes the need for private participation in biodiversity conservation and states:

“KwaZulu-Natal is fortunate in having a rich diversity of plant and animal life. However, only a small proportion of this diversity, and only 53% of priority species, receive protection within the existing protected area network. A further 1.4 million ha or 14.5% of the area of the province is required under formal conservation land-use in order to ensure comprehensive protection of the province’s biodiversity and thereby comply with the legal mandate and mission statement of the organization.”
“Combined with this is the recognized fact that 80% of the priority biodiversity is located outside of formally protected areas, making strategic partnerships with private and communal land owners crucial if our natural heritage is to be conserved.”
“EKZNW has launched a dedicated Biodiversity Stewardship Program through which a number of conservation options will be offered to landowners. The new biodiversity stewardship approach provides a small number of simple, legally-aligned options nationwide and ensures that landowners benefit from participation. These tools need to offer various types of incentives to offset any potential costs incurred by landowners associated with conservation commitments.”
What is stewardship?
“Stewardship definition – refers to the wise use, management and protection of that which has been entrusted to you as a landowner or is rightfully yours. Biodiversity stewardship is therefore the practice of effectively managing land-use outside the existing state-managed protected area system to ensure that natural systems, biodiversity and the ecosystem services they provide are maintained and enhanced for present and future generations.”

“What is different to other approaches?
STEWARDSHIP differs from other approaches in that it provides options that:
- Require **commitment** from landowners;
- Provide long-term **security** to biodiversity;
- Require that sites be **managed for conservation**;
- Require monitoring and **auditing** of sites;
- **Reward** landowners for committing land for the public good”.

Due to the substantial benefits of natural area corridors and biodiversity conservation in terms of not only global concerns of species extinction, carbon sequestration, but also due to the provision of habitat for natural predators of insect pests of cane enhancing natural biological control, biodiversity conservation should be an important consideration in the broad planning of farm layout. In Brazil 20% of farm land needs to be conserved in a natural state by law. Providing buffer zones of natural vegetation between cane fields and natural streams limits the amounts of soil, water and crop chemicals reaching streams and subsequently entering major rivers, estuaries and marine ecosystems (Fig. 3.2). Likewise, the option of establishing ponds or sediment traps to collect all irrigation runoff at the farm boundary before it enters streams and rivers and then recycling this water should be considered in the major layout planning stage. Biodiversity stewardship programs as described in Box 3.4 should be considered if available, as well as less formal systems involving voluntary membership of conservancies where members manage their land in an environmentally acceptable manner and in particular make efforts to control alien invasive plants and animals. Farmers have the opportunity of also providing recreational facilities for the public such as fishing, walking and bird watching, and these are included as options for consideration in a sustainable farming system promoted in South Africa (Maher 2007).

![Figure 3.2. Conservation of a proportion of the farm in natural state.](image)
The importance of a Land Use Plan (LUP) as used in South Africa

In order to minimize soil loss and conserve moisture on agricultural lands, as well as minimizing the impact of farm practices and infield transport on the environment, it is vitally important for sustainable crop production to relate agronomic, irrigation and mechanized harvesting practices to the climate, topography and distribution of soils of a farm. According to Platford (1980), “the optimum cane yields obtainable on different soil types and from different land use classes are seldom the same.” Deep red blocky clay soils derived from dolerite invariably have a better yield potential than the shallow grey sandy loams derived from granite under the same climatic conditions. Similarly, the deep moist soils in valley bottoms produce more cane than areas of shallow soil on hilltops. The sugarcane grower needs to be aware that the different areas on the farm cannot all be managed in the same way and that his management task is to integrate the practices into a balanced working plan, which provides for each unit of land to produce an economically optimum yield and protection of the natural resources on the farm. With all the variable factors in sugarcane growing to consider, it is essential for the grower to follow a prepared plan, much in the same way as the builder of a new home would follow the architect’s plan.

Land use planning approach
A LUP comprises a soil conservation network, a cane extraction network and a production management program, all based on the soils, slopes and climate of the area. The soil conservation works provide the framework for the field roads and cane breaks. Compared with other row crops, sugarcane is generally an exceptionally good conservation agent and, together with contour layouts and grassed waterways, ensures that soil and water losses are kept to a minimum.

A LUP normally contains details and specifications for:

- Soil conservation structures and grassed waterways
- Roads (major and minor) and loading zone sites
- Field layout for conventional, strip replanting and minimum tillage
- Fields for trash management
- Fields suitable for mechanization
- Fields suitable for irrigation
- Fields requiring drainage
- Protection of wetlands, natural stream banks and indigenous bush areas
- Workshops, chemical stores
- Staff, labor and housing
- Dams
- Quarries and rubbish dumps.

Main steps in the preparation of the LUP
In most cases there are four main steps in the preparation of the LUP (Maher and Platford 1994):

- Complete farm assessment
- Drawing the plan
- Checking the plan
- Developing a program to implement the plan.

The procedure is described in detail by Maher and Platford (1994) but may be summarized as follows:
• Identify streams, soil type boundaries, rocky outcrops, wet areas using 1:6 000 photos enlarged from 1:30 000 contact prints.
• Collect all available quota, soil and contour maps of the existing cane lands.
• Join the contour maps into workable sections and mark the existing cane areas onto a clear overlay together with the major drainage lines, crest lines, crest areas and valley bottom areas.
• The soils map and calculated % slopes are used to determine the terrace spacings. The soils are broken up into three main categories: resistant to erosion, moderately resistant and susceptible to erosion.

Planning large undeveloped areas requires relevant 1:10 000 orthophotos, which show topographic details identified by visual appraisal. Areas of potential development are demarcated and the contours are then digitized into the computer and processed. A slope analysis is done with a Digital Terrain Model generated by the computer (Wallace 1993).

Use of a Geographic Information System (GIS) provides an alternative quick and accurate method of slope analysis, enabling the determination of areas occupied by the hilltops, hillsides and valley bottom and the prediction of yield production.

**Developing the production plan**

Having carried out the above analysis and collected the necessary slope information, it is now possible to plan the crop establishment method, the cultivar disposition plan, harvesting plan and overall production potential of the farm.

Assume that the GIS analysis shows the following breakdown of potential areas that can be developed for sugarcane:

- Hilltops: 100 ha
- Hillsides: 200 ha
- Valley bottoms: 50 ha
- Total area: 350 ha.

The flat hilltop areas could be considered for a possible parallel layout system to accommodate a mechanized harvesting operation. The areas with steep slopes would be suited to a minimum tillage system on a strip cropping panel system. The good valley bottom land would be better suited to a separate management system.

In terms of cultivar disposition, a possible plan based on the use of fictitious cultivars could be as follows:

- Hilltops: use moderate potential cultivar ‘A’ cut at 16 months of age
- Hillsides: use moderate to high potential cultivar ‘B’ cut at 14 months of age
- Valley bottoms: use high potential cultivar ‘C’ cut at 12 months of age.

**Production target**

Having compiled all the information for this hypothetical farm, it is now possible to provide an estimate of the production target. In an industry where the top 10 % growers are achieving an average of 7.5 tc/ha/m, and if it is assumed that all the factors like rainfall, temperature, sunshine hours, crop husbandry or management, field layout, mechanization or labor utilization are at their highest possible level, then in a particular season, a production target of 37 500 tc is possible subject to the sequence of planting operations.
Implementation of the LUP

This will normally be implemented over a number of years, and will depend on the final field layout design, structures and waterways being established as fields are cut and ploughed out and whether drainage is needed in the valley bottom area, to mention just a few factors. Certain fields may have to be ploughed out prematurely to fit in with the change in layout, and to link up with a field already due for plough-out. With the use of GIS, specific decisions can be made as to which field can be worked on, keeping the targets in mind. The LUPs also facilitate the formulation of budgets for development projects.

Field layout

If the field has been planned for irrigation, the detailed survey and land leveling requirements appropriate for the irrigation system would be required (Dedrick et al. 2007). Technologies such as laser leveling with satellite and the use of Lidar are useful. The sensitivity of Lidar allows the soil surface to be mapped even under a tree or vegetation canopy and to an accuracy of 2.5 cm, and this allows for very accurate digital terrain modeling. Land forming is a very important (and expensive) requirement for surface irrigation, but may also be required for overhead irrigation to prevent formation of pools of water in field. (see Appendix 4)

Platford (1987) reported that, “It has been established from measurements on runoff plots and small catchments that 85 to 90% of average annual soil losses occur during the period when replanting takes place.” He further states that, “It is important to control losses at this stage if overall losses are to be limited. If the amount of soil disturbance can be reduced either by killing the crop chemically or by chipping it out, the erosion hazard can be reduced significantly. Care must nevertheless be exercised that an adequate amount of organic material is present to protect the soil. Even then, if deep interrow cultivation is required large amounts of loose soil can be available for transport during storms of high intensity which do occur regularly at the time when minimum tillage is most beneficial.”

Using the Universal Soil Loss Equation (USLE) modified for sugarcane, Platford (1987) calculated expected soil losses from sugarcane fields for combinations of factors including rainfall erosivity, soil erodibility, and land slope as fixed parameters, and tillage, strip replanting, terrace banks and trash mulching as management variables. On the basis of these soil loss estimates for each combination of circumstances and practices and in comparison with an acceptable soil loss figure, a nomograph was developed to enable the selection of an acceptable contour spacing. He emphasized the need for farmers who, for instance, used trash mulching as an input to determine terrace spacing, to continue to use green cane harvesting and a trash blanket to maintain the safety level for soil erosion control.

3.1.4 Monitoring and evaluation plan

As the LUP ideally takes into account all the various practices that will be followed on the farm, it makes sense to establish and follow an evaluation and monitoring program to allow for identification of shortcomings and opportunities for improvements. The incentives for applying Good Management Practices in sugarcane, apart from the ethical and public pressure aspects, include satisfying customer demand (e.g. Bonsucro (www.bonsucro.org), Fair Trade (www.fairtrade.net) or Rainforest Alliance (www.sanstandards.org) certification) and in order to become certified there will be a need for measurement of performance or adherence to good practices. Hence the value of a monitoring and evaluation plan. An example of a detailed monitoring and evaluation plan is the South African Sustainable Farm Management System as described by Maher (2007). This is based on three principles of economic, social and environmental sustainability and includes an auditing procedure, thus allowing for continuous assessment and identification of
opportunities for improvement. Maher states, “The audit check sheet makes use of scoring in order to:

- Determine the current performance level of the grower
- Highlight strengths and weaknesses
- Develop an action plan for corrective action.”

The Sustainable Farm Management System covers all aspects of the farming operation in some detail and is broken down into Principles, Criteria, Indicators and Verifiers. Each verifier has three aspects: (i) a legal requirement (scoring 3 points), (ii) non-legally binding best management practices (scoring 2 points) and (iii) additional measures (worth 1 point) (Maher 2007).

In 1995, Canegrowers (the Queensland cane growers) commissioned an independent environmental audit of the Queensland cane growing industry. The audit assessed the environmental performance according to (i) any off-farm impacts, (ii) level of compliance with regulations and policies, and (iii) activities related to ecological and social impact. The audit was carried out by an independent consultant to the ISO 14010 standard (Azzopardi 2002).

Box 3.7 Summary of good practices for land use planning

- Assess climatic suitability for sugarcane production.
- Conduct credible and comprehensive Environmental (and Social) Impact Assessment.
- Understand complete International, National, Regional laws and conventions with respect to new developments, expansions and continuing obligation for management of natural resources.
- Conduct detailed soil survey.
- Develop a LUP based on detailed soil information.
- Establish a monitoring and evaluation program for continued assessment.

3.2 Crop establishment

3.2.1 Introduction

This covers all the operations required (after the completion of field layout and infrastructure including roads, contours and waterways) to establish a growing crop of sugarcane.

New developments that require land forming, land planing and laser leveling, drainage work, irrigation infrastructure installation and, surface water management works are discussed in 3.3.5 above. Existing fields being replanted may or may not have required alterations to infrastructure such as roads or contours. Thus there may be various requirements and choices in respect of methods of eradicating existing vegetation and preparing a seed bed for new plantings. These options may have differing impacts on economics, the environment and even society and labor and would need to be weighed up in making the choice.

Crop establishment also includes re-establishment of a crop after harvesting. The objectives are to produce a sugarcane crop that will provide an economic return without negative impacts on the environment and without infringing on the rights of employees and the local community. The most likely environmental impact from crop establishment is due to soil disturbance. This causes a breakdown in soil structure, loss of organic matter, exposure of the soil to rain and wind erosion, a reduction in air filled porosity and hence water holding capacity. Thus from an environmental perspective it is usually beneficial to minimize soil disturbance in operations to establish a sugarcane
on crop. Clearly, some soils require disturbance to allow satisfactory germination and growth. The resultant choice will be a compromise to satisfy these two conflicting conditions. Factors which contribute to the ability to satisfy these major objectives and need to be considered are soil type, slope, season, labor availability, weather patterns, harvest system, irrigation type, planting configuration, soil ameliorants, and others. Of these, the major factors are soil type and slope.

In terms of environmental sustainability the following objectives need to be borne in mind when considering practice options:

Maximize organic matter in soils and soil surface cover (trash blanket).
Minimize soil loss and degradation (minimize soil disturbance, till soils according to type and slope).
Minimize water loss and quality loss (minimize chemical pollution of watercourses and improve water use efficiency).
Minimize impacts on air (limit burning as far as possible).

Crop establishment involves:
- Eradicating the old crop (or existing vegetation in new developments).
- Preparing a seedbed.
- Planting with first irrigation where appropriate.

3.2.2 Crop eradication

Objective: To completely kill the old crop
This is to prevent disease transmittance to the new crop and to prevent mixing of cultivars if a new cultivar is to be planted. Ratoon stunting disease (RSD) can be transmitted to the new crop by surviving cane stools as can the diseases smut and mosaic. There would be little point in efforts to utilize disease free seedcane if diseases were allowed to be transmitted to the new crop.

Methods include mechanical, chemical, hand hoeing and a combination of chemical and mechanical eradication methods.

Mechanical
A wide range of machinery and implements have been used worldwide to eradicate sugarcane stools, but this has generally involved ploughing the field in drier times of the year to invert the cane stools, followed by repeated cross cultivations with disced or tined implements to ensure desiccation of the old stools. Volunteers that subsequently emerged were generally dug out with a hand hoe or killed by repeated passes with discs. This can be very ineffectual and the cost is high, particularly if the operation needs to be continued into the wet season. A major disadvantage of mechanical methods is their potential to allow soil erosion if conducted in wet weather on erodible soils and on steep slopes. In endeavoring to improve the efficiency of mechanical methods of eradication, Dicks et al. (1981) tested a number of implements and showed that satisfactory eradication could be provided by the use of a moldboard plough set to a depth of 100 mm on heavier soils in winter, and by a rotary hoe in sandy soils. However, they found that summer harvested fields were better eradicated with the use of chemicals. Equipment tested included the chisel plough, power harrows and the conventional plough, in addition to the moldboard plough and rotary hoe.
Box 3.8 Implements for cane eradication

The moldboard plough is able to successfully cut the stool away from the roots without inverting the stool if set to a shallow depth (80-120 mm)

Disc ploughs are generally unable to kill the cane satisfactorily due to the difficulty of controlling the depth and this results in portions of the cane row not being affected.

Subsoilers with wings or stool ploughs have been found to be effective if operated in the same way as a mouldboard plough.

Heavy disc harrows are satisfactory when operated at shallow depths and high operating speeds.

All the above implements separate the plant from its root system and they require a further operation to lift the stools out of the soil to allow them to dessicate.

Spring tine rippers and cultivators can be used for the purpose of lifting stools out of the soil and they should be used at a higher operating speed which also results in a finer tilth.

The rotary hoe can be very effective when operated with the back flap open in sandy soils but also tends to pulverize the soil and cause severe damage to soil structure on heavier soils and in dry conditions.

Timing for efficient mechanical stool eradication

This must be conducted in the dry part of the year so that cane stools become desiccated after exposure. It is totally ineffective in the rainy season. This means that fields for plough out and replant should be harvested at the beginning of the harvest season, which normally coincides with the onset of winter in rainfed industries. This also coincides with the period of lowest growth potential and hence least loss of cane production. Also since the soil is most vulnerable to erosion in the ploughed state this is best conducted at this time of year when there is less potential for high rainfall events. In dry areas where irrigation is necessary the period of mechanical eradication can often be extended as the risk of rainfall and erosion is less.

Soil type also has a large influence on the success of mechanical eradication and needs to be taken into account. Examples of recommended procedures for mechanical crop eradication are included in Box 3.9 (SASRI 2002)
Box 3.9 Recommendations for mechanical eradication

**Objective:** Remove the cane stool from the ground, remove as much soil as possible from around the roots, invert the stool and leave it on the surface to dessicate.

On heavy soils: (loams, clay loams and loamy clays)

1. Moldboard plough with a depth wheel set to a depth of 100 mm. This cuts away the top part of the stool from the roots and inverts the stool allowing it to dessicate.
2. When shoots begin emerging from the old stools (usually about 4 weeks later) use a disc harrow to chop up the remaining live stools.
3. A single pass with a spring tine cultivator which brings stools to the surface.
4. Apply a second pass with a disc harrow (4 weeks later).
5. Follow up removal or spot spray of volunteers on a regular basis.

On light soils:

A rotary hoe set at a speed to chop the stool into small sections and fling them on to the soil surface is recommended. This is facilitated by leaving the flap in the open position, operating at a depth of 100 mm, with a forward speed of 2.5 km/h and using 200 revs/min.

This method is totally unsuccessful during wet times of the year.

**Costs of mechanical cultivation**

Proper costing can only be done in local situations but some general thoughts include the fact that fossil fuel costs are increasing faster than many other costs, thus placing mechanical cultivation at a disadvantage. Future costings will increasingly focus on the Net Energy Ratio (NER), which is the renewable energy output of biofuel and co-products divided by the fossil energy input in the whole production chain (see Ch 13.1.2). Future mechanical work on farms will increasingly be carried out with non-fossil fuels.

**Summary of advantages and disadvantages of mechanical eradication**

**Advantages**

Land is fallow during the least productive growth period.

**Disadvantages**

High risk of erosion.

Only effective in dry conditions.

Regrowing stools dispersed throughout the field and difficult to distinguish from new crop.
Chemical

With the limitations to mechanical eradication in respect of season and soil restrictions, it was fortunate that a chemical became available which was able to kill the crop without having a residual effect in the soil and thus avoiding damage to the subsequent planting. Glyphosate was found to show these properties and was tested for its effect at varying rates, at various growth stages and on a number of sugarcane cultivars and found to provide an acceptable kill (Iggo 1974). The disadvantage of conventional mechanical eradication was the length of time required to eradicate the volunteers, and the ability to spot spray these with an effective chemical was an added benefit of chemical eradication. Further work on glyphosate confirmed its ability to kill sugarcane and refined the conditions under which performance was acceptable (Turner 1980; Alonso et al. 1984).

Using chemicals to eradicate cane has distinct advantages in avoiding unnecessary soil disturbance and thus preventing erosion on steeper slopes. Glyphosate, which is totally inactivated on contact with soil and has no residual effect, needs to be applied to actively growing cane between 400 and 700 mm in height and with most tillers developed. The disadvantage is that the cane needs to be allowed to regrow after harvest and, under dryland conditions this must be done in spring or early summer thus only allowing the new crop to be planted later in summer. Only clean water can be used for spraying. If canal water containing silt is used, glyphosate is inactivated.

Advantages and disadvantages of chemical cane eradication (SASRI 1996)

**Advantages**
- Risk of soil erosion is reduced substantially compared with mechanical eradication
- Good kill can be achieved under favorable conditions
- Volunteers remain in the same lines and are more easily identified for removal
- Perennial weed problems can be eradicated at the same time.

**Disadvantages**
- Can only be used in summer and potential growth is lost
- Effectiveness is dependent on weather conditions.

Hand eradication

Sherwell (1990) reported on the use of hand chipping as a means of sugarcane eradication to complement minimum tillage and conventional tillage treatments on a sugar estate in KwaZulu-Natal in South Africa. This involved the development of a suitable implement which is able to split the stool from the roots and lever the stool out of the ground. The main advantage of the implement is the fact that cane harvested in early winter can be planted in spring without having to wait for regrowth before chemicals can be applied. Chipping can however be used at any time of the year.

Advantages and disadvantages of hand eradication

**Advantages**
- Can be conducted at any time of the year
- Risk of soil erosion is substantially reduced compared with mechanical tillage
- Can be used on steep slopes with erodible soils.

**Disadvantages**
- Difficult on heavy soils.
Combination tillage

Recognizing the value of planting new crops in spring to allow the best use of summer growing conditions led Butler (1992) to test the use of a combination of mechanical and chemical treatments. This technique was called combination tillage. The crop is first sprayed with either glyphosate (or fluazifop butyl) and then the stool is sheared mechanically at a depth of 100 to 150 mm below ground surface 3-7 days after spraying. The cane roots are severed and the stool lifted but not inverted, thus leaving the stool in its original position in the cane row. Results indicate that sugarcane can be killed earlier in the season, at a younger age and at lower rates of chemical.

Advantages and disadvantages of combination tillage

Advantages
Allows use of chemical eradication earlier in the season
More effective than either chemical or mechanical alone
Less risk of soil erosion than mechanical alone.

Disadvantages
Unsuitable for steep slopes.

Summary – criteria for selecting a cane eradication method

Table 3.1. An example of a selection chart for eradication methods used in South Africa.
(SASRI, 2002)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Slope</th>
<th>Season</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>High erosion hazard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10 % clay</td>
<td>0-20 %</td>
<td>Winter</td>
<td>Chipping</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chipping or Fusilade</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chipping or glyphosate/sulphosate</td>
</tr>
<tr>
<td>Moderate erosion hazard</td>
<td>&lt; 15 %</td>
<td>Winter</td>
<td>Chipping or shallow MB plough/harrow</td>
</tr>
<tr>
<td>10-20 % clay</td>
<td></td>
<td>Spring</td>
<td>Combination tillage or Fusilade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td>Combination tillage or glyphosate/sulfosate</td>
</tr>
<tr>
<td></td>
<td>&gt; 15 %</td>
<td>Winter</td>
<td>Chipping</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spring</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td></td>
</tr>
<tr>
<td>Low erosion hazard</td>
<td>&lt; 15 %</td>
<td>Winter</td>
<td>Plough/harrow</td>
</tr>
<tr>
<td>&gt; 20% clay</td>
<td></td>
<td>Spring</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td></td>
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<tr>
<td></td>
<td>&gt; 15 %</td>
<td>Winter</td>
<td>Chipping</td>
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<td></td>
<td>Spring</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer</td>
<td></td>
</tr>
</tbody>
</table>

Ploughing/harrowing (maximum tillage) is not recommended at all on highly erodible soils. No cultivation at all is permitted on these soils on slopes greater than 20 %.

Whatever method is selected, follow up eradication of volunteer plants is required after the initial operation. The choice of method may be restricted by law in some countries to prevent erosion on the most erodible soils and on steep slopes. However, even where mechanical methods are allowed, chemical and hand methods may be preferred purely because of their advantages in limiting erosion even further.
3.2.3 Seedbed preparation

The objective is to create a good tilth for planting with minimal soil disturbance to reduce the potential for erosion.

Eradicating an old crop and preparing a field for planting are likely to be the most sensitive stages of the crop cycle for potential soil erosion. Soil erosion is arguably the most serious environmental impact of growing sugarcane on slopes and therefore every effort should be made to minimize this.

Seedbed preparation is carried out only after the old crop has been effectively eradicated.

**Implements for seedbed preparation**

- **Hand hoe** – useful where the old crop was eradicated by hand hoeing on sandy soils and the new crop could be planted directly in the old (now excavated) crop row. It is also an option after chemical cane eradication on sandy soils where the soil already has a suitable tilth for planting.

- **Ridger only** – useful where the old crop was eradicated by chemicals and the soil does not need tilth preparation (sandy soils).

- **Rotary hoe** – useful for non-erodible soils and well structured soils where a tilth is required. Used on a narrow band (200 mm) on the interrow of the old crop where chemical cane eradication has been used. Unless correctly used, these implements can create too fine a tilth which can result in puddling and erosion.

- **Disc** – also useful where cane has been eradicated with chemicals to provide a banded tilth on the interrow, i.e. using discs on the old interrow only.

- **Plough and disc** – where the conventional method of maximum tillage has been used to eradicate the old crop a two phase operation may be necessary. The first phase involves a loosening process and is only necessary when heavy soils are too hard to permit the normal ridging to be done. Under these circumstances the soil should be disturbed by means of a ripper or plough to a depth of only 100 mm deeper than the depth of the planting furrow. The bottom of the planting furrow from the soil surface should be 100-150 mm, so plough depth need only be 200 to 250 mm. Where there is a great deal of vegetative material on the soil surface, this should be ploughed under rather than ripped or chisel ploughed.

Experiments conducted over a wide range of soils have shown that deep soil disturbance with rippers and large trailed ploughs is not required for optimum cane growth (Moberly 1969, 1972).

The second phase involves producing a fine tilth. Seedcane should be planted into a relatively fine seedbed. Large clods result in air pockets which cause desiccation of the seedcane and poor germination. Good soil/sett contact is essential to allow absorption of moisture from the soil.

Some soils require no tilth formation while others require only minimal working. In those that do require tilth formation this is much easier when the soil is moist but not too wet. In irrigated areas a fine tilth is less important because irrigating soon after planting can provide the right conditions.

Phase one is usually carried out using a disc, moldboard or chisel plough, and phase two follows within a few days with a heavy disc harrow for heavier soils and lighter disc harrow for lighter soils.
Rotary hoes are useful for incorporating lime where this is required but otherwise should be avoided on erodible and structureless soils where the risk of damage is substantial.

After land forming, leveling and irrigation layout, the minimum operations required to provide good soil tilth should be utilized.

Where fallow crops have been used, tilth forming operations need to be tailored to the situation. In the Australian SmartCane Plant Cane Establishment and Management booklet, Calcino et al. (2008) describe a system of controlled traffic, legume crops and reduced or zonal tillage in which improved sugarcane cropping is achieved.

**Minimum tillage**

In spite of the requirement of most crops for a good soil tilth at planting, the negative effects of disturbing the soil have also been recognized with a loss of organic matter, breakdown in soil structure and loss of moisture (Meyer et al. 1996). Minimum tillage is a term used to describe systems which attempt to reduce the conventional amount of soil tillage associated with growing a crop. In some industries the term has become synonymous with a particular set of operations, and care should be taken to understand the use of the term. However, the concept remains the same, namely carrying out crop operations with attention to minimizing the amount of tillage. In South Africa, minimum tillage has since the mid-1970s been associated with chemical crop eradication and replanting by tilling only on a band in the old interrow (Fig. 3.3). More recently, in Australia the term has been used to apply to a system of fallow legume cropping and subsequent field layout to accommodate controlled traffic and dual row spacings (Garside et al. 2009). Basic tillage requirements in each of these systems differs markedly but both provide a reduced amount of tillage compared to conventional or older practices.

![Figure 3.3. A field being prepared for minimum tillage planting in KwaZulu-Natal, South Africa.](image)

**Advantages and disadvantages of minimum tillage in South Africa**

**Advantages** (Iggo and Moberly 1976)

- Higher yields in certain soils
- A shorter fallow period between harvest and planting
- Substantially reduced risks of soil erosion, as at no stage would the land be denuded of vegetation
- Reduced cultivation costs
- Control of problem weeds by the application of glyphosate.
Disadvantages
The possibility of a poor kill of the old ratoon crop on account of unfavorable climatic conditions at the time of applying glyphosate.
When major alterations to the field layout are required some form of conventional tillage may be required for the new layout.

3.2.4 Planting

Since the costs of replanting a sugarcane field are far higher than those of re-establishing a field after harvest, it makes good sense to do everything possible to ensure a good and healthy plant crop. The requirements for a good and healthy plant crop are favorable soil and moisture conditions as well as healthy seedcane of the right cultivar. Factors such as depth of planting, depth of covering and timing all play a role. Of critical significance is the fact that 85-90% of erosion on a sugarcane farm occurs during crop re-establishment (Platford 1987). Mechanical planting has been adopted in many mechanized industries, but hand planting is still widely practiced.

Soil testing and amendments application (liming)

Soil sampling and analysis should be carried out immediately after harvesting to enable the formulation of plans to apply the required fertilizers, and importantly to identify the need for any ameliorative treatments such as lime. The simple exercise of applying fertilizers according to soil analysis and industry calibrated recommendations avoids excesses and saves costs, thus contributing to both economic and environmental sustainability. Where a legume fallow has been used it should also be remembered that the N recommendation at planting and in the first ratoon crop will need to be reduced. This could be regarded as one of the simplest and most effective ways of helping the achievement of economic and environmental sustainability (See Chapter 5).

Timing of planting

For irrigated areas temperature is not generally the limiting factor in timing of planting, whereas under rainfed conditions usually only a restricted time or season is available for planting. Diseases may be more prevalent at certain times of the year (mosaic is a problem in some areas planted after November in South Africa). Spring is the most common time of planting and this requires that the previous crop should have been eradicated in winter. It is important to ensure that time of planting is geared to minimize potential soil erosion by planting fields on steep slopes and with erodible soils when these would be least affected by heavy rain events. In areas having some winter rainfall, winter planting can be accomplished by applications of 3-4 L/m of water to the planting furrow. Although autumn planting allows the crop to be at full canopy early in the spring and enables best use of summer growing conditions, the previous crop would have been in fallow during the peak growing season.

Cultivar selection and seedcane production

Cultivars differ in a range of important characteristics and play a critical part in the economic success of a farming operation. Most industries have substantial breeding and evaluation programs for cultivars and make recommendations based on disease resistance, pest resistance, and yielding ability under the range of climate and soil type situations in their industries (see Chapter 2.4).
Diseases can have a major impact on yield and an effective means of preventing disease is to plant disease free seedcane. Some industries (e.g. Swaziland) manage a seedcane scheme to provide a source of disease free seed of the registered cultivars to all its growers. Some milling companies also provide seed for their growers and in so doing ensure the planting of the most suitable cultivars (see Chapter 8).

The planting furrow

The ideal depth of planting appears to be about 100 mm where soil temperature remains warm and allows for quick germination and emergence. Under hot conditions and in sandy soils it may be warranted to plant slightly deeper. A deep ridge and furrow leaves an uneven soil surface which is not ideal for herbicide application. With hand planting under rainfed conditions better germination is obtained if the time between opening the furrow and covering the planted seed is minimized to take advantage of soil moisture. Fertilizer placed in the furrow should be covered lightly before placing setts in the furrow, to prevent direct contact with the buds.

Seedcane preparation

Seedcane consists of stalks harvested from a nursery, and usually they would be cut at a younger than normal harvest age to ensure that the buds and stalks are all young and healthy. Buds below the top do not germinate unless the top of the stalk is removed or the stalk is chopped into sections. This is due to an effect of growth inhibiting auxins produced in the top of the stalk. With hand planting, stalks are generally placed whole into the planting furrow and then chopped manually into sections of about 400 mm, or the stalks have the trash removed and are then chopped into setts and dipped in a fungicide where necessary. For autumn or winter planting where germination may be slow, it is advisable to dip setts in a fungicide to prevent pineapple disease. It is important also to ensure that knives are dipped regularly in a disinfectant when chopping stalks, since RSD could be transmitted.

A seedcane rate of at least 8 t/ha should be used to provide a good stand. This usually results in an overlap of 30-50 %. It does not pay to skimp on seedcane (see Chapter 8).

Row spacing (and planting configuration)

To obtain maximum benefit from radiation a full canopy is required and hence any practice which increases the rate to 100 % canopy will be of benefit. Experiments in South Africa have shown that where moisture stress is not too severe, sugarcane yield increases as distance between the rows decreases within certain limits (Boyce 1968). There was a 3 % increase in yield for every 300 mm decrease in row spacing from 2.0 m to 600 mm. In practice a row spacing of 1 m is as close as most field equipment will conveniently allow. Much of the world’s sugarcane has been planted at 1.5 m spacing.

For practical reasons, a standard spacing should be used on all fields on the farm, and there are costs associated with narrower spacings. More seedcane is required, planting takes longer and many farm operations, notably irrigation, take longer and are thus more expensive. A number of factors affect the choice of row spacing and narrower row spacings are an advantage where growth is slow in cooler areas and where cane is grown on slopes or erodible soils.

Tramline row spacing has a number of advantages which may suit mechanized industries. The main benefit is that infield equipment is able to straddle the dual rows and thus prevent damage to the
rows themselves and minimize soil compaction. Mechanical harvesters are able to cut two rows per pass, and trailers for chopper harvesters are also able to avoid running on the cane rows.

Dual rows are used in Australia in their ‘New Farming System’ where legume crops are grown in the fallow. In this system controlled traffic is used in combination with a 1.85 m dual row, minimum tillage, legume breaks and a green cane trash blanket system. A wider row spacing of 1.85 m is required to alleviate the problems of compaction and stool damage caused by infield machinery on the standard 1.5 m rows spacing. Reservations were expressed about the possible loss in yield due to wider row spacing and a number of experiments were established by Garside and Bell (2009a,b) and Garside et al. (2009). It should be noted that the dual rows tend to grow into one wide row after two or more rations.

![Figure 3.4. Tramline planting on a large sugar estate in Mpumalanga, South Africa.](image)

The envisaged disadvantages to wider row spacings were not found to exist under good soil health conditions (fumigation), and further experiments demonstrated the ability of sugarcane to compensate for the lower stalk populations in wider spacings with heavier stalk weights. Although cultivars did differ in their response to wider row spacings, satisfactory yields could be obtained at wider row spacings by choice of the correct cultivar (Garside and Bell 2009b). Other reported benefits of this integrated system of crop establishment are savings in nitrogen fertilizer from using the legume breaks, even into the first and sometimes the second ratoon, better weed control and a marked improvement in soil health in terms of improved organic matter content and soil microbe diversity.
Box 3.10 Examples of the benefits obtained at Loeskow Farm with the new ‘Integrated Farming System’ at Bundaberg, Queensland, Australia (Garside, 2011, personal communication)

- Total farm size is 1 500 ha.
- 943 ha under cane and 134 ha under peanuts.
- Very poor sandy Arenosol soil.
- Has been farming new system since mid-1990s.
- Average cane yield has increased from 53 to 96 tc/ha.

In Argentina, yield responses and major cost savings between cycles from adopting these integrated farming systems were verified in trials conducted on an estate (J Meyer, Durban 2011, personal communication). The advantage is that only the interrows need to be maintained and that at the time of replanting, only the row area (zonal tillage) needs to be cultivated instead of the whole field. Other reported benefits include N savings in fertilizer use, much better weed control with the trash blanket and minimum tillage, and that many of the sett diseases appear to be better controlled following a legume break. In Swaziland some estates are using GPS tracks for the laying of drip irrigation lines in a dual row planting system. This allows land preparation equipment to avoid damage to the drip lines when eradicating the crop and creating a tilth for the next planting. On estates where standard row widths are still being maintained there is increasing use of GPS controlled steering of infield tractors, mechanized planters and harvesters to minimize stool damage.

Depth of covering

A depth of between 30 and 50 mm is sufficient, as long as this is uniform. Deep covering delays germination. Light consolidation of the soil over the row improves soil sett contact but too heavy a compaction, particularly in wet soils, is not conducive to good germination. Fine sandy loam soils are particularly sensitive to compaction.

Hand and Mechanical Planting

The basic planting requirements of placing cane stalks at the correct depth, at the correct density and overlap as well as ensuring adequate covering and suitable compaction can all be provided by mechanical or hand operations. The choice of system would depend on a number of factors including labor availability and slope as well as the need for dipping seed cane. Numerous studies have been conducted on seed cane preparation to assess the benefits of removing trash, chopping stalks into different lengths, depth of placement and rate of seed cane and in general most requirements can be satisfied by either mechanical planters (possibly with some adaptations) or hand labor. Small farms size lends itself to hand planting but labor shortages are resulting in the use of small mechanical planters even here.
Productivity of manual versus mechanized planting

At TSB in Mpumalanga, an average of 57 labor units and six tractor trailers are used to plant 8 ha/day when establishing tramline planting. With 1.5 m single row spacing, 10 ha can be established with the same resources. This is compared with an average productivity of 160 ha/day with a dual row mechanical planter that is used at San Martinho Estate in Brazil.

Some relatively new systems of planting

Techniques of rapid propagation are being developed for multiplication of new cultivars or to obtain disease free planting material.

Seedlings

Various industries have developed and tested methods of establishing cane from single eyed setts or stalk chips which include a bud, planting these into seedling trays usually in a medium enriched with appropriate fertilizers and then allowing these to become established plantlets. Trays of seedlings are then transported to the field for planting. A planting hole is formed and seedlings inserted singly. Row spacings of 0.5 m and 0.75 m were found to be acceptable and yield comparisons showed seedlings to be similar to conventional planting for autumn/winter planting, but inferior for spring planting in the plant crop at one site. Ratoon yields were similar but cultivar differences were evident. Seedlings have become an established method of nursery propagation in South Africa, but because of the cost involved have not become standard practice for commercial planting. Seedlings have been found to be more sensitive to some herbicide combinations, and the timing of herbicide application as well as the treatment of seedlings has been adjusted to accommodate this. Cutting seedlings back at the time of planting and applying herbicides soon after planting have been found to be acceptable (McIntyre 1993).

The use of single eyed setts for direct planting is also under investigation. This system incorporates the use of mechanical planters adapted for the application of fungicides and insecticides where required, and this has the advantage of a substantial reduction in the amounts of chemicals required.
for disease and pest control as they are applied to the sett and not the soil. Micropropagation techniques whereby certified disease free sugarcane plants are multiplied in vitro, hardened off, field planted and then propagated vegetatively are now being developed in various countries (Snyman et al. 2008). Micropropagation of one apical leaf roll can yield up to 700 plants compared to 10 plants/stalk using the normal seedling route.

Choice of planting system

The choice of planting system is dependent on soil type, slope, region and a number of other factors. An example of a planting system choice matrix is provided in appendix 3.

3.2.5 Ratoon management

Harvesting and transport are covered in Chapters 10 and 11, and for the standard management requirements of disease control, pest control, weed control and nutrition in ratoons, see Chapters 8, 9, 4 and 5. However, these topics may be referred to in discussing husbandry practices which include management of cane residues, management of stool populations and damage, interrow cultivation, irrigation channel reforming, hilling up, and ripping in ratoons. Generally, the choice of practices is made in the original LUP and is based on soil type, slope, season, rainfall or irrigation. The environmental conservation objectives of minimizing soil erosion, minimizing water loss and minimizing loss of applied chemicals should be a main driver for the selection of husbandry practices.

Management of cane residues (trash)

Green cane trash blanketing
The practice of burning sugarcane before harvesting has been favored in a number of sugarcane industries and the main reason is considered to be the ease of manually and mechanically harvesting burnt cane and associated lower costs and higher harvesting productivity, as well as the reduction in extraneous matter sent to the mills. This is despite the many advantages accorded to green cane harvesting and the retention of a trash blanket (tops and leaves). Under dryland conditions the main advantages have been reported by Thompson (1965) as moisture retention, weed control and increased nitrogen availability from trash. A number of other advantages have been recorded, as reported by van Antwerpen et al. (2008) and include increased soil organic matter, increased soil microbial activity, improved soil chemical and physical properties, and improved soil structure, as well as possibly the most important environmental benefit of less soil erosion.

Opposition to the practice of burning has also been expressed by various affected groups in residential and tourist areas adjacent to cane fields, reacting to particulates fallout after burning, and by the general public and environmental groups opposed to the air pollution caused by cane burning and more recently due to the greenhouse gas contribution of burning.

Average yield benefits to trashing of 9 tc/ha/an have been reported by Thompson (1965) when compared with burning and removal or re-burning of cane residue. van Antwerpen et al. (2008) and Moberly and McIntyre (1983) summarized yield responses from a series of burning versus trashing trials and showed that there were circumstances where negative responses were evident and that this needed to be taken into account in considering the merits of burning or trashing. Moberly and McIntyre (1983) further reported that burnt cane fields with the tops and leaves left scattered provided 60% of the benefit of a full trash blanket in terms of yields. Reporting on an experiment started in 1939 (the longest running sugarcane experiment in the world), van Antwerpen et al.
(2008) indicated that responses were largely associated with dry conditions in the early part of the growth of the crop. He summarized yield benefits to trash as followings.

**Yield responses to trash**

Average responses to trash (T) vs. burning (B) with tops removed (Bto) for all spring and summer harvested crops (starting in September) were 13% : 10% : 1% in dry, average and wet seasons respectively, and for T vs. burnt with tops left scattered (Bt) these figures were 6% : 5% : -1%.

For crops harvested in winter the responses to T vs. Bto were 4% and -15% for average and wet years, while the responses to T vs. Bt were -1% and -13% for average and wet years respectively.

There are clearly situations where a full trash blanket may be a disadvantage; it is often associated with greater than average rainfall during the pre-canopy period of crop growth. Thompson (1965) also reports on negative or no responses to a trash blanket in terms of yield from trials in Puerto Rico and Australia. Trash blankets are expected to create a problem with furrow irrigation but in at least one instance movement of the water along a furrow has been shown to be possible as it lifts the trash pieces and runs below them.

It is also apparent that burning and leaving the tops scattered provides a yield response which is less than that of a full trash blanket in dry conditions but better than a full trash blanket in wet conditions.

**Decision whether to burn or trash at harvest**

Under conditions of full irrigation in dry climatic zones, burning can outyield trashing (Gosnell and Lonsdale 1977). In Zimbabwe over a plant crop and six ratoons, at irrigation levels of 1 and 0.84 x Class ‘A’ pan, burning was superior to trashing in yield of cane and sugar/ha as well as in stalk count, smut count and most other parameters. At low levels of irrigation (0.68, 0.53 and especially 0.37 x pan) retaining the trash produced increased yield of cane and sugar/ha because of moisture conservation. Trashing resulted in thicker stalks and lower fiber % cane than did burning at all levels of irrigation.

A number of factors need to be taken into account in the decision to burn or trash at harvest and van Antwerpen et al. (2008) and Purchase et al. (2008) reported the development of a Decision Support System to evaluate the economics of trashing or burning. They included reference to the fact that a value could be placed on trash if removed and sent to the factory boiler station for use as fuel (see Chapter 13). There is also the possible payment for carbon via the clean development mechanism (CDM) which provided added incentives for trashing as opposed to burning.

**Public pressure to eliminate burning**

In spite of economic evaluations showing no benefit to trash in certain situations, it is likely that public pressure and a need to reduce greenhouse gases will result in moves to force industries to harvest cane green. Indeed, this is already the case in Brazil where burning will not be allowed after 2014 in fields harvested mechanically. The ramifications of this are that industries will have to find ways to mitigate the negative effects of trashing in these circumstances. If the trash blanket is a disadvantage it will need to be managed by parting the trash over the row or removing it partially or entirely from the field. Adjustments will be required to harvesting operations and managing the trash material, and in this way it is likely that the disadvantages can be overcome.

Burning with tops left scattered is clearly superior to burning with all residue removed. If residue was left lined and not re-burnt there is also likely to be a benefit compared to removing all residues.
Wynne and van Antwerpen (2004) concluded that more information was required in a number of areas including: (i) yield benefits of trashing under different circumstances, (ii) cane composition of different cultivars, (iii) rates of cane deterioration, (iv) influence of density on transport costs, (v) labor productivity under different trashing regimes and (vi) the costs associated with bottlenecks at sugar mills if trashing is widely adopted, (vii) the temperature effect in higher altitude areas, and (viii) the economics of trashed cane under irrigation. Subsequently van Antwerpen et al. (2008) conducted an exercise to test the sensitivity of the model by varying a selection of inputs such as the cane price, cost of fertilizers and herbicides and the number of labor units and their payment. All results could be explained using current knowledge with regard to trashing and cane growth, which leads to the conclusion that the model responds logically.

Use of a trash blanket in ratoons has a range of effects, as shown in Box 3.11.

**Box 3.11 Positive and negative aspects of a trash blanket**

**Positive effects**
- Trash provides an effective physical barrier to weed growth provided sufficient material is available (weed control cost reduced by 35 % (Nuñez and Spaans 2007; Fillols and Callow 2010).
- Trash conserves soil moisture and increases yields in summer and particularly dry seasons (savings of 90 mm evaporation/an) (Thompson 1965).
- Irrigation costs reduced by 10% (Nuñez and Spaans 2007; van Antwerpen et al. 2008).
- Trash may cause a change in the weed spectrum which may be positive or negative (Fillols and Callow 2010).
- Trash provides an effective soil erosion control mechanism and reduces droplet impact on the soil (Moberly and McIntyre 1983).
- Trash reduces the amount of herbicides required and associated costs of chemicals (Nuñez and Spaans 2007).
- Improves soil organic carbon (Eustace et al. 2009).
- Improves N in the cane residues from 0.55 to 0.85 % (Nuñez and Spaans 2007).
- Improves cane yields particularly under rainfed conditions in certain soils (Thompson 1965; van Antwerpen et al. 2008).
- Improves soil fertility and soil health (Graham et al. 1999).
- Improves soil biodiversity of microorganisms (Graham et al. 1999).
- No air pollution or other effects of burning.
- Stalk thickness increased and fiber % cane reduced by trashing under irrigated conditions (Gosnell and Lonsdale 1977).

**Negative effects**
- Trash may increase the incidence of certain pests (trash worm) (van Antwerpen et al. 2008).
- Trash may suppress cane emergence under cold conditions (van Antwerpen et al. 2008).
- Under conditions of full irrigation in hot climates trashing can reduce cane and sugar yields, stalk counts and other parameters (Gosnell and Lonsdale 1977).
- Furrow irrigation is difficult (but not impossible) under conditions of full trash (see 13.3.3).
- Trash may suppress cane emergence in wet conditions (van Antwerpen et al. 2008).
- Trash blankets may be a fire hazard.
- Increases harvesting costs for manually harvested cane and mechanical by 68 %) (Nuñez and Spaans 2007).
- General reluctance of cutters to harvest green cane.
- Increased extraneous matter usually results from trashing depending on the quality of trashing (Nuñez and Spaans 2007).
Box 3.12 Burnt cane with tops left scattered

Advantages
- Provides 60% of the yield benefit of a full trash blanket in summer and is superior to a trash blanket in the cold winter months (Moberly and McIntyre 1983).
- Field observations indicate that runoff is substantially reduced by any mulch, even when it is present in small quantities (Moberly and McIntyre 1983).

Disadvantages
- No reduction in weed control costs as would be obtained with a full trash blanket.
- Disadvantages associated with burning.

Box 3.13 Burnt cane with tops raked into windrows

Advantages
- Provides some soil erosion control and moisture conservation compared with re-burning of residues.
- Allows for a reduction in area to be treated for weed control.
- No trash worm likely.

Disadvantages
- Less effective than scattered tops for erosion control and water conservation.
- Yield disadvantage in dry climates.
- Some rows adjacent to the windrows may be disadvantaged as for a trash blanket.

Deep ripping in ratoons

Tejada (2010) showed benefits from subsoiling in terms of reducing compaction and increasing available moisture in an Alfisol in Colombia. Moberly (1969) reported on the effects of subsoiling in ratoon cane growing on 11 different soils in the South African sugar industry. The study was conducted because of the perception that subsoiling is beneficial because it shatters compacted soil layers, prunes the old root system, encourages the speedy development of new roots, results in improved rates of water infiltration, improves soil aeration, increases the effective rooting depth of the crop, and facilitates root penetration. Moberly reported that of the 11 soils tested three showed statistically significant reductions in yield, seven showed no difference and one showed a significant benefit. Deep tillage was compared with standard interrow cultivation. He concluded that, “Any benefits which may accrue from this practice such as soil aeration, the increase in effective rooting depth and the prevention of runoff, are seemingly nullified by the effects of root damage caused by the subsoiler tines.”

Deep ripping in ratoons was tested by Leibbrandt (1985) under irrigated conditions in Swaziland, and no benefits were recorded. A reason put forward for the lack of response was that the soils were generally of montmorillonitic clay and any compaction was alleviated by irrigation. Swinford and Boevey (1984) recorded yield responses from ripping in a Longlands form soil which had been intentionally severely compacted. van Antwerpen et al. (2000) observed that yields could be reduced by 50% from stool damage caused by cane haulage; machinery use infield was likely to increase; that harvesting in wet weather would sometimes be unavoidable and that an option was to use controlled traffic. Attempt should be made to use equipment that allows fewer passes, and that organic material, e.g. filter cake (especially with a low bulk density and in reasonable amounts, e.g. 15 t/ha) should be applied. Tire design and pressure were also mentioned.
Box 3.14 Recommendations and conclusions on deep ripping (from van Antwerpen et al. 2000)

1. Damage to sugarcane stools and soil compaction are two separate issues, but they can occur simultaneously, especially with wet soil.
2. Stool damage caused by cane haulage equipment can reduce yields by as much as 50% and reduce the number of ratoons before plough out.

In order to make provision for this growers should consider:

- Increasing the row spacing to suit the track width of infield equipment.
- Using pre-planned permanent zones for infield traffic. The principles of controlled zones for traffic and the use of infield tracks should be combined to restrict the area affected by compaction and to keep compacted zones in selected interrows.
- Not allowing transport into fields when soils are wet. Using transport with long tire and track footprints in the direction of travel rather than those with the same contact area but that are wider and shorter. Transport travelling in the interrow but next to the row is bound to cause surface root damage and compaction close to the stool, which will almost certainly have a negative effect on yield. A distance of 0.75 m between edge of the row and the wheel, as reported in the literature, will certainly be effective in avoiding stool damage and will reduce the effect of soil compaction on yield, but is unlikely to be accepted by growers as a practical measure.
- A more acceptable distance between the edge of the row and the side of the wheel would be 0.40 m, assuming that the width of the tire is 0.6 m.
- When labor is plentiful, cane can be carried out to the nearest hard surfaced road.
- This means that total interrow spacing from the centre of one row to the centre of the next row should be 1.8 m (or wider). However, this will not suit all farming systems and growers should decide on a row spacing that will best suit their infield transport. Alleviation of soil compaction with a subsoiler is a popular technique with growers although the results from trials conducted in South Africa and Swaziland have shown no yield benefit from this practice.
- Only soils with an E-horizon in the grey soil group have shown a positive yield response to subsoiling, although limited.
- It appears that the likelihood of a positive response to subsoiling is low in soils with a high clay content. An alternative to subsoiling is to harvest cane on soils most susceptible to compaction during the dry months. The observation that subsoiling with a vertical mulcher is more efficient in alleviating compaction compared with a single tine ripper has been confirmed.
- Where soil compaction is a major problem and there is a choice of organic materials available, the principle to be applied is the use of organic materials of lowest density, as these will be more effective in reducing soil density.
- Where there is little choice of material, any type of organic material in reasonable quantities will be better than none because of the general decline of soil organic matter in cultivated soils.
3.2.6 Summary of factors for consideration in achieving good management practices for ratoon cane

Box 3.15 Factors for consideration in choice of ratoon cane practices.

1. Trash or burn at harvest.
Choice depends on:
- Soil type: erodibility, moisture holding capacity, slope.
- Season: temperature and moisture, growing conditions after harvest.
- Altitude: due to temperature.
- Mill products: energy production, extraneous matter value.
- Irrigation or no irrigation.
- Proximity of housing, tourism areas.

2. Tops management after burning: Options: scattered, windrowed, reburnt.
Choice depends on:
- Soil type: erodibility, moisture holding capacity, slope
- Season: temperature and moisture, growing conditions after harvest
- Altitude: due to temperature
- Mill products: energy production, extraneous matter
- Irrigation or no irrigation

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4. WEED CONTROL

4.1 Background

Weed control is a necessity in sugarcane production if adequate yields are to be obtained, as yield reductions as high as 50% can be experienced without weed control in plant cane (Pearson 1961a). Although control measures such as hand hoeing and mechanical cultivation were widely practiced in the past, with the discovery of chemicals that could selectively control some plants and not others, the use of herbicides for weed control increased quickly and has become a major component of most weed control programs in sugarcane. However, movement of chemicals from the site of application by leaching to underground water tables, or by surface runoff to enter water bodies and streams has raised concerns about their negative environmental impact. Inorganic fertilizers, herbicides, insecticides and fungicides form substantial amounts of chemicals which are added to sugarcane fields each year. Simpson et al. (2000) reported the application of 1 048 000 kg active ingredient on 492 000 ha per annum in Queensland and New South Wales, Australia. Despite this being a small amount of material compared with fertilizers, which are often applied in excess of 300 kg/ha/y, the nature of herbicides renders them harmful to plants at very low concentrations. In terms of possible negative environmental impacts as well as health hazards for labor and the general public, chemical weed control is a critical aspect of production and every effort is required to minimize any off-site impacts.

4.2 The need for weed control in sugarcane

Weeds compete with sugarcane for water, light and nutrients and weed control is required from planting or harvesting until full canopy formation, after which the shading effect of the canopy generally prevents further weed growth (Pearson 1961a). Box 4.1 outlines the effects of correct timing of weed control on profitability.

**Box 4.1 The effects of timing of weeding operations on the yield of sugarcane**

- “Effective weeding and cultivation can give increments of the order of 50-75 tonnes cane per ha over the yields of an unweeded crop."
- There is a minimal control of weeds from scuffling the inter-row only, which will give yields capable of returning a profit from weeding of 22 to 35 tonnes per ha higher than unweeded yields, but 25-50 tonnes lower than that obtained from husbandry.
- There is an optimum control of weeds using small amounts of labor which, if timed correctly, can give the greatest profits. This involves an early hand weeding in the line, and the timing of this hand weeding is broadly from 30 to 40 days after planting, but is dependent on the stage of growth of the crop rather than the time from planting.
- There is a stage in the utilization of labor for the removal of weeds when it becomes unprofitable to remove weeds every 7-14 and 21 days which has no advantage over removing them every 28 days. At the 28 day removal stage a profit is shown for weeding.
- There is a stage of growth of cane at which weeds must be removed. This would of necessity be at a point of development in the young cane plant which is not necessarily measureable by the period from planting in days”.

Pearson (1961b) demonstrated the effects of weeding once only at 20, 30, 40 or 50 days after planting by lifting planted stalk pieces (setts) and examining the shoot and root growth. He showed that weeding at 20 and 30 days allowed the development of a healthy root system and good stool development, but delaying the first weeding to 40 or 50 days had a substantial negative effect. He
concluded that, “the time weeds should be removed from a line of cane is when the lower leaves of the primary shoot start to bend over and wave about.”

NB Leibbrandt (Durban, 2011, personal communication) has shown that minimal weed control actions were required to avoid competition from weeds in ratoon cane harvested at a favorable time of year; however, short interval weeding or pre-emergence herbicide treatments were essential to prevent damaging competition to plant cane established in autumn and subject to a long period before full canopy. He concluded that for small scale growers who tended to carry out the first hand weeding when weeds were already too advanced for effective avoidance of competitive effects, the use of pre-emergence herbicides should be promoted.

As shown by Pearson and Leibbrandt, the timing of weed removal has a major influence on yield reduction. Plant cane takes longer to canopy than ratoon cane and is more sensitive to weed competition (Pearson 1961a,b). Yield reductions of 30-50% and greater from weed competition have also been reported by other authors and these have a substantial influence on the economics of cane growing (Ali et al. 1986; Naidu et al. 1996; Turner 1983).

Weed growth habits and characteristics have an influence on the degree of competition; fast growing and tall growing weeds as well as creeping perennial weeds compete severely with sugarcane. Weeds can also negatively affect cane production by hindering water movement in irrigation furrows, harboring insect pests and diseases and hindering mechanical operations.

4.3 Weeds of sugarcane

4.3.1 Weed groups

Weeds can be grouped into broadleaf (dicotyledons), grasses (monocotyledons), and sedges (also monocotyledons) and the grasses can be further subdivided into creeping or tufted plants. A further classification of all types can be based on whether they are annual or perennial weeds.

Annual weeds which germinate, grow, flower and die in one year are usually less of a problem than biennial or perennial weeds, which germinate and grow in one year and then flower and produce seed in subsequent years as well. This means that if the plants are not controlled in any one year they continue to grow and compete with sugarcane. These classifications are particularly important for choice of chemicals as each herbicide has a specific spectrum of weeds which will be controlled, and often this coincides with the broad classification into broadleaf, grasses or sedges.

Perennial weeds are generally more difficult to control and problem weeds are most often perennial plants. A number of perennial weeds reproduce vegetatively by extending roots above ground (stolons) or below ground (rhizomes) and producing new plants from nodes.

There is a range of creeping perennial grasses including *Cynodon dactylon*, *Cynodon nlemfuensis*, *Panicum repens*, *Digitaria abyssinica*, and others which are extremely difficult to control adequately and which compete severely with sugarcane. Some of these such as *Cynodon dactylon* are suppressed substantially by the cane canopy, but often they are a symptom of other growth problems and occur extensively where cane is unable to grow satisfactorily, such as on very weak sands. Breaking the root systems of these creeping perennial weeds with hoes or cultivators usually has the effect of stimulating overall growth unless conducted under very dry conditions where the roots can be brought to the surface and left to desiccate.
Sedges reproduce by the production of corms or tubers, and each tuber produces a new plant. The two most important sedges in sugarcane fields are *Cyperus esculentus* (yellow flowered watergrass) and *Cyperus rotundus* (purple flowered watergrass). *Cyperus esculentus* produces single tubers on the end of individual rootlets, while *Cyperus rotundus* produces a chain of tubers on the roots. Both species are able to produce large numbers of plants in a short period of time. Yellow flowered watergrass is far easier to control than purple flowered, being sensitive to a wider range of herbicides. It is thus important to be able to distinguish between the two and the differences are illustrated in Figure 1.

![Figure 4.1. Diagram of differences between *Cyperus esculentus* and *Cyperus rotundus*.](image)

Vines have become a serious problem in many industries and particularly where green cane harvesting is conducted and a trash blanket is left in the field. These plants, e.g. *Ipomoea* sp. have the ability to germinate and grow through a trash blanket and may appear well after normal pre-canopy weed control operations have been completed.

Certain other perennial grass weeds such as *Sorghum halepense* can cause major negative effects on sugarcane growing in specific industries (Ali et al. 1986). *Panicum maximum* is a widespread tufted grass which is very vigorous and competes severely with cane if allowed to grow. Stools not completely controlled one year re-grow the next.

4.3.2 Weeds associated with poor growth areas

The occurrence of some weeds in cane are indicators of conditions unsuitable for cane growth but suitable for the weed. An example is *Paspalum urvillei*, which favors wet areas. In these cases it is preferable to correct the drainage problem, as effort on weed control can be wasted if the cane will not grow anyway.

4.3.3 Some problem species

Some perennial rhizomatous broadleaf plants may also cause a problem in sugarcane, such as *Physalis viscosa* (sticky gooseberry). Specific control measures are usually warranted as these plants most often occur in small patches within a field and whole field treatment could be a waste. A few species of parasitic plants can cause severe damage to cane of susceptible cultivars and under certain nutrient conditions (low nitrogen). *Striga asiatica*, *Striga hermonthica*, *Striga gesnerioides*, *Striga lutea* and *Striga euphrasioides* are examples. Examples of weed groups and species are provided in Box 4.2.
Box 4.2 Example of the weed groups and species encountered in sugarcane fields. Information from Weeds of the South African Sugar Industry (Leibbrandt 2001).

<table>
<thead>
<tr>
<th>Weed category</th>
<th>Annual</th>
<th>Perennial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadleaf (dicotyledons)</td>
<td>Bidens pilosa</td>
<td>Physalis viscosa</td>
</tr>
<tr>
<td></td>
<td>Amaranthus spp</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Portulaca oleracea</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ageratum conyzoides</td>
<td></td>
</tr>
<tr>
<td>Broadleaf creepers and vines</td>
<td>Ipomoea purpurea</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anredera bassellloides</td>
<td></td>
</tr>
<tr>
<td>Grasses (monocotyledons)</td>
<td>Tufted</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Panicium schinzii</td>
<td>Paspalum urvillei</td>
</tr>
<tr>
<td></td>
<td>Digitaria sanguinalis</td>
<td>Paspalum dilatatum</td>
</tr>
<tr>
<td></td>
<td>Digitaria nuda</td>
<td>Rottboellia cochinchinensis</td>
</tr>
<tr>
<td></td>
<td>Eleusine coracana</td>
<td>Panicum maximum</td>
</tr>
<tr>
<td></td>
<td>Brachiaria eruciformis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urochloa panicoides</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sorhum bicolor</td>
<td></td>
</tr>
<tr>
<td>Creeping</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digitaria abyssinica</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cynodon dactylon (star grass)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cynodon nlemfuensis (giant star grass)</td>
<td></td>
</tr>
<tr>
<td>Sedges (monocotyledons)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyperus rotundus (purple nutsedge)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cyperus esculentus (yellow nutsedge)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.2. A mixture of weeds in plant cane. Figure 4.3. Sedge, grass and broadleaf weeds

Figure 4.4. Ratoon cane where competition potential is usually less than in plant cane.
Patterns of weed germination and seasons of growth can affect the degree of damage in sugarcane. Spring germinating weeds, when soil and weather conditions are favorable for cane and weed growth, may be very well controlled by effective treatments at that time of the year. Weed identification is important for the selection of appropriate herbicide treatments and, ideally, records should be kept of the weed spectrum in each field. In order to ensure correct timing of treatments weeds also need to be identified at a very young growth stage.

4.4 Non-chemical weed control methods

4.4.1 Physical

Promote quick canopy formation
Weeds compete with cane for water, light and nutrients, and experiments on timing of weeding operations have shown that controlling the weeds in the period prior to canopy formation is critical to limit yield reductions from weed competition (Almond and King 1955; Pearson 1961a,b). Once canopy is formed germination of most weed species is inhibited. Thus any practice which improves the rate of canopy formation will help with weed control. In plant cane typical practices are shown in Box 4.3.

Box 4.3 Practices to improve the rate to canopy formation

- Use of adequate quantities of good quality seedcane.
- Choice of correct cultivar for the soil conditions.
- Planting at the most suitable time of year.
- Choosing the most appropriate row spacing for the conditions.

Other practices include:
- Gapping-up in rations.
- Application of the correct fertilizer treatments and rates.
- Accurate irrigation and water applications.
- Good disease and pest control.

Trash blanket in ratoons
For ratoon crops a trash blanket provides a physical barrier to weed growth if cane is harvested without burning and the cane tops and leaves are left in the field. Núñez and Spaans (2007) reported cost reductions in weed control and irrigation of 35 and 10% respectively after green cane harvesting.

If the yield from trashed cane is low, it is unlikely the trash will be sufficient to cover the whole area adequately to prevent weed emergence. In this case a practice has been to concentrate the trash in some inter-rows and leave others bare and then to apply herbicides (or other treatments) to the bare inter-rows. A yield of 100 t/ha was considered to provide sufficient trash to avoid the need for raking (Thompson 1965).

A trash blanket may cause a change in weed spectrum, with broadleaf weeds and grasses being reduced and vines increased. These are able to germinate from depth and are able to penetrate the trash blanket (Fillols and Callow 2010).

Recent studies have shown that pre-emergence herbicides are equally efficient when applied to bare soil or to a trash blanket, and that 6 t/ha of trash was sufficient to provide significant weed control. The weed spectrum was found to vary depending on the amount of trash (Fillols and Callow 2010).

Application of pre-emergence herbicides has been tested in a system where application is made during the mechanical harvesting operation and the trash is then immediately placed over the treated soil.

Green cane trash blankets, while suppressing warm and cool season weeds by 62%, still resulted in a reduction in cane yield if left over the cane row through the winter months in Louisiana (Richard 1999).

Precision application equipment is being tested, where sensors mounted on the sprayer detect weed patches in trashed ratoons and trigger applications on to the weed patches only (personal observation, Brazil, 2010).

Financial, social and environmental effects of trash blankets in respect of weed control practices are such that labor requirements may be increased or decreased, and costs may need careful evaluation, but the major impact would be a decrease in herbicide spraying, thus providing cost savings and reducing dangers to the applicators and the environment. Moisture retention, the reduction in greenhouse gas production and the reduction in particulates pollution in the air associated with green cane harvesting and the retention of a trash blanket are also relevant, and are discussed in Chapter 3.
Scattered tops left on the soil surface after harvesting burnt cane also provide a measure of physical weed control and, if the remaining cane material is raked into windrows, this may reduce the area which requires weed control measures (Moberly and McIntyre 1983).

4.4.2 Hand weeding and hand hoeing

Pulling weeds out by hand or hoeing is labor intensive if used as the main weed control method (and provides significant numbers of unskilled jobs in season) but highly effective for follow-up selective removal of weeds which have escaped herbicide treatment or were not within the spectrum of control of the chemical used. Box 4.4 shows advantages and disadvantages of hand weeding or hoeing.

Box 4.4 Other advantages of hand weeding or hoeing

- This practice prevents seeding of the weeds.
- Hand weeding or hoeing forms an important part of most integrated weed control programs.
- Allows for weeds in the cane row to be identified and removed.
- Useful where intercropping prevents the use of herbicides phytotoxic to the intercrop.
- All weeds can be removed and there is no build-up of herbicide resistant species.
- Hand weeding may also be the only feasible method of taking out grasses which are able to germinate and grow in the cane row even after canopy. *Rottboellia cochinchinensis, Sorghum bicolor* and *Panicum maximum* are weeds which are regularly hand weeded.

Disadvantages of hoeing are:

- Hoeing can be ineffective if conducted in wet conditions, as plants may simply be transplanted.
- Hoeing is ineffective on certain species – e.g. *Cyperus rotundus*, where breaking of the chains of tubers stimulates further growth.
- Hoeing in young cane has the risk of damage to the cane plants.

One efficient hand weeding operation in the cane row with subsequent weeding on the inter-row only has shown cost effective results (Pearson 1961a). However, as reported earlier, there is evidence to show that in practice yields can be significantly reduced where hand hoeing is the only
form of weed control when compared to chemicals and integrated systems, and this is due to the hand weeding operation being late and inefficient.

4.4.3 Mechanical cultivation

Mechanical cultivation involves soil disturbance with an implement, usually tines or blades, and efficiency and effort are dependent on weed growth stage and type.

Inter-row cultivation, whether using tractor drawn or animal drawn cultivators, is useful and effective if carried out regularly and on small weeds in suitable soils.

Care is needed to ensure no damage to the cane rows – row spacing needs to be accurate and consistent.

Generally only weeds in the inter-row are controlled unless specialized finger weeder are used.

Cultivation reduces or removes the need for herbicides, but does disturb the soil repeatedly thus subjecting it to increased risk of erosion, particularly on steep slopes. There is a high cost of energy for tractor drawn cultivation.

Soil conditions at the time of the cultivation operation also have an impact on the effectiveness of weed control.

Creeping grasses tend to be spread by cultivators both within a field and to other fields.

4.5 Chemical weed control

4.5.1 Broad categories of herbicides and their use

(Chemicals which are able to control weeds are termed herbicides)

Selectivity (non selective and selective)

This characteristic of herbicides is one of the greatest advantages compared with non-chemical methods of weed control. The other major advantage is the residual effect in the soil enabling long term control from a single application (discussed later in this section).

Selective herbicides

These are herbicides that affect certain plants and not others, e.g. they may affect the weeds and not the crop, or they may affect a group of weeds such as broadleaf and not grasses or sedges. Herbicides may also differ in their selectivity depending on rate or method of application. Newly discovered chemicals were screened for their effects on a range of species, and not only were they found to show selectivity between species, but also between rates of application and growth stages. This meant that chemicals could be used at specific rates to control a spectrum of weeds and yet remain safe to the crop.

Non-selective herbicides

These are herbicides which affect all plants including crops, e.g. glyphosate or paraquat.

Residual effects of herbicides (long or short residual effects)

An important advantage of the use of herbicides over mechanical or hand weeding is that herbicides may remain active in the soil for a considerable period of time. Effective weed control for as long as 12 to 14 weeks can be achieved by a number of herbicide treatments. This means that the number
of operations and amount of resources can be reduced substantially. However, associated with the residual properties of herbicides is the increased risk to the environment through movement of herbicides attached to soil particles or dissolved in surface water runoff or drainage (discussed later in this chapter and in Chapter 12, Agrochemicals and Farm Safety). Treatments are commonly divided into long term (e.g. 12 weeks) and short term (e.g. 4 weeks) for weed control planning purposes, but in both cases they are likely to provide weed control for longer than mechanical or hand weeding.

**Mode of action (contact or translocated/systemic)**

**Contact herbicides:** These affect the plant directly on contact and need to be applied to the foliage of emerged plants. They usually act quickly and require a relatively short period without rain or irrigation to take effect. A widely used example is paraquat but this has been phased out in some countries. (see Box 12.5)

**Translocated or systemic herbicides:** These herbicides are taken into the plant and move within it to the site of action. They can be taken up by roots or by foliage. These herbicides may affect processes such as photosynthesis, or act as artificial auxins or plant growth regulators or affect other processes in the plant.

**Point of uptake (germinating seeds, tubers, roots, foliage)**

**Germinating seeds:** Herbicides may be taken up by the developing cotyledon (emerging shoot from a germinating seed) and prevent the emergence of the weed above ground. These herbicides would need to be applied to the soil before seeds begin to germinate (e.g. acetochlor). They usually require some moisture after application or a moist soil, which facilitates the movement of the herbicide into the soil to the depth of the germinating seeds (10-15 mm within 7-10 days is often recommended), e.g. acetochlor.

**Germinating tubers:** The sedges produce tubers either singly on a rootlet (*Cyperus esculentus*) or in chains (*Cyperus rotundus*) and some herbicides are effective if taken into the soil by moisture or incorporated mechanically and mixed with the soil before the tubers begin to sprout, e.g. EPTC.

**Roots:** Some herbicides are taken up by the roots of plants and are usually more effective on small plants. They are effective whether applied before or after germination, and even after emergence of the weeds above the soil surface, provided the root system is not too developed. These herbicides need to be taken into the soil and therefore act best if the soil is moist at the time of application or if rainfall or irrigation occurs soon after application. Active growth of the weed is also beneficial as this increases the uptake of the herbicide into the roots. Examples of herbicides absorbed mainly through roots are atrazine and diuron.

**Foliage:** Many herbicides are taken up through the foliage and act either directly on contact with the leaf tissue or are translocated to another site of action. Generally these herbicides are more effective on small plants and once growth reaches a certain stage control may not be easy. Weather conditions are also important, in that systemic herbicides may require some time to be absorbed into the leaf and rainfall may wash the herbicide off the foliage if it occurs too soon after application. These are still most effective when the plants are young, e.g. ametryne and ioxynil + bromoxynil are absorbed mainly through foliage. MSMA is an example which is able to control relatively larger plants of certain species, but requires sunny conditions for effective activity.

**Roots and foliage:** There are a number of herbicides which are absorbed through both foliage and roots, but usually one of these pathways is dominant, e.g. hexazinone and metribuzin.
4.5.2 Chemical groups of herbicides
(adapted from and with acknowledgement to Bromilow 1995)

There are a number of chemical groups and the following are some which include important sugarcane herbicides.

**Acetanilides**
These herbicides act by inhibiting protein synthesis and disturbing cell division. They also affect the cell membranes. They are most effective in preventing seed germination particularly of grasses, but also have some effect on roots. A limited range of broadleaf weeds is also controlled and under ideal conditions sedges may be controlled to some extent.

<table>
<thead>
<tr>
<th>Acetanilides</th>
<th>alachlor, acetochlor, metolachlor, metazachlor</th>
</tr>
</thead>
</table>

**Bypyridilium compounds**
This is a small but very widely used group of herbicides typified by the chemical paraquat. They are non-selective, post-emergence and contact herbicides. They are rapidly absorbed by green tissue and only partially translocated. On contact with the soil they are immediately deactivated by being absorbed onto clay particles.

<table>
<thead>
<tr>
<th>Bypyridilium compounds</th>
<th>paraquat*, diquat *Note that paraquat is being phased out in some countries (see Box 12.5)</th>
</tr>
</thead>
</table>

**Dinitroanilines**
These are somewhat less volatile than the thiocarbamates (see below). Nevertheless, some do require incorporation into the soil and have long residual action. These herbicides are mainly grass killers.

<table>
<thead>
<tr>
<th>Dinitroanilines</th>
<th>pendimethalin</th>
</tr>
</thead>
</table>

**Organoarsenic**
One chemical from this group (monosodium methane arsenate, MSMA) is used fairly extensively in some sugar industries and acts as a defoliant on relatively difficult to control weeds. Warm, sunny conditions are required for effective activity.

<table>
<thead>
<tr>
<th>Organoarsenic</th>
<th>MSMA</th>
</tr>
</thead>
</table>

**Phenoxy compounds**
These herbicides act as artificial auxins or plant growth regulators by causing uncontrolled cell division and abnormal growth. They are commonly referred to as the ‘hormone herbicides’ and are mainly effective on broadleaf weeds.

<table>
<thead>
<tr>
<th>Phenoxy compounds</th>
<th>2,4-D amine, MCPA</th>
</tr>
</thead>
</table>

**Phosphorous herbicides**
These herbicides are active when applied post-emergence of weeds. They are non-selective and systemic, and act by inhibiting the formation of amino acids. On contact with the soil these products lose their herbicidal qualities and are broken down by soil microorganisms into carbon dioxide, nitrogen, water and phosphate.
Sulphonyl ureas
These are highly active at very low dosage rates, often being effective at rates as low as 10 g per hectare. Although the first discovered sulphonyl ureas were mainly post-emergence broadleaf weed killers, this group now contains products with a wide range of herbicidal action.

| Sulphonyl ureas | halosulfuron, chlorimuron-ethyl |

Thiocarbamates
The herbicides in this group are volatile and need to be incorporated into the soil to prevent loss by volatilization. They are selective and control mainly sedges and grasses, and also have a relatively long residual action. They are absorbed by the growing coleoptiles and although they do not prevent seed germination they prevent emergence of the weed. EPTC has been used successfully for control of *Cyperus rotundus* in plant cane in a program where the chains of tubers are broken up and the product incorporated into the soil in the same operation using a rotary hoe.

| Thiocarbamates | EPTC |

Triazines and ureas
These herbicides inhibit photosynthesis and are taken up by the developing roots of young plants. They are effective applied before or soon after weed emergence provided conditions favour their movement into the soil. Weeds may emerge from the soil but die back later as the roots absorb the herbicide. They are usually more effective on broadleaf weeds but also control some grasses under favourable conditions.

| Triazines | atrazine, cyanazine, ametryn, metribuzin, hexazinone |
| Ureas | diuron, tebuthiuron (urea carbamate) |

Uracil compounds
One herbicide in this group bromacil (Hyvar X) was widely used for industrial applications and in citrus, which was tolerant. When citrus orchards were converted to cane, serious damage occurred on cane, as bromacil is very long lived and adversely affects sugarcane.

| Uracil compounds | bromacil |

Other herbicides
Some chemicals do not fit into the existing chemical groups, e.g. isoxaflutole.

4.5.3 Timing of herbicide application (pre or post-emergence)
(including reference to site of absorption and mode of action)

Pre-emergence (of weeds)
Herbicides are applied to bare soil before any weed emergence. These may be taken up by the developing cotyledon (first shoot) of a germinating seed or by the roots of germinating seeds whose first shoot has not emerged through the soil surface.
Box 4.5 Requirements for effective action/factors affecting soil applied herbicides

- These herbicides generally require moisture after application to take them into the soil before weed seeds begin to germinate (10-15 mm within 7-10 days is often recommended) (SASRI 2010).
- An even soil surface without clods or obstructions.
- Some specific chemicals require incorporation into the soil and may also require existing weeds, even growing below the surface, to be chopped up just prior to application to ensure a pre-emergence condition (e.g. EPTC for control of *Cyperus rotundus*).
- Organic matter in the soil – herbicides may be adsorbed on to organic matter and be unavailable for plant uptake.
- Clay content of the soil – as with organic matter, some herbicides become less available for uptake at higher clay contents and higher rates may be recommended.
- Soil pH can affect the rate of breakdown and hence residual effects of a herbicide in the soil.

![Figure 4.7. Pre-emergence weed control in plant cane.](image)

**Post-emergence (of weeds)**

Herbicides are applied to existing (emerged) weeds. These:

- affect the foliage directly (**contact** chemicals, e.g. paraquat),
- enter the plant through leaves or stems and move to another site of action (**systemic** or **translocated** chemicals, e.g. glyphosate, or
- enter the plant through the roots of emerged plants and move to another site of action (**systemic** or **translocated – root absorbed** chemicals).
Box 4.6 Requirements for effective action/factors affecting foliar applied herbicides

- No rain during or soon after application to prevent chemical from washing off the foliage (this applies to foliar absorbed chemicals. Often chemical labels have stipulated periods of no rain after application e.g. glyphosate: no rain for 6-8 h after application) (SASRI 2010).
- Wetters, stickers or surfactants (surface active agents) which may be added to the spray solution to improve adherence of the chemicals to the foliage.
- No dust on the foliage.
- No excessive dew on the foliage which may accelerate runoff.
- Correct weed growth stage at application.
- Moisture in the soil during or after application for effective action from root absorbed products which are applied after emergence of the weeds.
- Water quality – when using herbicides that are de-activated on contact with soil, it is important to use clean water. Use of muddy water, e.g. from irrigation canals, nullifies the effectiveness of the herbicide.
- Actively growing plants take up systemic herbicides better than slow growing plants.

Figure 4.8. Post-emergence weed control.

Weed growth stage for post-emergence application
As mentioned in the introduction with respect to selectivity, chemicals may vary in their efficacy (effectiveness) depending on the stage of growth of the weed. Mature plants will require far higher rates or may not be controlled at all. In respect of sugarcane weeds and herbicides, the weeds generally need to be very small. Table 4.1 shows the ideal stages for the categories of pre-emergence, early post-emergence, post-emergence and late post-emergence application.
Table 4.1. Weed growth stages for effective weed control with herbicides (after SASRI 2010).

<table>
<thead>
<tr>
<th>Stage</th>
<th>Watergrass</th>
<th>Grasses</th>
<th>Broadleaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-emergence</td>
<td>No emergence</td>
<td>No emergence</td>
<td>No emergence</td>
</tr>
<tr>
<td>Early post-emergence</td>
<td>1 to 4 leaves</td>
<td>1 to 2 leaves</td>
<td>0 to 30 mm</td>
</tr>
<tr>
<td>Post-emergence</td>
<td>Pre to early flowering</td>
<td>2 to 4 leaves</td>
<td>&lt; 100 mm or pre-flowering</td>
</tr>
<tr>
<td>Late post-emergence</td>
<td>Flowered; most tubers have germinated</td>
<td>Tillered</td>
<td>&gt; 100 mm or post-flowering</td>
</tr>
</tbody>
</table>

For effective post-emergence control of sedges, sufficient foliage should be exposed to the spray and so a germinating population of sedges is best treated when most plants have developed sufficient green leaf tissue. However, once plants begin to flower they tend to produce more dormant tubers which will increase subsequent sedge populations. This means that sedges need to be controlled when most plants have emerged, but before flowering. A compromise recommendation uses a figure of approximately 20% flowering, so that most plants have emerged at the time of treatment.

**Herbicide combinations**

Some herbicides can be absorbed both through roots and foliage and hence could be applied pre or post-emergence (e.g. diuron, hexazinone, metribuzin). In field situations the weed spectrum is seldom limited to one type and one growth stage. As a result, there are benefits to the use of combinations of chemicals to cater for the weed spectrum and the range of growth stages (e.g. acetochlor + diuron + paraquat, where acetochlor is taken into the soil by moisture and controls germinating grass seeds pre-emergence, diuron is taken into the soil by moisture and acts on roots of germinating and emerged seedlings as well as having some foliar absorption on small emerged weeds, and paraquat acts through contact with weed foliage only and is inactivated on contact with the soil). Registration is required for each combination and is limited to a specific set of rates which have been shown to be efficacious, safe for the crop and acceptable in terms of government regulations concerning agrochemical use. Labels for the individual herbicides should stipulate the allowed mixing partners. Benefits to combinations may also be found where solubility of herbicides differs, the more soluble herbicide moving deeper in the soil than the less soluble herbicide (e.g. hexazinone + diuron, where hexazinone is more soluble than diuron).

**Effects on the crop**

Despite of the selectivity of herbicides in killing weeds and not sugarcane, many products do have some effect on cane, and registration is usually only granted after tests to consider the effects on cane. Herbicides are tested at both the recommended and double the recommended rate. Herbicides may cause foliar effects of chlorosis or necrosis when contact with the cane foliage is made, and this may lead to stunting of growth and even reductions in yield. Yield reductions from weed competition are so severe that some damage to cane and even yield reduction is tolerated from the application of herbicides in sugarcane. Average yield reductions from the standard post-emergence treatments may be as much as 3%. Applications directed between cane rows and at a younger stage of growth are usually less damaging than treatments applied over the cane rows and at later stages of growth. In contrast, no yield reductions were found on average from pre-emergence herbicide applications (Turner et al. 1990).
Successful effects from herbicides

Clearly a major factor in the success of many herbicides for weed control in sugarcane is application at a young growth stage. This may result in control of weeds before they would have caused any significant competition, but the benefits of ensuring effective long term control and of applying herbicides when they are least likely to affect the sugarcane are substantial. It is conceivable though that herbicide treatments are probably wasted in some situations where the weed pressure is low and the cane is harvested at a favorable time of year for cane growth.

4.5.4 Fate of herbicides in the environment

Simpson et al. (2000) suggest the following list of frequently asked questions in respect of herbicides in the environment.

1. How persistent are pesticides in soil?
2. With annual applications do pesticide levels build up in the soil?
3. Will pesticide residues carry over to the next cropping season and affect following crops?
4. Will there be off-site movement of pesticide residues caused by rainfall or irrigation with subsequent adverse environmental effects?
5. What can be done to minimize potential problems?

Herbicides vary in the characteristics which determine their fate in the environment and these factors include:

- Degradation rates (half-life)
- Degradation pathways
- Water solubility
- Photodecomposition
- Volatilization
- Adsorption to soil
- Reaction to pH.
Mechanisms for pesticide loss are discussed by Simpson et al. (2000) and include volatilization, particularly at high temperatures and in windy conditions, phytolysis (breakdown by sunlight), favored by hot, dry conditions, hydrolysis and oxidation, the rates being dependent on type of pesticide and conditions after application. Soil properties such as pH can have a major effect, atrazine being broken down at low pH and chlorpyrifos (an insecticide) at high pH. Microbiological breakdown also plays a major role in degrading pesticides in soil. Breakdown products may not be harmless and should also be considered.

In addition to the process of breakdown, pesticides can also be lost from the system in surface runoff and leaching. Soil adsorption and water solubility play a role in determining the amounts of pesticides that are lost through these pathways.

**Example of a scoring system for the potential risk of water contamination from a herbicide**

“To quantify the potential for water contamination associated with different herbicides, the Groundwater Ubiquity Score (GUS) was developed. This is based on the soil/water partitioning coefficient (Koc) and the soil half-life (DT50) of each herbicide. The basis of the model is that pesticides that are weakly adsorbed and have prolonged soil persistence will have a greater potential to contaminate groundwater. GUS indexes are converted to scores of 1-4, where 1=low, 2=medium, 3=high and 4=very high leaching potential. Using the equivalent 1-4 categories for risk to terrestrial and aquatic environments, a table has been developed showing the leaching potential and environmental risk scores for herbicides used in the South African sugar industry” (SASRI 2010).
### Box 4.7 Sample of herbicides used in the South African sugar industry and their environmental and health risks (SASRI 2010)

<table>
<thead>
<tr>
<th>Active ingredient</th>
<th>Label colour</th>
<th>Environmental risk</th>
<th>Label colour</th>
<th>Environmental risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Leaching potential</td>
<td>Toxicity to terrestrial and aquatic environments</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>GUS sand</td>
<td>GUS clay</td>
<td>Water bodies</td>
</tr>
<tr>
<td>acetochlor</td>
<td>Blue</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>alachlor</td>
<td>Yellow</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>ametryn</td>
<td>Yellow</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>imazapyr</td>
<td>Blue</td>
<td>4</td>
<td>4</td>
<td>x</td>
</tr>
<tr>
<td>atrazine</td>
<td>Yellow</td>
<td>4</td>
<td>3</td>
<td>x</td>
</tr>
<tr>
<td>sulfentrazone</td>
<td>Blue</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>diuron</td>
<td>Green</td>
<td>3</td>
<td>3</td>
<td>x</td>
</tr>
<tr>
<td>Sulcotrione</td>
<td>Yellow</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>+atonazine</td>
<td>Yellow</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>EPTC</td>
<td>Yellow</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Chlorimuron-ethy</td>
<td>Blue</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l +metribuzin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-metolachlor</td>
<td>Yellow</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluazifop butyl</td>
<td>Yellow</td>
<td>1</td>
<td>1</td>
<td>x</td>
</tr>
<tr>
<td>Triclopyr</td>
<td>Yellow</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Glyphosate</td>
<td>Green-blue</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Parquat</td>
<td>Yellow</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Mesotrione+s+met</td>
<td>Yellow</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>toluaci+terbuthylazine</td>
<td>Yellow</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>MCPA</td>
<td>Yellow</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Isoxaflutole</td>
<td>Green</td>
<td>4</td>
<td>1</td>
<td>x</td>
</tr>
<tr>
<td>metribuzin</td>
<td>Yellow</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>MSMA</td>
<td>Yellow</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Pendimethalin+met</td>
<td>Yellow</td>
<td>4</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>tribuzin+chlorimu-</td>
<td>yellow</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>erone-ethyl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halosulfuron</td>
<td>Green</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tebuthiuron</td>
<td>Yellow</td>
<td>4</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Terbuthylazine+bromoxynil</td>
<td>Blue</td>
<td>4</td>
<td>1</td>
<td>x</td>
</tr>
<tr>
<td>hexazinone</td>
<td>Yellow</td>
<td>4</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

* x = negative effects on plants or water bodies

The differences between herbicides in potential for negative environmental effects means that the choice of herbicide should be made carefully with these relative characteristics in mind. Safety data sheets should be available for all herbicides used.
Box 4.8 Pros and cons of chemicals for weed control

There are significant benefits to chemical weed control when compared with hand hoeing or mechanical cultivation:

- Herbicides can provide long term control, with one application lasting up to three months or more with some treatments.
- Herbicides are relatively easy to apply and large areas can be treated in a short space of time.
- Herbicides can control weeds in the cane row by the use of selective herbicides.
- Labor requirements are lower than for hand hoeing.

Disadvantages of chemicals include:

- The risk to the environment, operators and the community depending on the herbicides used.
- Poor control of resistant species.
- Cost of chemicals and application equipment.
- The need for a mixture of chemicals to control the full spectrum of weeds.
- The need for accurate timing of treatments with respect to weed growth stage, cane growth stage and weather conditions.

4.5.5 Choice of herbicide treatment

A number of factors should be considered in the choice of a herbicide treatment, including registration status of the products, weed spectrum, soil type, expected time to canopy, expected weather conditions, timing in respect of weed growth stage and potential for negative environmental impacts and human exposure.

An example of herbicide choice based on weed spectrum and growth stage is shown below in Table 4.2.

Table 4.2. Examples of herbicide choices for differing weeds and growth stages.

<table>
<thead>
<tr>
<th>Weed spectrum</th>
<th>Pre-emergence</th>
<th>Pre to early post-emergence</th>
<th>Post-emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadleaf weeds</td>
<td>MCPA; atrazine</td>
<td>MCPA + surfactant</td>
<td>MCPA + surfactant</td>
</tr>
<tr>
<td>Broadleaf and grasses</td>
<td>alachlor + atrazine; acetochlor + atrazine; metolachlor + hexazinone</td>
<td>tebuthiuron + diuron + surfactant</td>
<td>ametryn + MCPA + surfactant</td>
</tr>
<tr>
<td>Broadleaf, grasses and yellow watergrass</td>
<td>metolachlor + ametryne + paraquat</td>
<td></td>
<td>ametryn + MCPA + surfactant</td>
</tr>
<tr>
<td>Purple watergrass</td>
<td>EPTC</td>
<td></td>
<td>MSMA; halosulfuron + surfactant</td>
</tr>
</tbody>
</table>

Soil moisture, soil surface characteristics, temperature and rainfall all play a role in determining the final efficacy of the herbicide application.

In terms of optimum efficacy it is advisable to always aim at using pre-emergence treatments so as to prevent weed competition early on, and to reduce dependency on post-emergence products that can be damaging to the crop. It is believed that weed competition on sugarcane is greatest from...
grasses, followed by sedges, and least from broadleaf weeds. Herbicide programs should therefore cater for the most competitive species first.

4.5.6 Formulations

Herbicides consist of an active ingredient and additives which allow for a stable product or formulation. The majority of formulations fall into one of the following groups: dry flowable (DF), emulsifiable concentrate (EC), suspension concentrate (SC), solution (SL), water dispersible granules (WDG), wettable powders (WP), and water soluble granules (WSG).

Many old and new sugarcane herbicides are now available as dry formulations. The advantages of these formulations are:

- Much longer shelf life compared to SC formulations.
- Much easier to measure out granular quantities in the field – many come in 1 ha packs.
- Unlike liquids, dry concentrates can be pre-mixed for convenience prior to being taken to the field. To reduce error in the field, enough granulated herbicide can be volumetrically measured and pre-mixed in buckets (with lids), each for a full mixing tank.
- Far less risk of user contamination compared to liquids.
- Far less risk of user contamination following accidental spillages, which can be swept up.
- No need to triple rinse empty herbicide containers.
- Due to higher active ingredient loading and lack of water, transport costs are lower.
- Dry formulations, on average, have less of the non-herbicidal ingredients that are necessary in liquid formulations (pollutants).
- Dry formulations require less packaging and there are no drums for disposal.
- Far less storage space is required.

Table 4.3. Comparison between granular and liquid herbicide storage requirements.

<table>
<thead>
<tr>
<th>Product</th>
<th>Rate/ha</th>
<th>Hectares/pallet</th>
<th>For disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCPA 400 SL</td>
<td>3.50 L</td>
<td>183</td>
<td>32 drums</td>
</tr>
<tr>
<td>MCPA 700 WSG</td>
<td>2.00 kg</td>
<td>500</td>
<td>32 drums</td>
</tr>
<tr>
<td>Glyphosate 360 SL</td>
<td>8.00 L</td>
<td>80</td>
<td>32 drums</td>
</tr>
<tr>
<td>Glyphosate 500 WSG</td>
<td>5.76 kg</td>
<td>174</td>
<td>32 drums</td>
</tr>
<tr>
<td>Ametryn 500 SC</td>
<td>4.00 L</td>
<td>160</td>
<td>32 drums</td>
</tr>
<tr>
<td>Ametryn 750 WDG</td>
<td>2.67 kg</td>
<td>374</td>
<td></td>
</tr>
</tbody>
</table>
4.6 Application of herbicides

Product rates of herbicides range from as low as 50 g/ha up to 10 L or kg/ha or more. For effective control, even coverage is required of the target soil surface or weed population. Dilution in water as a carrier allows the use of a desired volume which can be applied evenly.

4.6.1 Application equipment

**Lever operated knapsack sprayers**
Containers holding 15-20 L, carried by operators, with a hand operated pump and single lance and nozzle. The single flood jet nozzle provides coverage of an inter-row and partial coverage of each adjacent row, or is applied directly over the row with the adjacent swaths overlapping on the inter-row. Application rate is dependent on constant walking speed, constant pumping action and correct swath width, which is determined by the height of the nozzle above the target. It is essential to calibrate the operators and the equipment regularly. Uneven ground, steep slopes and the onerous nature of the work makes this an uncomfortable operation for the applicator, particularly in hot climates. The advantages include the ability to treat small areas and fields with open drains and steeper land.

**Important issues:**
- Avoidance of drift.
- Safety of operators including exposure in windy conditions and contact with treated foliage when weeds are large, as application is made ahead of the operator.
- Effective coverage of target area.
- Constant application rate difficult to maintain accurately.
- Safe mixing.

**Controlled droplet applicators**
Spinning discs are able to provide uniform droplet sizes and allow application rates of far lower volumes, thus reducing the water supply logistics (50 L/ha as opposed to 200-400 L/ha with a knapsack sprayer). These can be very effective for steep areas and pre-emergence application where even soil coverage can be achieved. Where a heavy weed infestation is present with variable weed growth stages they tend to be less effective. They pose less danger to operators as droplet size is controlled, but herbicide concentration is higher. Ralfe (1988) reported on the substantial reductions in water use, labor requirements, tractor requirements and spraying efficiency on steep slopes for the use of an adapted controlled droplet applicator in comparison with a lever operated knapsack sprayer.

**Tractor drawn tanks with booms (with or without drop arms)**
Applying similar volumes to hand operated knapsack sprayers, large areas can be covered quickly, allowing accurate timing of herbicide application. Drop arms and single flood jet nozzles allow directed inter-row spraying, but rows need to be consistent and parallel for application to be accurate. Fanjets on a boom provide even coverage over the swath but application cannot be directed between cane rows.

**Tractor drawn tanks with hand held lances**
A system whereby lines are taken off from the tank and each line with a lance and single nozzle is operated manually. This allows more lines to be treated per swath, allows better directed inter-row spraying in uneven rows and on uneven terrain, and maintains application rates as speed and pressure are determined by the tractor. It is also less onerous for the operators.
Aerial application

For large areas on flat land aerial application can be effective, but suitable weather conditions are required to prevent drift. This provides less danger to labor, as fewer people handle the herbicides; however, the possibility of drift is a greater risk for surrounding communities.

Shields

Shields fitted to single lances or attached to arms trailed behind a tractor sprayer allow non-selective and stronger herbicides to be applied to weeds on the inter-row while avoiding contact with cane. Row spacing needs to be consistent and even, and terrain needs to be level for this to be successful. An example of successful use of shields is where non-residual chemicals such as glyphosate have been applied to inter-row weeds without damage to cane. This reduces the amount of residual herbicides released into the environment and hence the risk of contamination of off-site rivers, streams and eventually marine environments.

Nozzles

Nozzle patterns may be flat fan, hollow cone or solid cone, with the flat fan patterns being the most common in sugarcane herbicide application. These are of two types – being fanjets with angles of spray between 80 and 110 degrees, and floodjets with angles up to 180 degrees and providing a wider contact area when held at a similar height. Fanjets are used on booms, overlapping to provide a wide, even spray pattern and floodjets are used as individual nozzles per row or inter-row. Droplet size range is dependent on pressure, with high pressure tending to produce greater numbers of smaller droplets. A pressure of 1-2 kpa (bars) is sufficient to provide good coverage with limited drift under reasonable weather conditions.

Calibration

In order to ensure accurate application at the correct rates, calibration of equipment is critical. This is not only important to ensure effective weed control but also to ensure that excess herbicides are not applied which could lead to greater off-site contamination.

4.6.2 Weather conditions and drift control

Active growing conditions such as warmth and moisture usually favor uptake of herbicides into the plant. Low humidity and high temperatures will increase volatilization. Rain during application may be an advantage for soil absorbed herbicides, but an excess causes runoff of chemical from the leaf and is therefore a disadvantage for foliar absorbed herbicides. Low temperatures negatively affect the performance of MSMA, which needs at least 21 °C for adequate performance. Wind and relative humidity are important factors for consideration when spraying in order to minimize drift, and herbicides registered for aerial application usually specify acceptable relative humidity and wind conditions.

4.6.3 Chemigation

An attempt currently underway to evaluate the application of herbicides through pivot irrigation systems is described below (NB Leibbrandt, (Durban), 2011, personal communication).

Centre pivot irrigation systems, due to their design and operation, are ideal for the incorporation of crop protection chemicals. Recent research has shown that the introduction of herbicides into centre pivot irrigation water via a proportional injector pump has led to excellent herbicide performance (see Fig. 11). Products have been applied during irrigation cycles in rates of water ranging from 40 000 to 60 000 L/ha (4-6 mm). This equates, on average, to about 300 times more...
water than that in which herbicides are conventionally applied. Results have been spectacular, with herbicides intended for pre-emergence application providing additional knockdown of emerged weeds. This appears to be attributed to the high levels of water leading to more efficient root uptake of chemicals. The system has many other advantages over conventional systems, and these are shown in Box 4.9.

**Box 4.9 Advantages of herbicides applied through center pivot irrigation systems**

- Less labor is required (two operators).
- Far less chemical exposure to operators.
- Whole operation centralized at the pivot centre.
- Products are incorporated into the soil and therefore not prone to wind erosion and light degradation.
- Timing is optimized and application can be made immediately after planting or harvesting (Fig.11)
- Product efficacy and length of control is generally improved and follow-up treatments are often unnecessary.
- Less mechanical damage to the crop.
- No soil compaction by tractors.
- Large areas can be treated in a short period (one irrigation cycle – see Table 4.4).
- Highly significant cost saving (see Table 4.4).

**Table 4.4. Cost comparison: chemigation versus knapsack sprayer application for 50 ha center pivot. (SA Rand)**

<table>
<thead>
<tr>
<th></th>
<th>Knapsack</th>
<th>Tractor rig</th>
<th>Chemigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application cost/ha</td>
<td>136</td>
<td>142</td>
<td>20</td>
</tr>
<tr>
<td>Application cost/50 ha</td>
<td>6 800</td>
<td>7 100</td>
<td>1 000</td>
</tr>
<tr>
<td>Estimated saving</td>
<td></td>
<td>6 000</td>
<td></td>
</tr>
<tr>
<td>Time (50 ha)</td>
<td>6 days</td>
<td>3 days</td>
<td>1 day</td>
</tr>
</tbody>
</table>

Figure 4.10. Pre-emergence application.
4.6.4 Herbicide regulation – see Chapter 12, Agrochemicals and Farm Safety

While this is an important aspect of herbicide use the subject is covered in more detail in Chapter 12.

4.6.5 Responsible use of herbicides – see Chapter 12, Agrochemicals and Farm Safety

Since most herbicides are synthetic chemicals with varying levels of potential to cause undesirable side effects due to their toxicity to operators, the public and the environment, they should be handled with the utmost care and in such a way as to minimize any possible negative impacts. Legal regulations are in force in most countries, which involve a registration process and a requirement for explicit handling and use of instructions on herbicide labels. If label recommendations are followed exactly the risks of negative effects are substantially limited, but cannot be completely eliminated mainly due to the effect of weather conditions which cannot be controlled. Circumstances may also not always be ideal and accidents are possible. The most important action a user needs to take in order to apply the product safely is to follow the label instructions fully.

See Chapter 9 (Pest control) and Chapter 12 (Agrochemicals and Farm Safety) for further information on responsible pesticide use.

4.7 Integrated weed control

Successful weed control can only be achieved by the integrated use of chemicals, labor and in some instances mechanical methods of weed control (Wise 1982).

In order to control weeds from planting or harvesting until canopy formation and in certain cases at later stages as well (e.g. when winter die back re-opens the canopy or when creeping weeds emerge above the cane), an integrated weed control program involving chemicals and hand weeding or spot spraying is likely to be most appropriate. Herbicide treatments on their own are very seldom able to control all weeds for the full period from plant to canopy due to:

- Time to canopy exceeding the control period
- Weed spectrum including weeds resistant to the treatment
- Weeds escaping control due to growth stage at spray being incorrect (too large)
- Climate and soil conditions seldom being ideal.
As a result, follow-up treatments to extend the length of control or to control scattered escaped weeds or a new flush of weeds would be required.

The use of all practices to enhance crop growth would also serve as contributors to an integrated weed control program. Examples are correct fertilizer application and good pest and disease control measures, as well as correct choice of cultivar, correct row spacing, and timing of planting or harvesting. Problem weeds which escape standard weed control measures need special and extra attention, and in severe cases a whole-farm integrated approach can be beneficial. An example of such an approach for *Cynodon dactylon* control has been described by Campbell et al. (2007).

### 4.8 Weed control planning

Weed control planning needs to take the following factors into account:

- Weed spectrum and history in the field
- Harvest or plant date of the field
- Expected time to canopy
- Soil type
- Moisture conditions expected
- Variety
- Equipment availability
- Labor availability

Cane growth rates vary depending on season and, as a result, time to canopy varies. Rainfall patterns also vary and since many herbicides are dependent on moisture for successful activity, the choice of herbicide and timing of application are important considerations in planning a weed control program. Recording the weed spectrum in each field of the farm will build up a pattern of the most common weeds and help in deciding on the weed control and chemical choice strategy. A general program of treatments may be appropriate for most plant fields and a separate program for ratoon fields. Fields with specific problem weeds or to be harvested or planted at unusual times of the year, may warrant special programs.

### 4.9 Optimizing performance and minimizing negative impacts

Weed control practices have a major impact on economic viability and are an essential part of growing sugarcane, with potential yield reductions of the order of 50% if no weed control measures are applied (Pearson 1961a).

In terms of the social impacts of weed control practices, weed control requires high numbers of unskilled labor in the absence of the use of herbicides (Wise 1982). Application of herbicides including tractor operators, provides fewer jobs but at a higher level of skill. At the same time, herbicide application has the danger of possible exposure to chemicals. Communities adjacent to sugarcane farms may also be exposed to the effects of chemical application in the area. Adequate training of all personnel involved with herbicides and application is a logical step in optimizing performance (Kent 1999).

There can be negative environmental impacts from soil disturbance during weed control operations, e.g. inter-row cultivation can lead to increased opportunity for soil erosion and chemical applications have the potential to contaminate the soil and pollute water bodies, as well as drifting in the air to non-target areas.
Optimization of operations with respect to safety, social responsibility and environmental sustainability is likely to have the added benefit of improvements in economic viability (Rhegenzani et al. 2001). Table 4.5 provides information on the economic, social and environmental risks and benefits from the range of weed control options.

### Table 4.5. Summary of economic, social and environmental risks and benefits from the range of weed control options.

<table>
<thead>
<tr>
<th>Weed control methods</th>
<th>Economic impacts</th>
<th>Social impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical (anything which improves crop growth and suppresses weed growth, e.g. close row spacing, trash blanket, gapping-up)</td>
<td>Contributes to higher yield and overall improved efficiency.</td>
<td>Insufficient on its own for control of all weed competition. Trash can increase pest infestations (e.g. trash caterpillar).</td>
</tr>
<tr>
<td>Hand weeding/hoeing</td>
<td>Timing not as critical as chemical control. Useful as a follow-up treatment to chemicals.</td>
<td>High labor cost, short lived control. Hoeing can damage cane. Ineffective under certain conditions and for certain weeds. Disturbs soil. Often results in economic losses compared to chemicals.</td>
</tr>
<tr>
<td>Cultivation</td>
<td>Avoids chemical damage on cane. May improve infiltration.</td>
<td>Causes loss of moisture. May damage cane if not precise. Promotes soil erosion.</td>
</tr>
<tr>
<td>Chemical weed control</td>
<td>Efficient operation. Covers large area quickly. Long term control. Large product selection.</td>
<td>Cost of chemicals, damage to cane High management input More variables than other systems and therefore higher probability of failure.</td>
</tr>
<tr>
<td>Integrated weed control</td>
<td>Most effective and efficient for complete weed control.</td>
<td>Requires source of labor.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weed control methods</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical (anything which improves crop growth and suppresses weed growth, e.g. close row spacing, trash blanket, gapping-up)</td>
<td>No exposure to chemicals for labor and community.</td>
<td>None.</td>
</tr>
<tr>
<td>Hand weeding/hoeing</td>
<td>Provides unskilled jobs.</td>
<td>Tedium.</td>
</tr>
<tr>
<td>Cultivation</td>
<td>Provides jobs.</td>
<td>Dust.</td>
</tr>
<tr>
<td>Chemical weed control</td>
<td>Provides opportunity for semi-skilled jobs.</td>
<td>Possible exposure of operators and community to potentially harmful chemicals. Possible drift and contamination of water sources, food crops and air. Temptation for theft.</td>
</tr>
<tr>
<td>Integrated weed control</td>
<td>Provides jobs.</td>
<td>None</td>
</tr>
<tr>
<td>Weed control methods</td>
<td>Environmental impacts</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>Physical (anything which improves crop growth and suppresses weed growth, e.g. close row spacing, trash blanket, gapping-up)</td>
<td>Avoids chemicals and soil disturbance. Minimizes exposure time of bare ground to erosion.</td>
<td>May be insufficient on its own for control of all weed competition.</td>
</tr>
<tr>
<td>Hand weeding/hoeing</td>
<td>Very low impact; avoids disturbing the whole field.</td>
<td>None.</td>
</tr>
<tr>
<td>Cultivation</td>
<td>Avoids use of chemicals.</td>
<td>Causes soil disturbance and may increase erosion. Causes loss of moisture, nitrogen and carbon.</td>
</tr>
<tr>
<td>Chemical weed control</td>
<td>Can avoid excessive cultivation and consequent erosion.</td>
<td>Possible contamination of surface water bodies, soil, air and groundwater. Possible danger for insects and beneficial soil organisms.</td>
</tr>
<tr>
<td>Integrated weed control</td>
<td>General effectiveness means better crop growth and profitability. Minimizes over-use of inputs such as chemicals.</td>
<td>None.</td>
</tr>
</tbody>
</table>
Box 4.10 Suggested actions for optimizing performance in respect of effective weed control, minimizing cost, minimizing negative social impacts and minimizing negative environmental impacts

- Good husbandry practices to promote fast and healthy cane growth – correct variety choice, row spacing, seedcane quality and quantity, timing of harvest and planting with respect to soil type and weather conditions.
- Knowledge of the weed spectrum in all fields.
- Selection of a suitable weed control program (based on weed spectrum, expected time to canopy, soil type, available herbicides for specific weeds, season, moisture regime, labor availability).
- Timing of herbicide application with respect to weed growth stage, soil tilth and moisture conditions (most pre-emergence herbicides require 10-14 mm of rain within two weeks of application).
- Training of spray equipment operators in application and safety.
- Sufficient spray capacity so that the operation can follow closely behind planting or harvesting (e.g. one knapsack/15 ha).
- Servicing and calibration of spray equipment to ensure accurate application rates and coverage (including use of low pressures and correct nozzle selection for coverage and low drift. All knapsacks should be fitted with pressure regulators and operators should be trained on their maintenance. Promoting the use of shields where appropriate to prevent drift.
- Preference for directed inter-row application and minimizing contact with cane.
- Selection of appropriate chemicals for stage of application (soil applied or foliar applied); weed species; minimizing possibility of leaching to groundwater and from contaminating surface water; minimizing potential for poisoning of operators and toxic effects on micro and macro fauna; minimizing residual chemicals.
- Abiding by label instructions and laws for safety, efficacy, disposal and washing with all chemical applications.
- Minimizing chemical use where possible.

Practice of choice:

Harvest Cane without Burning and Use the Trash Blanket For Weed Control

This is the ideal solution for providing effective weed control, minimizing weed control costs, preventing herbicide damage, and added benefits of enhancing soil carbon, preventing soil erosion and conserving moisture. It is argued that the downside of trash blankets such as increased pests, poor regrowth in wet and cold conditions, higher cost and usually poorer quality of manual harvesting, increased fire risk, and problems with some weeds adapted to trash blankets, are not insurmountable and, with some consideration and adjustments to systems, can be successfully overcome.
4.10 References


SASRI (2010). Herbicide Guide. Published by the South African Sugarcane Research Institute, Mount Edgecombe, South Africa.


### CHAPTER 5 SUGARCANE NUTRITION AND FERTILIZATION - JAN MEYER

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5. SUGARCANE NUTRITION AND FERTILIZATION

5.1 Introduction

In terms of crop production, an adequate supply of nutrients has the next greatest impact on sugarcane yields after the water requirements of the crop have been met. In an era of ever increasing economic constraints and community pressure to maintain the integrity of the environment, there is the need to fertilize efficiently. Over-application of fertilizers will not only affect the profitability of cane operations, but also the loss of applied nutrients such as nitrogen through surface runoff and leaching will impact adversely on aquatic environments and groundwater quality. Gaseous losses of nitrogen through volatilization and denitrification will also contribute significantly to greenhouse gas emissions.

A basic understanding of sugarcane nutrition will be of paramount importance to estate field managers and agronomists to ensure that a correct balance is maintained between the nutrient requirement of the crop, the capacity of the soil to supply nutrients and fertilizer management in terms of the amount, placement and timing of fertilizer, without compromising soil fertility and the other components of the environment. Information on general cane nutrition is available from texts such as Humbert (1968), Samuels (1969), Husz (1972), Blackburn (1984), Anderson and Bowen (1990), Calcino (1994), Bruce (1999), and a series of Information Sheets published by the South African Sugarcane Research Institute (SASRI) (1993-2008). More specialized information dealing with the relationship of plant nutrients to biochemical behavior and physiological functions may be obtained from Mengel and Kirby (1982) and the relationship between plant nutrition and diseases from Datnoff et al. (2007).

In this chapter some principles and concepts in crop nutrition for improved nutrient management are considered along with roles of mineral nutrients, the amounts of nutrients removed by sugarcane in relation to the stage of growth, symptoms of deficiency, how fertilizer recommendations are made and good management practices for minimizing adverse environmental impacts.

5.1.1 Nutrients required by sugarcane

Sugarcane essentially consists of water, organic material and minerals made up from a wide range of elements as listed in the periodic table. However, only 16 elements are required for good growth. The three structural elements carbon, hydrogen and oxygen, comprise about 95 % of the fresh mass of the plant and comes mainly from water and the air. The remaining 5 % is the mineral component, of which at least 13 elements are considered to be essential for good growth and for maintaining the reproductive cycle of sugarcane.

<table>
<thead>
<tr>
<th>Box 5.1 Definition of essentiality</th>
</tr>
</thead>
<tbody>
<tr>
<td>The definition of essentiality as originally proposed by Arnon and Stout (1939), made provision for the following three conditions:</td>
</tr>
<tr>
<td>• The plant cannot complete its full life cycle, from germination to production of viable seed, if the element is absent.</td>
</tr>
<tr>
<td>• The function of the element in question is specific and cannot be substituted by another element.</td>
</tr>
<tr>
<td>• The essential element must be directly involved in the nutrition of the plant through a metabolic pathway.</td>
</tr>
</tbody>
</table>
The macronutrients include nitrogen (N), phosphorus (P) and potassium (K), known as the primary nutrients, and calcium (Ca), magnesium (Mg) and sulfur (S), which are considered to be the secondary nutrients (Fig. 5.1).

![Figure 5.1. Essential plant nutrients.](image)

The remaining seven elements termed trace elements or micro nutrients that form part of the tertiary group, include zinc, copper, iron, manganese, boron, chlorine and molybdenum. These elements are essential for plant growth in small quantities, usually taken up in tens of grams compared to the macronutrients that are taken up by the sugarcane crop in tens of kilograms per hectare.

Silicon is the 14th element that has received widespread attention in recent years and, although it is not essential to plant growth, sugarcane is a large accumulator of this element. Because of its functional importance, Si is termed a beneficial nutrient for sugarcane (Berthelsen et al. 2001; Kingston 1999; Savant et al. 1999; Meyer et al. 1999).

5.1.2 Principles of nutrient management

The relationship between growth rate or yield and nutrient supply is described by the well known ‘Law of Diminishing Returns’ (Mitscherlich 1909) which indicates that, as the supply or availability of nutrients increases, the growth rate and yield increase but with diminishing returns. An important characteristic separating micronutrients from macronutrients is the high efficiency value of micronutrients, since very small amounts are sufficient to produce optimum effects, while slight deficiencies or excesses can result in severe yield declines. This effect is illustrated by the comparative response curves in Fig. 5.2, which show that when nutrients are expressed in the same mass units, the yield response curve to micronutrient treatment, when deficient, tends to have the steepest slope compared to the response curves for macronutrient treatment that tend to show shallower slopes.
5.1.3 Amounts of nutrients taken up by sugarcane

Cane is capable of rapidly depleting the soil of mineral elements, particularly N and K. This is demonstrated in Table 5.1 which compares the elemental uptake of selected nutrients for average cane crops reported from a number of cane producing countries. The wide variations in nutrient removal are due to differences in prevailing climatic conditions, differences in nutrient use efficiency between cultivars, and differences in soil fertility and fertilizer practices. In general, sugarcane growing under irrigation in high temperature environments will remove more nutrients than sugarcane produced under rainfed conditions in cooler climates.

Table 5.1 Examples of comparative rates of nutrient removal by sugarcane for a range of countries (adapted from data given by Kingston 2000)

<table>
<thead>
<tr>
<th>Country</th>
<th>Source</th>
<th>Macronutrients (kg/t)</th>
<th>Micronutrients (g/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Australia</td>
<td>Kingston 2000</td>
<td>1.3</td>
<td>0.18</td>
</tr>
<tr>
<td>India</td>
<td>Zende 1983</td>
<td>1.2</td>
<td>0.20</td>
</tr>
<tr>
<td>Brazil</td>
<td>Malavolta 1961</td>
<td>0.8</td>
<td>0.132</td>
</tr>
<tr>
<td>South Africa</td>
<td>Thompson 1988*</td>
<td>1.35</td>
<td>0.16</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Humbert 1968</td>
<td>1.13</td>
<td>0.29</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1.16</td>
<td>0.19</td>
</tr>
</tbody>
</table>

*Pooled plant crop data from three different growth analysis trials

*Pooled data
5.1.4 Impact of climate on nutrient uptake

In South Africa in the Pongola valley, a high yielding irrigated crop of cultivar N14, producing 165 t/ha can remove up to 250 kg N, 30 kg P and 650 kg K, depending on crop stage and cycle (summer or winter). The high rate of K uptake is exceptional and can largely be attributed to luxury uptake of K in a plant crop of sugarcane growing in a deep, fertile sandy clay loam soil on relatively new alluvial land. Results from an adjoining lysimeter trial located adjacent to the field trial showed a K uptake of 250 kg/ha for a similar biomass yield. It appears that the shallower profile in the lysimeters (1 m of soil), provided much less K for the crop than did the surrounding land, due not only to the shallower depth, but possibly also more severe K depletion during the preceding 19 years of crop growth. On a nearby site it was shown that root activity of sugarcane can extend to a depth in excess of 3 m (Thompson and Boyce 1968).

The rate of nutrient accumulation by the crop depends very much on the start of the crop cycle. Summer cycle crops accumulate N rapidly and, after four months, 82 % of the final N is usually taken up in the above-ground portions of the crop. This compares with only a 12 % of final N uptake for crops starting in April in South Africa. This differential N uptake has important implications for fertilizer management, as will be seen later in this chapter.

Table 5.2 Comparison of nutrient uptake at four and six months of age for spring and autumn cycle crops at Pongola on a Hutton clay soil (after Thompson 1991).

<table>
<thead>
<tr>
<th>Element</th>
<th>Spring start (% final kg/ha)</th>
<th>Autumn start (% final kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At 4 months</td>
<td>At 6 months</td>
</tr>
<tr>
<td>N</td>
<td>82</td>
<td>99</td>
</tr>
<tr>
<td>P</td>
<td>66</td>
<td>90</td>
</tr>
<tr>
<td>K</td>
<td>60</td>
<td>82</td>
</tr>
<tr>
<td>Ca</td>
<td>57</td>
<td>85</td>
</tr>
<tr>
<td>Mg</td>
<td>78</td>
<td>95</td>
</tr>
</tbody>
</table>

5.1.5 Soil factors affecting nutrient supply

As shown in Chapter 2, the physical, chemical and biological properties of soils exert a dominant influence on the growth of sugarcane and its management. Soils also differ widely in their ability to meet the nutrient requirements of sugarcane; most have only moderate natural soil fertility but can be considerably improved through the application of fertilizers and soil amendments. Before covering the fertilizer requirements of sugarcane and good management practices for applying fertilizers, it is necessary to explain that the term ‘soil fertility’ comprises a complex range of physical, chemical and biological properties that should be optimized as the basis of good management practices. These properties are summarized in Box 5.2, and further details concerning the physical property requirements can be found in Chapter 2.
Box 5.2 Properties that make up a fertile soil

**Soil depth** (determining the volume of soil accessible to the root system): Under dryland conditions, sugarcane prefers to have at least 1.2 m of freely draining soil without any obstructing layer.

**Soil texture:** Is a measure of the relative proportions of sand (largest particles), silt (intermediate) and clay (smallest particles). Unlike sand and silt, clay particles have the largest negatively charged surface area and chemically the most active in terms of attracting and storing plant nutrients. Although sugarcane can grow over a wide textural range of soils, usually sandy clay loam soils (20 to 35 % clay), such as the deep red Oxisols and Nitosols that occur extensively in Sao Paulo State in Brazil, tend to be the more productive soils.

**Soil structure:** A network of solid particles distributed to form an interlinked web of channels and pores, introduces the concept of aggregation and structure in soils. This determines the distribution of pore sizes which is decisive for the supply of air and water to the roots, as well as mechanical impedance to roots, and soil temperature. In general, roots prefer soils with some degree of structure, preferably crumb to microstructure. The extremes of massive and prismatic structure are not root-friendly.

**Organic matter:** Derived from the breakdown of plant and animal matter, that ranges in composition from polysaccharides in the active fraction to humic and fulvic acids in the more stabilized humus fraction. Organic matter has a greater cation exchange capacity than a similar mass of clay, giving it a strong capacity to attract nutrients and to act as a potential source on N, P and S through mineralization. There is no optimum level of organic matter, except to maintain levels as high as possible through good management practices.

**Cation exchange capacity (CEC):** Is a measure of the amount of negative charge on clay and organic matter particles that attract positively charged cations such as potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), hydrogen (H) and aluminum (Al). The higher the CEC, the more cations the soil can retain. Ideally, a fertile soil should have a CEC value in excess of 10 mmol/kg with less than 10 % of the CEC occupied by Al and H ions.

**Soil reaction:** Generally refers to the soil pH status, which is a numerical measure of acidity and alkalinity on a scale of 0 (extreme acidity) to 14 (extreme alkalinity). The pH status of a soil is important as it governs the solubility and availability of nutrients to the plant. A pH range from 5.5 to 7.5 is considered desirable for sugarcane.

**Soil organisms:** An incredible diversity of soil organisms make up the soil food web, the diversity of which is widely regarded as the basis of soil health. These organisms, also referred to as biota, range in size from the tiniest one-celled bacteria, algae, fungi and protozoa, to the larger more complex nematodes and micro-arthropods, to the visible earthworms, insects, small vertebrates and plants. Highly productive agricultural soils tend to have fungal to bacterial ratios of just below 1:1, while the ratios in forestry soils generally range from 5 to 10:1 but can be as high as 100:1 in a deciduous forest.
5.1.6 Clay minerals

Chemical composition and properties of clay minerals vary from one soil to another. Two of the most typical soils of tropical and sub-tropical areas where cane is grown are:

- **Ferralsols**: Highly weathered very red or yellowish-brown acid soils (also known as Ferralitic or Latosols in Brazil).
- **Vertisols**: Dark colored usually black cracking and swelling clays.

The characteristics exhibited by these extreme soil types are affected by differences in the predominant clay minerals. Some of the main properties are listed in Table 5.3.

### Table 5.3 Properties of Ferrasols and Vertisols

<table>
<thead>
<tr>
<th>Ferrasols (Oxisols, USA)</th>
<th>Vertisols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay mineral – kaolinite</td>
<td>Clay mineral – smectite, montmorillonite</td>
</tr>
<tr>
<td>Little swelling when wet</td>
<td>Strongly swelling when wet</td>
</tr>
<tr>
<td>Low nutrient adsorption capacity</td>
<td>High nutrient adsorption capacity</td>
</tr>
<tr>
<td>Strongly weathered</td>
<td>Less strongly weathered</td>
</tr>
<tr>
<td>Highly porous and strongly leached</td>
<td>Often waterlogged and lacking aeration</td>
</tr>
<tr>
<td>Develop in acid environments</td>
<td>Develop in slightly acid to alkaline environments</td>
</tr>
</tbody>
</table>

5.1.7 Cation exchange capacity

Sand and silt particles in the soil are relatively inactive, whereas clay and organic matter particles of the order of 0.0001 mm or smaller in diameter, known as colloids are chemically very active. Due to the very large surface area, colloids are able to absorb and exchange ions of nutrients such as ammonium \((NH_4)\), potassium \((K)\), calcium \((Ca)\), magnesium \((Mg)\) and other elements. The ability of the clay particles to hold and exchange elements is called the cation exchange capacity (CEC), which forms the soil’s nutrient storehouse. Large amounts of nutrient elements may be adsorbed and gradually released to the soil solution, from which the roots can absorb them.

The concept of CEC within a soil may be illustrated by the example of a magnet where the unlike poles attract and like poles repel each other. In the same way negatively charged colloids attract the positively charged nutrient cations but will repel the negatively charged anions (Fig. 5.3).
Figure 5.3. Attraction of cations to clay surfaces.

The CEC is normally expressed as mmol/kg, although the former unit of milliequivalents per 100 g soil, also commonly referred to as me %, is still widely used.

5.1.8 Soil organic matter

Soil organic matter broadly comprises a complex mixture of organic material present in various stages of decomposition. This ranges from undecayed living organic material (roots, microorganisms and animal remains), to decomposing plant and animal tissues referred to as the active fraction, comprising mainly polysaccharides to the stabilized organic humus fraction made up of mainly humic and fulvic acids (Fig. 5.4).

Figure 5.4. Main fractions in organic matter.

Although organic matter is present in small proportions relative to clay, it can have a huge impact on soil properties.

- Improving soil structure and tilth.
- Improving cation exchange capacity (CEC) and pH buffering capacity of the soil.
- Supplying soil nutrients especially nitrogen, phosphorus and sulfur.
- Binding soil particles together that reduces erosion.
- Increasing soil water holding capacity, and resistance to compaction.
- Encouraging build-up of soil microorganisms as a food and energy source, which assist in breakdown of herbicides and other plant toxins.
- Buffering the effects of changes in soil ph.
- Organic matter (%) may be estimated as 1.72 x organic carbon (%).

5.1.9 Soil pH, acidity and alkalinity

Soils are acid when excessive concentrations of hydrogen and aluminum ions predominate over hydroxyl ions in the soil solution, while in alkaline soils the reverse occurs with hydroxyl ions dominating over hydrogen ions. A pH of 7 indicates neutrality, while values between 7 and 0 indicate increasing acidity and 7 and 14 increasing alkalinity. Pure water has a pH of 7. The scale is logarithmic since a change of 1 unit on the scale represents a 10-fold change in acidity. Soil pH tests are normally conducted in water but other electrolytes such as very dilute calcium chloride or potassium chloride may also be used. In this manual all references to pH values are based on tests in water.

The pH status of a soil is important as it governs the solubility availability of nutrients to the plant. Increased acidity (pH < 7), causes reduced availability of important nutrients such as N, P, K, Ca, Mg and S while micronutrients such as Cu and Zn become more available (Fig. 5.5). Under acid conditions below a pH 5.3, Al becomes soluble and is toxic for root growth, especially for legume crops that may be used in rotation with sugarcane. Most cultivars of sugarcane tend to be tolerant of high levels of Al (Hetherington et al. 1986), although a regular program of liming is nevertheless important to reduce soil acidity to pH values in the range 5.5 to 6.5. This aspect and especially suitable diagnostic soil criteria will be dealt with later in this chapter. Under high pH conditions above a value of 8, the availability of all micronutrients except molybdenum will be reduced.

![Figure 5.5. Nutrient availability is strongly influenced by pH (after Truog 1948).](image-url)
5.1.10 Movement of nutrients in the soil

Nutrients in the soil can be transported mainly by two different mechanisms: mass flow and diffusion.

- **Mass flow**: This occurs when solutes are transported by the convective flow of water from the soil to the plant roots when water enters the soil after a heavy shower or an irrigation event. The amount of nutrients reaching the roots is dependent on the rate of water flow or consumption of the plant. Nitrogen and phosphorus are present in the soil as part of compounds with a net negative charge on them, and thus are not held by the soil colloids. They move to the roots mainly by mass flow.

- **Diffusion**: This occurs when a nutrient ion is transported along a gradient from a higher to a lower concentration by random or thermal action. A concentration gradient is created when the concentrations of nutrients in solution are lowered as a result of uptake by roots. The depleted solution is replenished by nutrients which diffuse through the soil water from areas of higher concentration. Potassium is an example of a cation that is transported to plant roots mainly by diffusion.
5.2 Nitrogen (N)

5.2.1 Importance of nitrogen

Nitrogen is the fourth most abundant element in sugarcane and together with carbon, hydrogen, oxygen and sulfur, is essential for the production of amino acids, proteins, enzymes, hormones, phytoalexins and phenolics.

Nitrogen is involved in many interactions with other nutrients. For example, K increases NO$_3$ while P and Cl decrease NO$_3$ uptake and promote the uptake of NH$_4$ (Huber and Graham 1999). N is by far the most widely reported element affecting plant diseases, especially fungal diseases, but in sugarcane unfortunately very little research has been conducted into the impact of cane nutrition on disease susceptibility. There is anecdotal evidence from an N treatment trial conducted in Swaziland that high N treatment increases the susceptibility of sugarcane to smut.

5.2.2 Physiological role of nitrogen

<table>
<thead>
<tr>
<th>Box 5.3 Functions of nitrogen and impact on cane quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>• N is essential for photosynthesis and sugar production and is taken up by the roots from the soil solution mainly as the ammonium cation or nitrate anion although organic forms of N can also be absorbed.</td>
</tr>
<tr>
<td>• Approximately 80 to 85% of the total N is sequestered into proteins via the amino acid link, which in turn are the building blocks of enzymes that govern the rate, timing, direction and extent of metabolic reaction pathways.</td>
</tr>
<tr>
<td>• N is important to meristematic activity and in this way stimulates vegetative growth and tillering. Rapid growth invariably implies higher levels of N, moisture and non-sugars and lower sucrose content within the cane plant prior to harvest.</td>
</tr>
<tr>
<td>• Sugarcane is able to reabsorb more N than necessary for its vegetative growth by storing N. As physiological age advances, the N content of the tissue decreases markedly and reaches its minimum in well-matured cane.</td>
</tr>
<tr>
<td>• However, too much N can cause lodging, delayed maturity, reduced sucrose levels, and increased color of the mixed juice, as well as increasing the risk of certain fungal diseases such as smut and increased susceptibility to borer damage.</td>
</tr>
<tr>
<td>• N deficiency symptoms comprise light green to yellow leaves from the base of the plant upwards, often with necrosis (death of tissue) on the tips and edges of older leaves, with a resultant reduction in cane yield.</td>
</tr>
<tr>
<td>• Emphasis on correct and timely placement of N fertilizer is a key management factor as sugarcane is notoriously inefficient in recovering applied N (6-45%).</td>
</tr>
<tr>
<td>• Leaf analysis is a reliable tool to measure plant nitrogen status (Fig. 5.6).</td>
</tr>
</tbody>
</table>
5.2.3 The Nitrogen cycle

Gains in plant available soil nitrogen
Nitrogen from the atmosphere is potentially an important indirect source of N in the soil. Approximately 78% of the air comprises nitrogen which translates into about 78,000 tonnes of N above each hectare of cane land. Within the soil an internal cycle functions, through which a small amount of this atmospheric N source becomes available as part of the organic N pool through microbial symbiotic and/or non-symbiotic fixation of N by microorganisms, and also through ammonia and nitrates in rainfall (Fig. 5.7). Some of the fixed N is made available as NH₄⁺ or NO₃⁻ ions through mineralization and nitrification respectively. The nitrification process by the bacteria *Nitrosomonas* spp. and *Nitrobacter* spp. respectively, and extent of mineralization of soil organic matter, reflects the soil’s nitrogen mineralizing potential.

Both ammonium and nitrate ions, which can also be supplied from fertilizer, are absorbed by sugarcane and assimilated as amino acids in the root tissue and translocated through the xylem to the youngest leaves with the highest growth rates, until they have reached maturity (Burr *et al.* 1958).

---

### Nitrogen deficiency
- Affects older leaves first.
- Light green to yellow leaves from base upward often with necrosis on leaf tip and edges.
- Stunted growth with short internodes and slender stalks.
- Reduced tillering.
- Low yields and low sucrose content.

<table>
<thead>
<tr>
<th>Country</th>
<th>Leaf tissue</th>
<th>Age (months)</th>
<th>Critical N %</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>TVD*</td>
<td>3-5</td>
<td>1.6-1.8</td>
</tr>
<tr>
<td>Brazil</td>
<td>TVD</td>
<td>4-9</td>
<td>1.65</td>
</tr>
<tr>
<td>Mauritius</td>
<td>Punch</td>
<td>4-6</td>
<td>1.45-1.66</td>
</tr>
<tr>
<td>Florida</td>
<td>1st no. midrib</td>
<td>4-6</td>
<td>1.20</td>
</tr>
</tbody>
</table>

**Figure 5.6. Symptoms of nitrogen deficient cane and critical values used for leaf analysis.**
Box 5.4 Nitrogen turnover

Nitrogen can be immobilized biologically by microorganisms during decomposition of organic matter, but the loss in availability of N to the plant is generally temporary as the immobilized N can be released through mineralization on the death of the organisms concerned. Generally speaking, fresh organic materials contain C:N ratios above 30:1 and, when added to the soil, immobilization of any free N in the soil will occur during the early stages of decomposition. When partly decomposed organic residues with a C:N ratio of between 20 and 30 are added to the soil, neither immobilization nor mineralization is likely to occur to any great extent (Wood 1972). Well decomposed organic residues such as mature compost contain C:N ratios below 20, and under these conditions a rapid release of mineral N may be expected (Birch 1959). The C:N ratio of undisturbed topsoil usually falls in the 10 to 12 range.

The cycling of products in the above manner is referred to as ‘nitrogen turnover’ and takes place continuously in all soils.

5.2.4 Nitrogen losses

Sugarcane acquires most of its N requirement from nitrogen that is made available through the mineralization of soil organic matter as well as fertilizer inputs. Generally only about one third of the nitrogen applied as fertilizer to a crop of sugarcane is removed by the crop in the year of application. The rest of the nitrogen goes into the soil reserves or is lost by leaching of especially nitrate, denitrification of nitrate through reduction to volatile nitrous and nitric oxide gases under
waterlogging, and volatilization of ammonium to ammonia gas. Other major ‘losses’ of N from the production system are through the removal of harvested cane.

The conversion of NH$_4$-N to NO$_3$-N in the soil by bacteria of the genera *Nitrosomonas* and *Nitrobacter* is referred to as nitrification. Leaching losses of fertilizer nitrogen applied at planting or after harvesting a ratoon can deprive the plant of much of its N requirement, especially on sandy soils. These losses can be minimized where the applied N is retained by the soil in the NH$_4$-N form for a reasonable period before being wholly converted to NO$_3$-N which is subject to more pronounced leaching. An important factor governing the rate of nitrification in the soil is pH. Under acid conditions the rate of nitrification is reduced, whereas increasing the soil pH through liming will increase the conversion of NH$_4$-N to NO$_3$-N, increasing the risk of N loss in the nitrate form (Robinson 1963).

**Box 5.5 Comparative N use efficiency outcomes for various countries (updated from Kingston 2000)**

- **Australia**: 32% (Chapman *et al.* 1992) and 24-41% (Keating *et al.* 1993) fertilizer N recovery based on field studies using $^{15}$N labeled fertilizer.
- **Florida**: 30-42% N use efficiency very cultivar dependent (Gascho *et al.* 1986)
- **Taiwan**: 23-40% fertilizer N recovery for a range of Taiwanese genotypes (Tung-Ho *et al.* 1993).
- **South Africa**: 27-36% N recovery by total biomass (including roots). Nitrate based fertilizer was more efficient than ammonium N fertilizer in terms on N recovery (Wood 1972). Meyer *et al.* (2007)
- **Guadeloupe**: 6-34% efficiency of fertilizer N uses in Vertisol soil systems (Courtilliac *et al.* 1998).

Denitrification occurs in waterlogged conditions under anaerobic conditions. Significant losses of between 2-12 kg N/ha/week have been measured for clay soils in Australia and less than 1 kg N/ha/week for lighter textured soils (Keating *et al.* 1993).

The other major N fertilizer loss pathway is volatilization loss from urea applied to trash blanketed soil. Considerable attention has been given to researching the timing and placement of urea as well as alternative N fertilizer carriers in the Australian sugar industry (Freney *et al.* 1994) and more recently in the South African sugar industry (Schumann 2000). Further reference to the outcomes of these studies will be made in the section dealing with N fertilizer management.

**Box 5.6 Impact of nitrogen losses to the environment**

Apart from affecting sugar quality, loss of N through poor management practices can potentially have considerable ecological significance by impacting on:

- Increased concentrations of N in the root zone (Keating *et al.* 1997).
- Through leaching losses of N in light textured soils, the quality of groundwater may be affected (Thorburn *et al.* 2003).
- This in turn impacts on the quality of surface streams and rivers (Bramley *et al.* 1996).
- Ultimately the quality of water for human consumption and the balance of riverine flora will be affected. In Australia, Keating *et al.* (1996) found that 2% of sampled boreholes contained nitrate levels in excess of the WHO limit of 50 mg/liter.
Apart from the potential of affecting ground water quality, increased application of N fertilizers can impact on soil acidification and enhance greenhouse gas emissions. (Keating et al. 1997; Haynes and Hamilton 1999).

Where N is lost from sugarcane systems through denitrification, greenhouse gas emissions are enhanced.

In addition to potential health issues, community concern in coastal areas over the deterioration of sensitive offshore reef systems, such as the Great Barrier Reef, will lead to greater regulation.

5.2.5 Factors affecting the nitrogen requirement of sugarcane

5.2.5.1 Economics
Fertilizer nitrogen requirements of sugarcane have traditionally been based on an economic yield optimum derived from rates of nitrogen experiments. A number of studies have been reported during the early years, with trial results reported from South Africa (du Toit 1957), Hawaii (Stanford and Ayres 1964), Brazil (Malavolta 1982), Louisiana (Golden and Ricaud 1965), India (Singh 1963), Peru (Husz 1972) and Puerto Rico (Samuels and Alers-Alers(1964). These early trial studies were usually conducted in different agro-climatic regions, on a range of soil types with little or no consideration for the large differences in N mineralizing potential that existed between soils. Invariably the conclusions led to broad distinctions being made between nitrogen rates for the production potential of environments. In terms of commercial practice, the recommended nitrogen rates were based on expected cane yield, with rates of N varying from 1.5 to 2.0 kg N/t cane. The emphasis was mainly on fertilizing the crop rather than on managing the soil, which led to a period of excessive and inefficient N usage.

5.2.5.2 Climate
Climatic factors such as moisture, radiation and temperature have a huge impact on crop yield, which in turn will have a major impact on the rate and quantity of nitrogen removed by the crop. A climatic benchmark of yield is essential if the contribution of management and especially nitrogen management is to be fully assessed. In practice climatic potential has been determined by a well known formula derived by Thompson (1976):

\[ Y = \frac{E_o}{100} \times 9.8 \]  

where \( Y \) = yield (tc/ha/y), and \( E_o \) = Class A pan evaporation per annum in mm fully replenished by rainfall and irrigation.

These yields are possible where moisture is not limiting under experimental conditions. Effective rainfall (70 % of total precipitation) can be used in place of \( E_o \), but this is a much less reliable measure.

Based on the author’s experience, under African conditions climatic yield potentials can vary anywhere from 120 to 170 tc/ha/y subject to no moisture limitations. However, under commercial practice, and under the highly variable soil conditions that occur in Africa, the achievable estate yields under irrigation are likely to be between 20 and 35 % lower than potential yield. These days a whole range of crop simulation models are available that combine crop, soil and weather databases which can be used to simulate multi-year outcomes of crop management strategies for sugarcane at any location in the world. The use of models is more fully discussed in Chapter 14.
5.2.5.3 Crop stage (plant or ratoon) and cycle

Research findings from trials conducted worldwide have confirmed that plant cane is far less responsive to applied N than ratoon cane. In general, results suggest that the N requirement of plant cane is on average about 40 kg/ha N lower than that of ratoon cane. The main reason for this difference is the extra release of mineral N from the soil following a fallow period.

Age of cane and season are important factors responsible for most of the variation in N uptake. The variable impact of season on crop removal of nutrients was illustrated earlier in this chapter by nutrient uptake data of cultivar N14 grown in a lysimeter at Pongola in South Africa (Thompson 1988). Favorable seasonal cycle crops can accumulate N rapidly, to the extent that over 80 % of the N requirement can be taken up after four months, whereas in an unfavorable cycle just over 10 % of the N may be taken up by the crop. This differential N uptake has important implications for the timing of fertilizer placement and especially when designing a fertigation program. Research findings in South Africa have shown that fertigation is more effective than conventional surface applied N for cane grown on an unfavorable cycle (Autumn to Autumn), whereas with a favorable growth cycle there was little or no difference in efficacy between conventional and fertigation N applications (Weigel et al. 2008).

5.2.5.4 Age

In South Africa, an 18 month old crop growing in the elevated areas of the Midlands, starting in May (Autumn) and ending in November (Summer), will invariably be out-yielded by an 18 month old crop starting in November and ending in May, because the first crop effectively has one summer compared with the second crop which has two summers. More mineral soil N becomes available during two summer cycles compared with the single summer cycle, implying that less N may be needed in a favorable cycle.

5.2.5.5 Cultivars

In some countries such as Taiwan, India, Argentina and more recently in South Africa, differences in N fertilizer use efficiency amongst cultivars is becoming an increasingly important factor. Trials conducted in Pongola and Mpumalanga in South Africa have shown that using the ratio of sucrose yield to N accumulation, cultivars may be classified into one of three categories: (i) efficient N use responders, (ii) inefficient non-responders and (iii) inefficient responders (Schumann 2000).

High N use efficiencies for N12 and N19 were 65 % and 63 % above the ‘reference’ cultivar NCo376. In contrast, N14 was 19 % less efficient than NCo376 (Fig. 5.8). These data suggested that substantial benefits may be derived from cultivar-specific N fertilizer recommendations for sugarcane, rather than a single recommendation based on NCo376. Current fertilizer recommendations for N14 have been increased by 30 kg N/ha, based on field trial data, and a reduction of 20 kg N/ha will be recommended for N19. Further confirmation of genotypic differences to N treatment was obtained in a large scale pot trial in which 30 clones from the well known AA40 population, comprising 153 clones from a single cross, were subjected to a low and high rate of N nutrition.
5.2.5.6 Soil N mineralization potential

More recent studies in determining the N requirement of sugarcane have focused on factors such as climate, soil type, cane cultivar, crop class, legume usage during the fallow, rainfall, length of time green cane trash blanketing has been practiced, and irrigation. For example, early studies conducted in South Africa have shown that mineralization of organic N to ammonium and subsequent nitrification of the ammonium to nitrate, is a continuous process but is largely driven by the organic matter status of soils, drying and wetting cycles, the duration of drying prior to wetting up, temperature changes, soil pH, biological activity and soil disturbance through tillage operations (Wood 1964).

South African studies

Follow-up investigations based mainly on N rate trials conducted in South Africa, Swaziland and Zimbabwe have shown that the relative response obtained to applied N was inversely related to the amount of N released as measured by soil incubation and the organic matter content of soils:

- Soils with low (< 25 mg N/kg), moderate (20-40 mg N/kg), high (40-60 mg N/kg) and very high (> 60 mg N/kg) N release, were associated with average responses to applied N of approximately 50, 30, 20 and 10% respectively (Moberly et al. 1982).
- The results implied that the probability of a response to applied N decreased markedly with increasing soil organic matter content and greater N release (Meyer et al. 1983).
- The results also showed that the response to applied N was broadly related to the nature of the diagnostic topsoil horizon when classified according to the South African Binomial system (MacVicar et al. 1977).
- Average response declined in the order grey orthic > melanic/vertic > red to brown orthic > humic A horizons.

These early studies formed the basis of an improved system of N recommendations for the sugar industries in South Africa and the SADEC countries (SASRI Information sheets 7.1 and 7.13), that take into account regional differences in climatic potential, whether the crop is rainfed or irrigated, stage of crop (plant or ratoon), soil mineralization potential index and more recently cultivars (Meyer et al. 1986; Meyer et al. 2007). The current N recommendations for plant and ratoon cane are summarized in Table 5.4. For ratoon cane the lower value in the range applies to rainfed cane with
an achievable yield potential of 100 tc/ha over 15 months, and the upper part of the range refers to irrigated cane with a yield potential of 125 tc/ha/an. Soils with the lowest organic matter content (< 2 %) receive the highest N recommendation of 140 kg/ha N for dryland cane and 100 kg/ha N for soils with a high organic matter content (> 4 %) due to the higher N mineralization potential. These rates approximate baseline rates of 1.6, 1.4, 1.2 and 1 kg N/t cane used respectively for the given soil N mineralization categories of low, moderate, high and very high N mineralization potential (Meyer et al 1983). Economic assessments that have been conducted periodically have shown that these rates can all be economically justified (Thompson 1980, Prins et al. 1997 and Schumann 2000). A more detailed explanation of the economic benefits is given in section 5.4 of this chapter.

**Australian studies**

In Australia, Chapman (1994) and Calcino (1994) underlined the importance of climatic regions when assessing the N requirement of sugarcane. For example, the Burdekin region with its fertile soils, higher temperatures and access to water, has a higher yield potential than most other districts, and higher N rates were needed for cane growing on the same soils in other regions. For some time the N requirement of sugarcane was based on a general rule of 1.4 kg N/t expected sugarcane yield plus an additional 1 kg N/t cane yield above 100 t/ha (Keating et al. 1997).

Subsequent investigations highlighted the importance of soil organic matter and the nitrogen mineralization potential and, as is the case in South Africa, a soil nitrogen mineralization index, based on soil organic matter content was proposed for refining nitrogen inputs for two regions of the Australian sugar industry (Schroeder and Wood 2001). Further advances in rationalizing the N requirement of sugarcane was made with the introduction of revised N fertilizer recommendation guidelines based on a combination of district yield potential and a six point soil mineralization index (Wood et al. 2003; Schroeder et al. 2005; Schroeder et al. 2007). For dryland ratoon cane the N recommendations vary from 100 kg/ha N for cane growing on soils with more than 2.4 % organic matter to 160 kg/ha N for soils with less than 0.4 % organic matter (Table 5.4). The N rates for plant cane show a similar trend but are 20 kg/ha lower than the ratoon rates where there has been no green fallow. Plant cane N rates are reduced further by as much as 80 kg/ha N following a soybean/cowpea fallow. As in South Africa, the improved system of making N recommendations has led to more efficient N use and an overall reduction in N application, with economic and environmental benefits in terms of reduced costs and reduced N losses.

**Other countries**

The important effect of organic matter and soil mineralization potential on the N requirement of sugarcane has also been recognized in Brazil (Penatti et al. 1997) and in Florida with its large areas of peat, as well as sandy soils where four categories of soil mineralization potential are recognized.

In India, N rates range from 0-50 kg/ha N in Bihar, to 250-300 kg/ha N in Karnataka and Maharashtra, to over 350 kg/ha N in the south-east coastal area of Tamil Nadu. In general, the rate matches the intensity of irrigation which is higher in the tropics than in the subtropics (except the Punjab). As a simple rule, 1 kg N/t cane expected is given for plant cane and 1.25-1.50 kg N/t cane expected for ratoon crops. The optimum for ratoons is at least 25 % greater than for plant cane.

The rate is adjusted to the extent of 10 % of the recommended rate to allow for leguminous green manure of compost and farm yard manure which has been used, but no correction is permissible for any residual N from one sugarcane crop to the next.
### Table 5.4. General recommendations for application of nitrogen fertilizer for sugar industries in South Africa, Australia, Florida, Brazil, Hawaii and India.
(adapted from data given by Kingston 2000)

<table>
<thead>
<tr>
<th>Country</th>
<th>Organic matter status (%)</th>
<th>N mineralizing capacity</th>
<th>Crop stage and kg N/ha</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>South Africa</strong> (Meyer et al. 1986)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2</td>
<td>Low</td>
<td>120-140</td>
<td>160-200</td>
<td>Actual rate depends on bioclimatic region, rainfed or irrigated</td>
</tr>
<tr>
<td>2-4*</td>
<td>Moderate</td>
<td>100-120</td>
<td>140-160</td>
<td></td>
</tr>
<tr>
<td>2-4**</td>
<td>High</td>
<td>80</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>&gt; 4</td>
<td>Very high</td>
<td>60</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td><strong>Australia</strong> (Schroeder et al. 2005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 0.7</td>
<td>Very Low</td>
<td>140</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>0.7-1.4</td>
<td>Low</td>
<td>130</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>1.4-2.1</td>
<td>Moderately low</td>
<td>120</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>2.1-2.8</td>
<td>Moderate</td>
<td>110</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>2.8-3.5</td>
<td>Moderately high</td>
<td>100</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>3.5-4.2</td>
<td>High</td>
<td>90</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>&gt; 4.2</td>
<td>Very high</td>
<td>80</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td><strong>Florida</strong> (Anderson 1990)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy</td>
<td>Low</td>
<td>200</td>
<td>200?</td>
<td>Sandy soils, split applications</td>
</tr>
<tr>
<td>OM &lt; 35 %</td>
<td>Moderate</td>
<td>120</td>
<td>120</td>
<td>Sandy muck soils</td>
</tr>
<tr>
<td>OM 35-85 %</td>
<td>Very high</td>
<td>34</td>
<td>34</td>
<td>Mucky sand soils</td>
</tr>
<tr>
<td>OM &gt; 85 %</td>
<td>Very high</td>
<td>0</td>
<td>0</td>
<td>Muck soils</td>
</tr>
<tr>
<td><strong>Brazil</strong> (Penatti et al. 1997)</td>
<td>General</td>
<td>–</td>
<td>50 + fixation; legumes, wastes</td>
<td>100 + fixation; legumes, wastes</td>
</tr>
<tr>
<td><strong>India</strong></td>
<td>General</td>
<td>–</td>
<td>50-100</td>
<td>150-200</td>
</tr>
<tr>
<td><strong>Hawaii</strong> (Stanford and Ayres 1962)</td>
<td>General</td>
<td>–</td>
<td>224</td>
<td>224</td>
</tr>
</tbody>
</table>

*Refers to mainly non-red soils **Refers to mainly deep red clays (Nitosols, Rhodic Luvisols and Ferralsols)

### 5.2.6 How to adopt soil specific nitrogen recommendations

#### 5.2.6.1 Main steps involved

Fertilizer may comprise up to 30% of the variable costs of sugarcane production. Cost effective fertilizer advice is offered by many research service organizations and reputable fertilizer service providers. The optimum N fertilizer rate for the best economic return with minimal environmental risk, depends on a number of factors. These include climate, rainfall, crop stage, soil type, soil organic matter status, use of a legume break, history of burning versus green cane trash blanket practices, cultivar and irrigation. The following mainly soil specific guidelines for estimating the N requirement of sugarcane, based largely on South African and Australian experience, are proposed for general testing in other industries where no other system is available.
Box 5.7 Steps in adopting soil specific nitrogen recommendations

Step 1: Establish the moisture regime (whether the crop is rainfed or irrigated), the crop stage (whether plant or ratoon) and the length of the crop cycle.

Step 2: Determine the achievable crop yield potential from the guidelines given below.

Step 3: Determine the organic matter content and clay status from a laboratory analysis of a representative soil sample for the field concerned. If soil analytical data is not available proceed to step 4. If available, proceed to step 6. Estimate the soil nitrogen mineralization potential.

Step 4: If a soil map is available identify the main soil type of the field in terms of the World Reference Base soil classification system. Proceed to step 5 even if no map is available.

Step 5: Using the practical guidelines in the table below determine the main soil properties such as soil color, texture (especially clay content), structure and an estimate of soil organic matter.

Step 6: Refer to Table 5.5 and decide on the N mineralization potential category by matching the information obtained from step 2 or steps 3 and 4 with one of the available soil mineralization categories shown in the table.

Step 7: Plant cane N recommendations for either dryland or irrigated cane are inferred from Table 5.5. The ratoon N recommendations are inferred from the N usage baseline factor for the appropriate soil mineralization category multiplied by the achievable potential yield up to 100 t/ha. One kg of N is added for each additional t/ha above 100 t/ha. Examples are provided of calculated N requirements for achievable yields of ratoon cane ranging from 85 to 130 t/ha.
Table 5.5. Provisional guidelines for N recommendations based on achievable crop yield potential and soil nitrogen mineralization potential index (Modified from Meyer et al 2003 and 2006).

<table>
<thead>
<tr>
<th>Soil criteria</th>
<th>Nitrogen mineralization potential index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>WRB soil classification</td>
<td>Fluvisols,</td>
</tr>
<tr>
<td></td>
<td>Regosols,</td>
</tr>
<tr>
<td></td>
<td>Arenosols</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant soil colour</td>
<td>Pale light grey to bleached</td>
</tr>
<tr>
<td>Organic matter%</td>
<td>&lt; 1.00</td>
</tr>
<tr>
<td>Clay% range</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Structure</td>
<td>Structureless</td>
</tr>
<tr>
<td>Sample density range (g/ml)</td>
<td>&gt; 1.45</td>
</tr>
<tr>
<td>Estimated mineral N release (kg N/ha)</td>
<td>0</td>
</tr>
<tr>
<td>N baseline factors (kg/ha N)/tc</td>
<td>1.6</td>
</tr>
<tr>
<td>Dryland plant cane after bare fallow</td>
<td>120</td>
</tr>
<tr>
<td>Dryland ratoon (85 tc/ha)</td>
<td>140</td>
</tr>
<tr>
<td>Irrigated plant cane after bare fallow</td>
<td>140</td>
</tr>
<tr>
<td>Irrigated ratoon (100 tc/ha)</td>
<td>160</td>
</tr>
<tr>
<td>Irrigated ratoon (110 tc/ha)</td>
<td>170</td>
</tr>
<tr>
<td>Irrigated ratoon (120 tc/ha)</td>
<td>180</td>
</tr>
<tr>
<td>Irrigated ratoon (130 tc/ha)</td>
<td>190</td>
</tr>
</tbody>
</table>
5.2.6.2 Achievable yield potential guidelines

Box 5.8 Practical hints to be used in relation to Table 5.5

- Achievable yield potential using good management practices and assuming water is not limiting: This can be estimated from the formula previously mentioned (Thompson 1976; 1988) and multiplying by 0.80:

\[ Y = \frac{E_o}{100} \times 9.0 \]  

(5.2)

where \( Y \) = yield (tc/ha/an), and \( E_o \) = Class A pan evaporation per annum in mm fully replenished by rainfall and irrigation.

Alternatively, the average yield of cane in a particular district multiplied by 1.2 can also be followed as is practiced in Australia (Schroeder et al. 2006).

- Baseline N rate: This is considered to be the minimum or baseline rate for the respective N mineralization category. The corresponding baseline ratoon rates for the five N mineralization classes are 1.6, 1.45, 1.3, 1.15 and 1.0 kg/ha N for the low, low to moderate, moderate, moderate to high and high N mineralization categories (Meyer et al. 1983).

- Clay content may be estimated by feel (see Chapter 2). In general, clay content is well correlated with soil organic matter and correlations may be developed for local soil conditions.

- Sample density refers to the mass of a 100 ml of the air dried soil in grams divided by 100. Generally, sample density is inversely correlated with the soil organic matter content. In South Africa the relationship \( y = -5.7009x + 9.4758 \) has worked fairly well, where \( x \) is the sample density in g/ml and \( y \) the percentage organic matter content. As this relationship is strongly influenced by the content and composition of clay as well as the silt fraction, it is strongly advised that calibrations be developed specifically for local soil conditions.

5.2.6.3 Other specific factors that can affect N requirement

Factors that may require N recommendations to be altered:

Use of a legume fallow: Plant and ratoon crop N recommendations can be reduced by an amount ranging from 20 to 120 kg/ha N depending on the legume species and amount of biomass left in the field. A safe average for plant cane appears to be about 60 kg/ha N (see Schroeder et al. 2005).

Use of mill waste products: Where as much as 100 t/ha filter press mud is used at planting, 50 kg and 25 kg N/ha may be deducted from the N requirements of the plant crop and subsequent two ratoons respectively. Where fly ash/filter press mud is employed at 100 t/ha, the the above rates can usually be halved. As these products contain other valuable nutrients, a better practice will be to have a sample of the material analyzed by your local laboratory for moisture and a full nutrient content. Remember that adjustments need to be made for the moisture content of the material.

Soil depth: Within the constraint of moisture availability, the yield potential of cane growing on shallow soils is likely to be much lower under dryland cropping than that from cane growing on deeper soils. The results indicate that the N requirement can be reduced by 20 kg/ha for cane growing on shallow soils.
**Poor drainage:** In poorly drained soils, particularly in wet years, N losses through denitrification will be high and subject to leaf analysis. N dressings may have to be split.

**Pests:** Where damage from pests such as stalk borer, white grubs or nematodes is likely to be significant, the optimum level shown in Table 5.5 may be reduced by between 20 to 30 kg/ha N.

**Salinity/sodicity:** Salts at depth can potentially reduce effective rooting depth and the ability of roots to take up nutrients, and again the optimum N rate should be reduced by 20 to 30 kg/ha N.

**Harvesting age:** Where cane is harvested at a younger age than usual and at a low sucrose period, consideration can be given to reducing the N recommendation by 20 to 30 kg/ha N.

**Cane price to fertilizer cost ratio:** Where this is likely to be lower than usual, or in times of cane restriction, a reduction in N usage could be considered.

### 5.2.7 Nitrogen fertilizers

#### 5.2.7.1 Mineral fertilizers

A wide range of mineral fertilizers have been developed to supplement soil nutrients and to meet the high requirements of crops. Most mineral fertilizers are mineral salts, except for some organic chemicals such as urea, which are easily converted in the presence of water to form a weak ammonium carbonate salt. The range of N based fertilizers that are commercially available are shown in Box 5.9. They are categorized according to their main chemical groupings, whether amide, ammonium or nitrate based, and are valued according to their total nitrogen content.

- **Urea** is probably the most commonly used N carrier in many sugar industries because of high N concentration which translates into low transport and application costs. It is available in both granular and prilled form but is hygroscopic, particularly the prilled form. The granular form costs more because the granules are coated, and are therefore less prone to volatilization. When applied to soil, urea must first be converted by microbial action to ammonium, but the rate of transformation is temperature dependent. A major disadvantage of this carrier is the potential to lose N through volatilization especially when applied to unbuffered sandy soils, on all soils with a pH above 7.5 or when applied to organic residues such as trash due to the inherently high urease activity.

- **Calcium cyanamide** is expensive but, in addition to its fertilizer value, it has herbicidal and fungicidal properties due to intermediate decomposition products.

- **Anhydrous ammonia** has the highest concentration of N (82 %), but needs specialized equipment for its application. It is usually substantially cheaper than other N carriers and has been widely used in Swaziland (Batchelor & Shipley (1991) However, his carrier is not recommended for trashed fields nor in heavy or sandy fields as the application makes sealing of the tine furrow difficult.

- **Ammonium carriers:** Ammonium sulfate (AS) is among the lowest N content fertilizer (21 %) and was used extensively in the early days when urea was not available. A highly acidifying fertilizer and very suitable for application to alkaline soils. Also a valuable source of sulfur.

- **Nitrate N carriers** are generally very soluble and immediately available in the soil solution for uptake by sugarcane, but of all the N forms are the most prone to leaching losses. Because of their high solubility, nitrate carriers like potassium nitrate find favor in fertigation programs.

- **Ammonium nitrate carriers** such as calcium ammonium nitrate (CAN), also known as limestone ammonium nitrate (LAN), are widely used in many sugar industries. It is available in granular
form and because it is not excessively hygroscopic, it flows easily. There is no pH limitation when applying to soils.

- Ammonium N is also readily taken up through the root system, but its effect is a little slower than nitrate because it is first adsorbed and then only gradually released and nitrified.

**Box 5.9. Types of N fertilizers (N content refers to total N)**

**Amide fertilizers:**
- Urea (45-46 % N), calcium cyanamide (20 % N).

**Ammonium fertilizers:**
- Anhydrous ammonia (82 % N), ammonium sulfate (21 % N), ammonium bicarbonate (17 % N), all moderately quick-acting. Uptake by plants can be retarded by addition of nitrification inhibitors, e.g. dicyandiamide (DCD).

**Nitrate fertilizers:**
- Calcium nitrate (16 % N), sodium nitrate (16 % N), Chilean nitrate, all quick-acting and increasing soil pH.

**Ammonium nitrate fertilizers:**
- Ammonium nitrate (about 34 % N), calcium ammonium nitrate which is a combination of ammonium nitrate and calcium carbonate (21-27 % N), ammonium sulfate nitrate (26-30 % N).

**Solutions containing more than one form of N:**
- Urea ammonium nitrate solution (28-32 % N).

**Slow release fertilizers:**
- Either derivatives of urea with N in large molecules, or granular water soluble N fertilizers encased in thin plastic film, but slow or very slow-acting according to type of coating; partly including a quick-acting component.
- Or other means of slow release, e.g. sulfur coated urea (SCU).

**Multinutrient fertilizers containing N**
- NP: nitrophosphate NP (20-23 % N)
- Monoammonium phosphate = MAP (11 % N)
- Diammonium phosphate = DAP (18 % N)
- Liquid ammonium polyphosphates (e.g. 12 % N)
- Various granular mixes containing either NK or NPK.

### 5.2.8 Managing N fertilizer

#### 5.2.8.1 Choice of nitrogen carrier

Despite the fact that urea is subject to NH$_3$-N losses by volatilization and LAN, AS and urea suffer field losses of NO$_3$-N by leaching and denitrification, for many years the quoted average yield response to applied N from different carriers tested across a wide range of soils, have largely shown that different forms of N tended to give the same yield response (du Toit 1957; Wood 1968, Prammanee 1989; Wood *et al.* 1990; Denmead *et al.* 1993; Meyer 1995). In practice, the choice of N carrier is still largely driven by the price of a unit of N ($/kg N). The higher N content forms are usually the most cost effective, but increasing attention is being paid to improving fertilizer use through better placement and timing of operations.

#### 5.2.8.2 Placement of urea

In Australia subsurface placement of urea fertilizer is preferred to surface application, as this operation avoids volatilization NH$_3$-N loss and has out-yielded surface applied urea in field
experiments (Calcino and Burgess 1995). The environmental impact is also a lot lower as the risk of nitrogen loss in surface runoff is minimized. In practice with ratoon cane, the urea is placed below the surface on either side of the cane row, or knifed into the centre of the stool, behind a coulter disk. Equipment has been developed to bury the urea through a trash blanket but this increases the cost of N application. Urea should under no circumstances be placed on top of the trash as the urease enzyme contained in trash will generate a huge loss of N through volatilization NH$_3$-N loss. Delaying application of urea until the canopy is approximately 50 cm in height (Freney et al. 1994) also reduces volatilization losses, but was not as yield effective as was the subsurface placement (Calcino and Burgess 1995).

Recent research conducted in the South African sugar industry has underlined the importance of basing the choice of N carriers on soil-specific conditions (Schumann 2000). Field tests showed that volatilization loss of N from urea was greatest with band placement compared with broadcast placement and that light textured soils especially sands and loamy sands were associated with the highest risk of N loss. A new soil test permits soil-specific recommendations for good management practices (GMP) of urea, and advises the use of more stable solid alternatives such as LAN, ASN or ammonium sulfate using the % volatilization loss threshold values shown in Box 5.10 where applicable.

**Box 5.10 Thresholds for rating potential ammonia volatilization loss (after Schumann 2000)**

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 15%</td>
<td>Recommend a change from urea to a different N source such as LAN. Ammonium sulfate can be recommended where S is needed or where mild soil acidification is desirable, but definitely not on acid sandy soils.</td>
</tr>
<tr>
<td>5-15%</td>
<td>Recommend improving urea N efficiency by broadcasting rather than banding urea.</td>
</tr>
<tr>
<td>&lt; 5%</td>
<td>No special advice is given for the use of urea, which is the preferred source, provided its price remains competitive.</td>
</tr>
</tbody>
</table>

5.2.8.3 Timing of N fertilizer applications

With plant cane, timing of N fertilizer is not as critical as ratoon cane because the growth pattern is generally slower and there is an abundance of released mineral N following a crop fallow. With ratoon cane, timing is more important if fertilizer N use efficiency is to be maximized. Ideally, timing should be synchronized with the pattern of N uptake by the crop. In southern Africa the following guidelines are generally recommended for timing N fertilizer application to ratoon cane.

**Summer harvest:** top-dress all N within two weeks of harvesting previous crop.

**Winter harvest:** In the warm irrigated areas no significant benefits have been obtained from splitting N, except during very cold winters when regrowth is very slow and N uptake is inefficient. Under these conditions splitting is recommended for all N carriers as follows:

- March-May harvest: 1/3 N within two weeks of harvest, + 2/3 in August/September.
- June-July harvest: 1/2 N within two weeks of harvest, + 1/2 in August/September.
- August onwards harvest: Apply all N within two week of harvest. In the cooler region of the Midlands, N application can be delayed until September.

Under certain conditions, splitting may be beneficial on soils with restricted drainage to prevent loss of N through denitrification and on sandy soils (Meyer and Wood 1994). Use a six to eight week split according to the harvesting season:

- May-June harvest: apply 1/3 initial, + 2/3 top-dressed.
• July-August harvest: apply 1/2 initial, + 1/2 top-dressed.
• September onwards: apply all initial.

5.2.8.4 Fertigation
Drip irrigation is considered efficient as it facilitates more accurate and flexible application of soluble fertilizers through the irrigation system (fertigation), leading to greater N fertilizer efficiency compared with conventional N application. It has been demonstrated in the Australian and Mauritian sugar industries that N applied as split treatments through the dripper can reduce N usage by between 30 and 50 % (Thorburn et al. 1998; Ng Kee Kwong et al. 1999). However, a major disadvantage is that fertigation schedules will rely heavily on seasonal factors and the phenology of the crop. Nutrients are continuously taken up by sugarcane in accordance with the different growth stages. There is initially a great emphasis on N and P during the germination and canopy phases, increasing for a summer crop in an exponential manner, followed by a linear uptake of N, P and K during the grand growth phase (see Chapter 1), with a marked tailing off of N but a continued uptake of K and P during the crop maturation phase. The variation in N uptake for different cropping cycles is illustrated by the N growth curves shown in Fig. 5.9.

![Figure 5.9. Nitrogen accumulation in cultivar N14 for three cropping cycles (Thompson 1991).](image)

In the irrigated areas of Swaziland, cumulative nitrogen uptake curves were tested for a late season summer cycle plant crop and for an early season winter cycle first ratoon crop. Results indicated that the winter N uptake curve correctly predicted the proportional monthly N demand of a winter ratoon crop, but appeared to underestimate the N demand of a summer plant crop between January and April (Butler et al. 2002). Follow-up trials conducted in neighboring Mpumalanga province of South Africa showed that splitting the fertilizer applications and applying N via the irrigation system was of special advantage in early season cycles. This is attributed to the lengthy demand for N in early season crops as reflected by the N demand curve being better matched by the split doses. In the late season summer cycle trial there was no yield advantage to splitting N compared to the single incorporated urea placement treatment (Weigel et al. 2008).
Box 5.11 Advantages and disadvantages of fertigation

Advantages include:
- Better control of nutrient supply according to growth stages.
- Flexibility in adapting nutrient supply according to different crop cycles as determined by season.
- Control of leaching losses of nutrients especially in sandy soils which has environmental implications.
- Where urea is used as the N carrier, N losses through volatilization as ammonia can be greatly reduced.
- Less labor is needed.

Disadvantages include:
- Crop removal of nutrients is highly dependent on season, locality, soils and cultivar. This implies that multiple growth curves must be drawn up and levels and ratios of nutrients determined for the conditions in question.
- Management factor must be very high and an understanding of the physiology of the plant is needed.
- Invariably the inherent soil fertility status in this approach is ignored and there is likely to be a build-up of nutrients over time, which will lead to luxury uptake of nutrients and a negative impact on quality.
- High purity nutrient sources are required, which increases the cost of crop production.
- Fertigation with vinasse or CMS may result in blockages, depending on the type of dripper used.

5.2.8.5 Side effects of nitrogenous fertilizers
An important side effect of nitrogenous fertilizers is the acidifying effect of ammonium and amide fertilizers during the nitrification process. The proton release $H^+$, associated with the nitric acid that is formed, is a powerful acidification source. Since this has to be counteracted by liming, it is convenient to express it in terms of the equivalent loss of CaO (Table 5.6).

Table 5.6 Soil acidification by nitrogen fertilizers (after IFA World Fertilizer Use Manual 1999)

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Amount of lime (kg) needed to neutralise acidification induced by 1 kg of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium ammonium nitrate (27 % N)</td>
<td>1</td>
</tr>
<tr>
<td>Ammonia, urea, ammonium nitrate</td>
<td>2</td>
</tr>
<tr>
<td>Diammonium phosphate, ammonium sulfate nitrate</td>
<td>3.5</td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>5</td>
</tr>
</tbody>
</table>

The transformation of ammonium to nitrate by bacteria, proceeds quickly when temperatures increase. At temperatures of 20-25 °C an application supplying 50-100 kg/ha N has the potential to nitrify in about one to two weeks. Special nitrification inhibitors added to fertilizers can delay nitrification for several weeks.

5.2.8.6 Organic nitrogen carriers
Inorganic fertilizers are generally more popular than organic by-products such as chicken litter and filter press mud, mainly because organic products are bulky to transport and are sometimes difficult to apply. If not packaged and certified they need to be analyzed before use, as their nutrient balance is often not suitable for sugarcane and might need to be supplemented with inorganic fertilizers.
However, given the recent volatility in the price of fertilizers, as well as environmental and health concerns, there has been an increasing demand for advice based on the use of bio-fertilizers such as chicken litter, filter cake, kraal manure and pig slurries. Poultry litter is potentially the most valuable as it usually contains less than 35 % moisture, and at least 60 % of the total N and 50 % of the total P is considered to be immediately available to the crop (Moberly et al 1971). Five t/ha in the furrow can provide sufficient N, P and K for a plant cane crop growing on a humic soil without using additional fertilizer. This provides a saving of between 10 to 25 % to the grower, subject to the landed cost of the poultry litter. Similar savings may be obtained for fertilizing ratoon cane with poultry litter. Where co-products or agricultural wastes are available at reasonable prices, they are certainly worth considering (Table 5.7).

Some farm wastes are used because recycling is the only effective and beneficial means of disposing of them. An example is vinasse, also known as stillage or distillery slops, which is produced at about 13 liters for each liter of ethanol from molasses, or around 8 liters from cane juice. The product is widely used as a potassium source in Brazil as well as in other countries producing ethanol from sugarcane. In South Africa, Condensed Molasses Solubles (CMS) which contain 45-50 % solids, has recently been developed from the evaporation of vinasse to a Brix value of between 50 and 60 %. The main driver has been to reduce the cost of transport of raw vinasse from the distillery to distant farms (Lyle 2006). Impressive yield and soil fertility benefits have also been obtained from using vinasse in Brazil (Korndörfer and Anderson 1997), Taiwan (Wang et al. 1996) and Zimbabwe (Matibiri 1996), and with CMS in Swaziland (Turner et al. 2002). More detailed information on the use of both products is given in Chapter 13.5.

| Table 5.7. Range in nitrogen content for selected organic N carriers. (after Barry et al. 1998) |
|---------------------------------|------------------------|
| Organic carrier                 | N % range              |
| Mill Waste materials            |                        |
| Filter mud                      | 0.8 - 2.2              |
| Filter mud/ash mixtures         | 0.4 - 0.8              |
| Mill ash                        | 0.1 - 0.5              |
| Vinasse/dunder                  | 0.05 - 0.8             |
| General wastes                  |                        |
| Sewage sludge                   | 0.5 - 6.6              |
| Animal manures (farmyard manure, |                        |
| liquid manure, slurry)          | 0.5 - 5.0              |
| Compost (mixture of decomposed  |                        |
| plant residues, etc.)           | 0.5 - 3.5              |
| Green manures (leguminous or    |                        |
| other crops incorporated into the soil) | 1 - 3.5 |
5.3 Phosphorus (P)

5.3.1 The importance of phosphorus

Phosphorus, along with N and K, is an essential element for sugarcane growth and reproduction and the central role of P is its contribution in energy transfer and metabolism in the cane plant, especially in establishing a healthy root system. Phosphorus is present in both the organic and inorganic forms and is absorbed by the roots mainly in the form of \((H_3PO_4)\) when the soil pH is below 7.2, and as \((HPO_4)^2\) when the soil pH is above 7.2.

The impact of phosphorus in enhancing crop yields in highly weathered acid soils is well documented (Fageria and Baligar 2001) and for sugarcane in particular (Meyer and Wood 1989). The risk of P deficiency is particularly high for sugarcane growing on the red oxisol soils that are common throughout tropical and subtropical cane producing areas, due mainly to their inherent capacity to strongly fix applied P.

5.3.2 Physiological role of phosphorus

<table>
<thead>
<tr>
<th>Box 5.12 Functions of phosphorus in sugarcane</th>
</tr>
</thead>
<tbody>
<tr>
<td>- A component of nucleic acids which are crucial for cell division.</td>
</tr>
<tr>
<td>- Needed for energy rich bonds (ADP and ATP) and therefore plays a role in carbon dioxide assimilation from photosynthesis.</td>
</tr>
<tr>
<td>- Important in cell division and plant proteins needed for growth of root systems, tillering and shoot growth.</td>
</tr>
<tr>
<td>- P deficient plants show poor tillering and thin, short stalks with short internodes, while leaf blades are dark green to blue-green, often with red or purple tips and margins in advanced deficiency (see Fig 5.10).</td>
</tr>
<tr>
<td>- P is not very mobile in the soil and in highly weathered soils applied P can be fixed, necessitating the application of P fertilizer in the furrow at planting to ensure a readily available supply of P to the newly developing roots.</td>
</tr>
<tr>
<td>- Great care must be exercised to avoid over-application of P in view of potential severe environmental impacts as a pollutant of water sources.</td>
</tr>
</tbody>
</table>
Phosphorus deficiency

- Thin, narrow short leaves with a bronze blue/green or purple color, affects the the older leaves first
- Die back occurs from the tip, leaves become thin
- Stalks become thin and poor tillering is very characteristic of P deficiency
- Very poor stunted roots
- Excess P may cause micronutrient deficiencies in the plant (Zn and Fe)
- Most countries use a leaf critical value of Between 0.17% and 0.19%

Figure 5.10. Symptoms of P deficient cane and critical values used for leaf analysis.

5.3.3 Phosphorus cycle in the soil

Although phosphates move quickly through the sugarcane plant, the P cycle in the soil is by comparison a complex and slow process that involves the soil, plants and microorganisms. The important components of the P cycle are P uptake by sugarcane, recycling through the breakdown and biological turnover of trash and the return of mineralized P, solubilization of mineral phosphates of calcium, aluminum and iron through microorganisms, fixation of soluble forms of P through precipitation by soluble forms of Al, Fe or Ca and adsorption by sesquioxic clay colloids (Fig. 5.1). Available phosphorus is found in a biogeochemical cycle in the upper soil profile, while phosphorus found at lower depths is primarily involved in geochemical reactions with secondary minerals. Plant growth depends on the rapid root uptake of phosphorus released from dead organic matter in the biochemical cycle.

In new land, P reserves in soils are invariably unavailable for plant uptake, being held in organic, inorganic or sorbed forms. Only a small proportion of the total soil phosphorus is therefore available for plant uptake. On the other hand, in many of the older more established sugarcane areas, P has accumulated in the soil due to a history of recycling P rich filter press mud back to sugarcane lands. In these circumstances, and depending on the soil test P values, P is usually not required, although where levels are just above threshold, maintenance applications of P fertilizer may be considered.
5.3.4 Factors affecting phosphorus availability

5.3.4.1 Mineral P forms
Traditionally mineral soil phosphorus reserves have been divided by Heck (1934) into three fractions according to their availability to the plant:

1. Readily available (water soluble \( \text{H}_2\text{PO}_4^- \) and \( \text{HPO}_4^{2-} \) anions from \( \text{Ca} (\text{H}_2\text{PO}_4)^2\cdot\text{H}_2\text{O} \)
2. Slowly available (\( \text{AlPO}_4 \))
3. Very slowly available reserves \( \text{Ca}_3(\text{PO}_4)_2 \) and \( \text{Fe PO}_4 \).

A glasshouse study conducted in the South African sugar industry by du Toit (1957), using single superphosphate, aluminum, iron and calcium tri-phosphate as sources of P fertilizer, confirmed that the availability of P to sugarcane from the \( \text{AIPO}_4 \) was surprisingly high, equivalent to 60% of the response from single superphosphate, whereas P from \( \text{Ca}_3(\text{PO}_4)_2 \) and \( \text{Fe PO}_4 \) were only slightly beneficial.

More recently a further glasshouse study was conducted to determine the amount and rate of P available to sugarcane from the various P fractions under continuous cropping on different soils (Meyer and Wood 1989). More P was removed by five successive cane crops than could be accounted for by the decline in Truog extractable P. Changes in the amounts of Al, Fe and Ca phosphate with time indicated that most of the additional P was derived from \( \text{AIPO}_4 \). Over the cropping period the amount of P present in the soil in this form declined from 65 to 25 mg/kg soil. The difference of 40 mg was only slightly less than the total amount of 45 mg/kg P removed by cropping.
5.3.4.2 Soil pH
Phosphorus availability is at an optimum in the pH range 5.5 to 7.2 when both plant available ionic forms of P, namely \((H_2PO_4)^{1-}\) and \((HPO_4)^{2-}\) will simultaneously be available. If the pH is increased too high, \((PO_4)^{3-}\) ions will dominate which will become prone to precipitation by soluble forms calcium and Mg.

5.3.4.3 Fixation by chemical precipitation
A further consequence of pH change is that phosphate binds tightly to iron and becomes unavailable to plant roots, especially at a soil pH below 5 (acidic), and with aluminum fixation also occurs but not to the same extent, nor is the process irreversible as research outcomes have shown (Meyer and Wood 1989). If the soil has a low pH, applying lime will raise the pH and lessen the tendency for the P to become unavailable. Conversely, at high pH (alkaline soils), calcium binds to P and reduces its availability. P is most available at a pH of between 6 and 7 (see Fig. 5.12).

![Figure 5.12. Relationship between pH and different forms of P fixation.](image)

5.3.4.4 Fixation by hydrous oxides
In addition to chemical and precipitation reactions, there is another mechanism referred to as physiochemical fixation of phosphorus, which is caused by the adsorption of P onto positively charged colloids comprising sesquioxides rich in iron (iron and aluminum oxides, allophane, kaolinite) and humus-aluminum complexes. A rapid soil test based on using P adsorption isotherms, referred to as the phosphate desorption index (PDI), is used to provide information on the extent of phosphorus fixation in a soil sample, which is then used to modify phosphorus fertilizer advice in the South African sugar industry (Meyer and Dicks 1979). In the Australian sugar industry, P fertilizer recommendations are also now modified using a phosphorus buffer index (PBI) test (Burkitt et al. 2000).

5.3.5 Phosphate carriers
In general with the exception of rock phosphate, mill mud and mill ash, all the values reported in Table 5.8 are water soluble P contents. The values range from 9.5 % for single super to an average of 23 % for phosphoric acid. Fertilizers such as single, double or triple superphosphate, mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP) and various NPK mixtures are applied
in the furrow at planting to ensure healthy root development for newly established cane. The choice of carrier will depend on the cost of per unit P of the carrier, which will vary from country to country. In Australia, for example, triple superphosphate is usually the cheapest form of phosphorus but the savings in application costs by using mixed fertilizers such as MAP or DAP, and the benefit of some N in the furrow enabling quicker canopy and better weed control, makes the latter P carriers the favored choice at planting, in many cane producing areas. Rock phosphate generally works well when applied as a broadcast treatment to acid soils and has good residual P effects that often last into the fourth and fifth ratoon crops, but should initially be supplemented with an in-furrow application of about 30 kg/ha P as MAP. However, care should be exercised in having the cadmium content of rock phosphate checked, given that this heavy metal has potential health and environmental risks.

Traditionally filter press mud has been a valuable source of plant available phosphorus, but the high moisture content (60 to 70 %) when taken fresh from the mill, greatly adds to the transport costs to the extent that usage is normally restricted to within 15 km of the mill. Many of the large mills in Brazil now compost mixtures of the mud, often with ash and other ingredients such as vinasse, to reduce the moisture content to below 30 % of its mass and the C/N ratio to below 20:1.

5.3.6 Managing the P requirement of sugarcane

5.3.6.1 The value of soil testing

Various chemical extractants to estimate plant available P and fertilizer P requirement have been employed in sugar industries across the world. Details of extractants used in selected countries are shown in Table 5.8. It would appear that acid extractants are still the most favored means to estimate plant available P levels, and that the modified Truog method (Truog 1930), is still the most widely used for advisory purposes in countries such as Mauritius, Brazil, the Philippines, Hawaii, Australia and South Africa.

In South Africa the Truog extractant has been carefully calibrated for sugarcane over many years under a wide range of bioclimatic and soil conditions, by correlating soil analysis data with yield responses to P treatment in 31 exploratory 3Nx3Px3K factorial trials and 53 4Nx2Px3K regional fertilizer trials. Of the many methods that have been tested, including Bray P1 and a surrogate method of Ambic, the modified Truog extractant gave the best correlation between soil P levels and response to applied P fertilizer (du Toit et al. 1962). The trial data indicated that the response to applied P for plant cane was inversely related to the level of plant available P prior to treatment, and economic responses at soil P levels in excess of 30 mg/kg were extremely unlikely. For whole cycle crop advice a threshold value of 31 mg/kg has been used at SASRI to meet the P requirement of the plant and fIrst ratoon crop but for single ratoon crop advice a threshold value of 11 mg/kg has been shown to be adequate(Wood 1985). In a number of countries soil P levels have built up over many years usage of filter press mud at planting. Under Australian conditions, use of P fertiliser cannot be justified economically for ratoon cane where soil analysis shows phosphorus levels are well in excess of the threshold for a response eg. >40 mgP /kg soil (Kingston 2000). For soils with P levels closer to the yield response threshold level, maintenance fertilising should be implemented, with applications varying in accordance with biomass removal from 20-50 kgP/ha.

In South Africa, from an advisory viewpoint, sufficient P is recommended at planting to raise the soil P level to 40mg P/kg soil in accordance with the amounts of P extracted from the soil. The amount of P needed to make up 40 mg P/kg soil is sufficient to meet the P requirements of at least the plant crop and the first ratoon (Wood 1985 and SASRI Information sheet 7.2). In South Africa single superphosphate, ammoniated supers, mono-ammonium phosphate and di-ammonium phosphate are commonly recommended, as well as NPK mixtures such as 2:3:4 or 2:3:2. Subsequent ratoon
cane requirements should be top-dressed as soon after harvest as possible.

Because conventional extractants cannot predict the fate of applied P fertilizer in terms of P fixation, a rapid phosphorus desorption index (PDI) soil test method, based on the P adsorption isotherm principle, was introduced for mainly Ferralsol and Oxisol soils to supplement the standard soil extraction procedure (Meyer and Wood 1989). Depending on whether the soil is strongly, moderately or weakly P-fixing, the furrow application is increased to 120, 100 or 90 kg P/ha respectively. For medium and high P-fixing soils with Truog P levels below 13 mg/kg, supplementary broadcast P applications are also now recommended in conjunction with the normal furrow P applications (SASRI Information sheet 7.2).

Table 5.8. Soil tests used in selected countries in relation to soil P threshold values and P fertilizer recommendations. (adapted from data given by Kingston 2000)

<table>
<thead>
<tr>
<th>Country</th>
<th>Australia</th>
<th>South Africa</th>
<th>Hawaii</th>
<th>Florida</th>
<th>Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main soil type</td>
<td>Fluvisols</td>
<td>Cambisols, Arenosols</td>
<td>Ferralsols</td>
<td>Histosols</td>
<td>Ferralsols, Nitosols</td>
</tr>
<tr>
<td>Soil test</td>
<td>Modified Truog</td>
<td>Modified Truog</td>
<td>Modified Truog</td>
<td>Bray P2</td>
<td>Resin</td>
</tr>
<tr>
<td>Main extractant</td>
<td>Acid 0.005M H₂SO₄</td>
<td>Acid 0.01M H₂SO₄</td>
<td>Acid 0.01M H₂SO₄</td>
<td>Acid 0.03M NH₄F</td>
<td>Water</td>
</tr>
<tr>
<td>Critical soil</td>
<td>&lt; 10 mg/kg</td>
<td>&lt; 11 mg/kg</td>
<td>30 mg/L</td>
<td>&lt; 14 mg/kg</td>
<td>&lt;5mg/kg</td>
</tr>
<tr>
<td>Optimal soil</td>
<td>&gt; 20 mg/kg</td>
<td>&gt; 31 mg/kg*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant cane P/ha</td>
<td>20-80</td>
<td>0-60</td>
<td>0-200</td>
<td>0-40</td>
<td>0-50</td>
</tr>
<tr>
<td>Ratoon cane P/ha</td>
<td>0-80</td>
<td>0-50</td>
<td>0-100</td>
<td>0-40</td>
<td>0-30</td>
</tr>
<tr>
<td>Comment</td>
<td>Rate depends on soil value and cane yield</td>
<td>Rate modified by PDI up to 160 kg P/ha</td>
<td>P split if &gt; 50 kg P/ha</td>
<td>Rate depends on soil value</td>
<td>Rate depends on soil value</td>
</tr>
</tbody>
</table>

5.3.6.2 The reliability of soil tests

Given that P is the most expensive primary nutrient on a unit basis in most cane producing areas, the question may well be raised as to how reliable soil test procedures are in predicting the P requirement of a sugarcane crop. A literature search will normally reveal very little information on this aspect.

In testing the reliability of these threshold values, Bishop (1967) concluded that responses to applied P would have been correctly predicted in 72% of instances and incorrectly in 16%, while predictions in the remaining 12% would have been of doubtful value. Subsequent trials conducted in Pongola have confirmed these threshold values (Meyer and Wood 1989), while a recent study carried out on Swaziland soils, using a range of soil extractants, showed that the Truog soil extractant provided the best correlation with yield response to applied P fertilizer (Henry et al. 1993).

A word of caution to new users, when you select a soil test laboratory for the first time, apart from checking on the normal accreditation requirements for a laboratory to operate, make sure that the...
methods being used have been calibrated in the field under local conditions, for at least the P and K requirement and that published peer reviewed publications are available to support this. If in doubt, request the laboratory to use one of the recognized soil extractants for which soil P threshold values have been established in the field, such as the modified Truog or Bray P2 for acid soils, or the Olsen extractant where soil pH values are most likely to be above 7.5. Even if free soil tests are offered, the temptation should be avoided to convert threshold values derived for a recognized extraction procedure to threshold values for another method by using conversion factors, based on a regression function for analysis of a range of soils.

A case study conducted in Mpumalanga, South Africa, showed that many growers were applying excessive amounts of P fertilizer because they had switched to a laboratory that was using a weaker extractant for P, but the weaker P extractant values were still being related to the Truog 31 mg/kg threshold value. Workshops were organized locally with fertilizer companies, laboratories and consultants, and on a national level with the Fertilizer Society of South Africa and AgriLASA, to standardize the soil test procedure for P requirements in sugarcane (Botha and Meyer 2004). This initiative was successful and all parties involved agreed to standardize on the Truog method subject to any changes that may be indicated by new research outcomes.

5.4 Potassium (K)

5.4.1 Importance of potassium

Unlike N and P, potassium (K) in the soil is predominantly present in inorganic forms, in minerals such as feldspars and micas. However, while a range of soils may be well supplied with these minerals, showing a high total K content, actual plant available K levels may be low due to the low solubility of K in these minerals. Potassium is acquired as the K⁺ ion from the soil solution by roots, and is found mainly in water soluble forms in the cytoplasm.

When the exchangeable K reserves of the soil fall below the respective threshold value the concentration of K⁺ in the soil solution also becomes depleted and sugarcane will soon show classic symptoms of K deficiency in the older leaves, due to the redistribution of potassium to actively growing tissue. Lower leaves develop a deep yellow to orange color, with tips and margins becoming necrotic, while younger leaves may remain green. In advanced deficiency scorching of outer edges of the leaf occurs, as well as red discoloration of the midrib.
5.4.2 Physiological role of potassium

Box 5.13 Functions of potassium and impact on cane quality
- K is essential for plant growth and photosynthesis.
- Plays an important role in controlling the moisture economy of the plant through osmo-regulation in stomata.
- K is the most abundant in cane juice to the extent that between 30 to 50 % of ash in cane juice comprises K$_2$O (Irvine 1978; Clarke 1981).
- Increased ash in juice results in lower recovery of sugar crystal from cane (Irvine 1978; Clarke 1981).
- Regulates at least 60 enzymes involved in plant growth.
- Associated with maintaining photosynthesis by preventing degradation of chlorophyll, by maintaining the necessary pH gradient for ATP synthesis.
- Assists with the control of starch formation in the stalk and stimulates translocation of sugars in the phloem.
- Some evidence that K treatment can assist with reducing the incidence of eyespot disease (Lee and Martin 1928).
- Leaf symptoms of K deficiency are shown in Fig 5.13.

Potassium leaf deficiency symptoms
- Leaf borders and tips show yellow to orange chlorosis
- Scorching of the outer edges
- Midrib may have a red colouration
- Older leaves may be entirely fired
- Young leaves remain dark green
- Critical leaf value is 1.05 % in most countries with leaf values in excess of 1.75 % pointing to luxury K uptake

Fig 5.13 Main symptoms of potassium deficiency shown in the TVD leaf (after Anderson and Bowen 1990).

5.4.3 Potassium cycle in the soil

Almost all K in the soil is present in the inorganic form. The average content of K in the lithosphere is approximately 2.6 % with about 0.8 % occurring in soils (Lindsay 1979). K is present in essentially four main forms which are in dynamic equilibrium with each other. These include soluble K (0.1-0.2 % of the total), exchangeable K (1-2 %), non-exchangeable K (1-10 %) and mineral K (90-98 %) (after McLaren and Cameron 1996).

Therefore only a small fraction of the total K, namely the soluble and exchangeable K forms are available for plant uptake. The non-exchangeable pool is only slowly available while the mineral pool
is relatively unavailable. The bulk of this unavailable K is contained in K bearing feldspars and micas which on weathering releases only small amounts of K which is released into the slowly available non-exchangeable pool. The non-exchangeable K pool consists mainly of K that is trapped between layers of 2:1 lattice clays, but which can be released on drying and the released K is available to replenish the exchangeable K and soil solution K pools. Of the readily available K, about 10% is found in the soil solution and the balance on the clay particles (Fig. 5.14).

![Figure 5.14. Potassium cycle in the soil-plant-animal system (from Syers 1998).](image)

The importance of slowly available sources of K should not be overlooked from the point of view of fertilizer usage, as many soils can release substantial amounts of non-exchangeable K during a season, e.g. certain alluvial soils and those derived from granite/schist, which contain large amounts of non-exchangeable K.

5.4.4 Factors affecting potassium availability

K uptake during sugarcane growth is a dynamic process with periods of active growth and K depletion from the root zone causing an imbalance in the equilibrium and a shift in the reaction to the right in the above schematic, with release of mineral and non-exchangeable K to restore the K in the exchangeable and soluble K pools that was removed by the crop.

Clay mineralogy and K fixation

An imbalance in the soil K equilibrium can also occur when there has been an over-exploitation of soil K reserves, and application of fertilizer K results in a shift of the above reaction to the left with applied fertilizer K being fixed by K selective clay minerals within the clay lattice. In recent N/K fertilizer trials, particularly those in the Swaziland lowveld, potash applications have sometimes either failed to increase leaf K content, or these increases have been relatively small following substantial applications of K fertilizer (Wood and Meyer 1986). This could be because some of these soils exhibit strong K-fixing properties, as many of them contain a high proportion of K selective clay minerals such as smectite and vermiculite.

Although higher applications of K fertilizer are required under these conditions, the application of K may not immediately rectify the problem. Further applications of K will result in smaller quantities being
fixed, with more K being available for crop growth. Ultimately, after several applications of K fertilizer, a state of equilibrium will again be achieved, fixation will be at a minimum, and the grower need only apply maintenance dressings in sufficient amounts to prevent a recurrence of the former condition. The precise mechanisms that govern fixation and release of K are not as yet finally established, although it has been shown that 1:1 lattice clays such as kaolinite fix little potash, whereas the 2:1 lattice clays such as montmorillonite and smectite by comparison have a high potential to fix K. Thus, highly weathered soils such as Ferralsols that contain mainly kaolinite fix little potash when compared with Vertisols that have a high capacity to fix K, particularly under cool wet conditions. In contrast to the heavy soils where fixation of potash easily exceeds losses of K by leaching, the opposite occurs in sandy soils such as the Arensols and Regosols. Here leaching of K is a problem and fixation is negligible to the extent that growers are advised to split the fertilizer K application.

**Soil temperature and moisture**
The interaction between soil temperature and moisture content is also important in the uptake of K by crops. These two factors influence chemical and biological reactions in the soil and the physical movement and availability of K (Leverington et al. 1962). Low soil temperatures in the winter under wet conditions were the reasons initially proposed by Meyer and Wood (1985) and later confirmed by Donaldson et al. (1990) for low leaf K levels in sugarcane despite the fact that laboratory analysis showed the soils to be well supplied with K. The laboratory analysis is carried out on oven-dried samples at an extraction room temperature of around 22 °C, conditions that are very different from soils close to field capacity and soil temperatures of 16 °C in the field. To improve the accuracy of the soil test method, Donaldson et al. (1990), recommended a higher threshold value for soil K for base saturated soils, with more than 40 % clay and where irrigation generally does not allow drying and cracking of the soil. The higher threshold indirectly makes provision for K release from the exchange complex when the soil is dried for analysis. Furthermore, for cane cut on a winter cycle, K fertilizer should be applied soon after harvest for cane grown on 2:1 clay soils.

**Calcium and magnesium antagonism**
Availability and uptake of K may be inhibited by high levels of Ca and/or Mg in soil, as identified in British Guiana (Evans 1959), British Honduras (Humbert 1968), South Africa (Wood and Meyer 1986) and Hawaii (Santo et al 2000). Unlike Ca and Mg, which are rapidly translocated in the transpiration stream by mass flow, K moves more slowly by diffusion across an electrolyte gradient between soil and roots, and there is some speculation that high levels of Ca and Mg will further interfere with the migration of K. Donaldson et al. (1990) suggest that K nutrition needs special attention when base saturation as measured by the ratio (Ca+Mg)/K is greater than 20 (when units of measurement are mg/kg for cations). In Hawaii, long term use of irrigation water rich in Mg, has increased the Mg status to the extent of producing visual symptoms of K deficiency, despite applying the standard rate of K fertilizer (Santo et al, 2000).

**Subsoil K**
A factor which has received insufficient attention when K fertilizer recommendations are made for cane is the contribution that the subsoil makes to the available K requirement of the crop. Routine soil testing is generally restricted to the topsoil (0 to 200 mm) although roots can also take up nutrients from greater depths. Grimme (1980) found that as moisture content of a loess topsoil decreased together with nutrient uptake rates, up to 50 % of the daily K requirement of the crop could be supplied by the subsoil. Work at Mount Edgecombe has confirmed that considerable amounts of crop available K were present to depth, together with substantial K reserves based on electro ultra filtration (EUF) and HNO₃-K methods (Wood 1985).
5.4.5 Potassium sources

These sources are mainly derived from geological saline deposits. Although low-grade, unrefined materials can be used directly, most fertilizer available is now in the form of higher concentration products, all of which are water soluble and quick acting. Of the mill wastes and co-products, vinasse and CMS are probably the most widely used in various cane producing areas. VINASSE, also known as stillage or slop, is a by-product from the distillation process to produce ethanol from molasses or sugarcane juice. It has a brown color when it is released from the still but becomes darker in color when exposed to the air. It has a low pH in the range 4 to 5 due the presence of sulfuric acid which is used in the fermentation process (Korndorfer and Anderson, 1997), (Donzelli et al 2005). CMS is produced by evaporating vinasse and can be supplemented with N or P to provide a valuable liquid fertilizer (Lyle 2006), (Turner et al 2002). Further details concerning the composition, and management of these two products is given in Chapter 13. Potassium sources that are available, both as fertilizers and as mill co-products and wastes, are summarized in Table 5.9.

Table 5.9. The potassium content of a range of fertilizer materials and mill wastes.

<table>
<thead>
<tr>
<th>Potassium carrier</th>
<th>Potassium content %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fertilizer</strong></td>
<td></td>
</tr>
<tr>
<td>Potassium chloride (muriate of potash)</td>
<td>50.0</td>
</tr>
<tr>
<td>Potassium sulfate (sulfate of potash)</td>
<td>41.0</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>38.3</td>
</tr>
<tr>
<td>Potassium magnesium nitrate</td>
<td>18.0</td>
</tr>
<tr>
<td>Potassium carbonate</td>
<td>56.0</td>
</tr>
<tr>
<td>Potassium monophosphate</td>
<td>29.0</td>
</tr>
<tr>
<td>Potassium diphosphate</td>
<td>45.0</td>
</tr>
<tr>
<td>Potassium magnesium sulfate (potash magnesia)</td>
<td>33.0</td>
</tr>
<tr>
<td><strong>Mill wastes</strong></td>
<td></td>
</tr>
<tr>
<td>Vinasse</td>
<td>0.15-0.40</td>
</tr>
<tr>
<td>CMS</td>
<td>3.5-4.5</td>
</tr>
<tr>
<td>Fly ash</td>
<td>1.5-3.0</td>
</tr>
<tr>
<td>Filterpress mud</td>
<td>0.05-2.0</td>
</tr>
</tbody>
</table>

5.4.6 Managing the K requirement of sugarcane

Some notable advances have been made in determining the K requirement of sugarcane worldwide which includes field trials to determine optimum rates of K fertilizer and the calibration of soil and leaf tests against yield response to applied K. Early pioneers in the fifties and sixties such as Innes and Chinaloy (1951) in Jamaica, du Toit (1957) in South Africa, Vallance (1952) and Leverington et al. (1962) in Australia, and Locsin (1956) in the Phillipines, conducted hundreds of NPK factorial experiments to determine the N, P and K requirements of sugarcane, establish threshold values of these nutrients in soil as well as leaf analysis. Subsequent studies by Humbert (1968), Haysom, (1971), Wood and Burrows (1980), Hunsigi and Srivastava,(1981). Wood and Meyer (1986), Donaldson et al (1990) and Hawaii (Santo et al. 2000) focused on refining the previously established threshold values to improve the reliability of predicting the K requirement of sugarcane.

Response of sugarcane to applied K

In general sugarcane response to applied K is not as marked as that of nitrogen. Results from a number of countries indicate that ratoon cane is more responsive than plant cane because soil K reserves are converted to available forms during the fallow period. As an example, in South Africa
under dryland conditions only nine out of 31 exploratory 3Nx3Px3K trials and 18 out of 53 RFT 4Nx2Px3K trials showed a significant response to applied K in the plant crop. The combined average response to the 93 kg K/ha treatment amounted to 5.5 tc/ha while a further 93 kg K/ha gave little additional response (Wood and Meyer 1986). The response to K treatment in ratoon cane was considerably better than that for plant cane. In 15 exploratory and 24 RFT trials, significant responses were obtained to applied K. In the RFT trials, the average response to the 140 kg/ha and 280 kg K/ha treatments amounted to 13 and 17 tc/ha respectively.

Response to applied K in relation to soil K levels
In light textured soils, responses to K treatment were found to increase progressively in succeeding ratoons. In the heavier textured soils, responses to applied K in succeeding ratoons tended to be smaller due to the build-up of residual K from previous applications. In general, for the above trials, the response to applied K in the ratoon crops was inversely related to the pre-treatment soil K level using a 1N ammonium acetate extraction procedure (see Fig. 5.15). Significant responses to applied K could be expected when the exchangeable K content of the soil was below 112 mg K/kg soil (0.29 cmolc/kg) or in the case of leaf analysis when the K content of the third leaf fell below 1.10 % K. Bishop (1967), in an unpublished report, discussed the reliability of predicting yield responses to potassic fertilizers based on the early factorial trial data. Using a soil threshold value of 0.29 cmolc/kg, he concluded that responses to K would have been predicted correctly in 74 % of the trials and incorrectly in 16 %, while predictions for the remaining 10 % would have been of doubtful value.

Figure 5.15. Relationship between response to applied K and soil exchangeable K level.

For many years the threshold value used by the SASRI Fertilizer Advisory Service was 0.28 cmolc/kg for all soils, but this was modified in 1982 to allow for differences in soil texture following results from glasshouse trials (Wood and Burrows 1980) and a reassessment of over 100 potassium fertilizer trials (Meyer and Wood 1985). Threshold levels of 0.38 cmolc/kg (150 mg/kg) and 0.58 cmolc/kg (225 mg/kg) were subsequently introduced for soils with clay contents of 30-40 %, and > 40 % respectively. Further results from K trials in the northern irrigated areas indicated that even 225 mg/kg was too low for a winter cycle crop in heavy textured, base saturated Vertisols, containing a high proportion of K-selective clay minerals (Donaldson et al. 1990). Some of the largest responses to applied K were obtained on these soils and a threshold of 0.83 cmolc/kg (320 mg/kg) has since been implemented on an advisory basis (Meyer et al 2004).
In Australia, exchangeable potassium is determined with a relatively mild extractant such as 1N ammonium acetate and non-exchangeable potassium is assessed by a more aggressive 1N nitric acid procedure (Haysom 1971; Wood 1985). Large differences in the exchangeable and nitric acid extractable potassium values, imply a reserve of potassium which can be released to the exchangeable pool. These reserves are usually associated with K held in the lattice of 2:1 clays or by organic matter.

In Mauritius the 1N nitric acid procedure is also used and maximum yields will be obtained from treatment when the K test value is below 0.3 cmol_c/kg. There is little or no response when the K test value is greater 0.5 cmol_c/kg (Deville 1991). In Indonesia it has been shown that K requirement is related, not only to the ammonium acetate extractable K levels, but also to the degree of soil acidity and the nature of the soil parent material. Evidence from field trials indicated that cane in acid soils responded better to applied K than it did in neutral to alkaline soils deficient in K (Soepardi 1991).

In the Dominican Republic, cation exchange capacity (CEC) is used when determining the K requirement of cane. The exchangeable soil K value is expressed as a percentage of CEC (i.e. K saturation) and should ideally be above 2% (Redman 1991). The advantage of this method of interpretation is that it automatically provides for any differences in texture and clay mineralogy in relation to K availability. For example a K saturation of 2% in a sandy loam would equate to a K threshold value of about 0.10 cmol_c/kg (40 mg K/kg soil) whereas in a heavy cracking clay the threshold would amount to about 1.02 cmol_c/kg (400 mg K/kg soil).

A summary of soil threshold values and associated K recommendations, initially prepared by Kingston (2000), has been modified to include updated threshold values based on texture in South Africa as well as soil threshold K values used in Cuba as shown in Table 5.10.

Table 5.10. Summary of selected soil K threshold values and K fertilizer recommendations for a range of sugarcane producing areas. (modified from Kingston 2002)

<table>
<thead>
<tr>
<th>Country</th>
<th>Australia</th>
<th>South Africa*</th>
<th>Hawaii</th>
<th>Florida</th>
<th>Brazil</th>
<th>Cuba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold</td>
<td>&lt; 0.24¹</td>
<td>&lt; 0.29 (&lt; 30 % clay)</td>
<td>&lt; 0.35¹</td>
<td>&lt; 0.36</td>
<td>&lt; 0.22</td>
<td>&lt; 0.48</td>
</tr>
<tr>
<td>Soil exh. K</td>
<td>&lt; 0.38 (&lt; 30 % clay)</td>
<td>&lt; 0.58 (&gt; 40 % clay)</td>
<td>0-560</td>
<td>0-233</td>
<td>0-116</td>
<td>0-120</td>
</tr>
<tr>
<td>cmol_c/kg,</td>
<td>&lt; 0.83 (&gt; 40 % clay) Ca + Mg &gt; 4000</td>
<td>&gt; 30 % clay  0-200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg K/ha²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant cane</td>
<td>0-100</td>
<td>0-175</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg K/ha</td>
<td>&gt; 30 % clay  0-200</td>
<td>0-560</td>
<td>0-233</td>
<td>0-116</td>
<td>0-120</td>
<td></td>
</tr>
<tr>
<td>Ratoon cane</td>
<td>0-120</td>
<td>0-175</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg K/ha</td>
<td>&gt; 30 % clay  0-200</td>
<td>0-560</td>
<td>0-233</td>
<td>0-108</td>
<td>0-180</td>
<td></td>
</tr>
<tr>
<td>Comments</td>
<td>Rate modified by soil analysis for exch. K and non-exch K</td>
<td>Rate modified by soil analysis for exch. K in irrigation water</td>
<td>Rate modified by soil analysis and K in soil; 139 kg K/ha for all soil tests for ratoon ≥ 3</td>
<td>Rate modified by exch. K in soil</td>
<td>Leaf threshold of 1.2 % used to modify advice where needed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*SASRI Information sheet 7.3
Economics of increased K fertilizer usage
In terms of the maximum amounts of K recommended for the various countries in Table 5.9, certainly in the South African situation, based on the average responses quoted for the RFT trials, rates of up to 150 kg/ha K for plant cane and 200 kg/ha K for ratoon cane applied to soils deficient in K, are still likely to be profitable at the current prices of K and the value of a tonne of cane. However, the maximum rate of 560 kg/ha K as recommended in Hawaii, would certainly not be profitable under the current economic climate if applied to the South African situation.

Given the volatility in the price of fertilizers that followed the oil price, a greater emphasis needs to be placed on soil and leaf analysis to ensure that fertilizers are used efficiently and that the rates of fertilizers applied provide an economical return.

Of interest is that a response of 21 t cane was required in 1910 to pay for a third of a tonne of each of the three principal nutrient carriers, N as ammonium sulfate, P as single superphosphate and K as muriate of potash. Between 1960 and 2000, the amount of cane needed to cover the cost of the same amounts of N, P and K declined to between 6 and 12 t cane. During the oil crises in 2008, the breakeven amount of cane needed to cover the fertilizer costs jumped to over 50 t cane and, despite the recent drop in fertilizer prices the ratio is still above the 1910 value. Certainly in the South African situation, based on the average responses quoted for the RFT trials, rates of up to 150 kg/ha K for plant cane and 200 kg/ha K for ratoon cane were profitable.

5.5 Calcium (Ca)
At an average content of 3.6%, calcium (Ca) is the fifth most abundant element in the earth’s crust. In soils the Ca content is very much a function of parent material, degree of weathering, pH and cropping history in terms of the frequency of fertilizer, lime or organic mill wastes usage. Soil pH is a strong indicator of exchangeable Ca availability in soils, ranging from levels of deficiency below a pH of 4.5 to sufficiency above a pH of 7.5.

Calcium is important as a plant food and mainly essential for the development of the spindle, leaves and roots. An adequate supply of Ca stimulates the root hairs and growth of the entire root system. One of the most widely reported functions of Ca in the plant is in membrane stability and maintenance of cell integrity. Cell walls are comprised mainly of calcium pectate and are also bound to the plasma membrane. Important functions of Ca are summarized in Box 5.14 and leaf deficiency symptoms shown in Fig 5.16.
Box 5.14 Importance of calcium

- Required for cell division.
- Plays a critical role in stabilizing and strengthening cell walls in the form of calcium pectate and regulating membrane permeability (Legg et al 1982).
- In the absence of Ca the membrane can become leaky and solutes may be lost from the cytoplasm. The plasma can also be damaged if bound Ca is replaced by heavy metals (Jones and Lunt 1967).
- Required for activity of only a few enzymes.
- Counters soil acidity and the toxic effects of aluminum and manganese accumulation in the roots.
- Deficiency causes reduced growth. Younger leaves show minute chlorotic spots that later darken and coalesce into reddish-brown spots. With advanced deficiency the young leaves become hooked and spindle dies off at the tip, while older leaves turn pale green with yellow mottling. Overall leaf growth is reduced and tops tend to appear shaped as a fan.
- Is able to suppress the development of disease symptoms in many plant pathogen interactions in a range of crops, but in sugarcane the relationship between Ca and disease resistance has not been determined and needs to be researched.
- Excess Ca at soil pH above 7.5, brought about by over-application of filter cake or lime application, or in saline sodic soils, can interfere with the availability of trace elements such as Fe, Mn, Zn and Cu. Calcium, along with magnesium, can interfere with uptake of potassium from naturally high base soils (Wood and Meyer, 1986).

Figure 5.16. Typical Ca deficiency symptoms expressed in the TVD leaf (after Anderson and Bowen 1990).
5.6 Magnesium (Mg)

The content and forms of Mg found in soils are largely determined from the geological parent material from which the soil is derived, climate which determines the degree of weathering and position of the soil in the landscape. In general soils derived from igneous and metamorphic rocks containing the minerals olivine, biotite, hornblende and chlorite tend to be well supplied with Ca and Mg (Wood and Meyer 1986), whereas soil from sedimentary rocks such as sandstones are quickly exhausted of Ca and Mg, as well as most other nutrients. Sugarcane absorbs Mg in the divalent cation form (Mg$^{2+}$), which in turn is derived from mainly three sources, (i) the soil solution, (ii) from exchange sites on clays in soil, and (iii) in the leachate from decomposing organic residues. Magnesium is more prone to leaching in soils than is calcium.

Magnesium’s most important role is in photosynthesis, to build up structural tissues as a constituent and central atom of the chlorophyll molecule. It is associated with rapid growth, high protein levels and carbohydrate metabolism. Further essential physiological and biochemical functions are summarized in Box 5.15 and leaf deficiency symptoms in Fig 5.17.

**Box 5.15 Importance of magnesium**

- Involved in protein synthesis and the preservation of the ribosome structure and integrity, with up to 90% of the cellular Mg being bound in ribosomes.
- Involved in energy transfer reactions involving phosphate reactive groups.
- Acts as a promoter for many enzymes, for example Mg-ATPase, and assists in the formation of DNA and RNA.
- Unlike Ca, Mg is translocated from mature to actively growing regions of the plant (Huber 1991).
- Like other cations, also assists with achieving electro-neutrality in the cytoplasm.
- As in the case of soils, Mg has a much greater mobility in plants than does calcium. Up to 70% of the Mg can be removed in aqueous extracts.
- Deficiency of Mg retards cane growth and tillering is poor. Visually, the leaf symptoms show a pronounced orange freckling, most intense on older leaves while younger leaves may remain green. This condition is often referred to as ‘orange freckle’, but should not be confused with rust disease of sugarcane.
- High levels of Mg can interfere with potassium uptake (Evans 1959; Humbert 1968; Wood and Meyer 1986; Donalson *et al.* 1990; Duvenhage and King 1996; Santo *et al.* 2000).
Managing the Ca and Mg requirement of sugarcane

Soil analysis has proved to be a reliable tool for indicating the Ca status of a soil and how much agricultural limestone or dolomitic limestone is required to correct a potential deficiency of Ca. In general, the threshold values for Ca range in a number of countries from 0.50 to 1.5 cmol/kg and Mg from 0.2 to 0.3 cmol/kg. In Australia, a threshold value for Ca of 1.5 cmol/kg is used, while for Mg a threshold value of 0.3 cmol/kg is applied (Kingston 2000). As calcium and magnesium deficiency are closely associated with acid soils, the reader is referred to chapter 2.9.6 where the management of acid soils is addressed in more detail.

5.7 Sulfur (S)

As is the case with N and P, sulfur is present in both organic and inorganic forms. Organic matter is an important source of organic sulfur and is mineralized to the plant available sulfate form. The potential of the soil to supply S is therefore generally related to organic matter content, and like with N, is related to soil N supply. Sandy soils that have low organic matter contents are low in both plant available N and S reserves, while heavier clay soils, naturally endowed with higher organic matter contents, contain a greater capacity to supply both plant available N and S, through the mineralization process. Sulfur can also be supplied from various inorganic sources such as the readily available fertilizer carriers ammonium and potassium sulfate, and the less readily available forms such as single superphosphate and gypsum. Soil S can also be replenished from atmospheric sulfur dioxide which is brought down by rainfall or supplied to the crop through irrigation water, both supplying between 5 to 18 kg/ha/y. Other potential atmospheric sources of S are sulfur dioxide from volcanoes and the burning of fossil fuels, sulfate from sea spray in coastal areas, and hydrogen sulfide from the decay of organic residues.

Low lying coastal areas comprising marine muds contain iron sulfides which, when drained, oxidize to release sulfuric acid, resulting in a drastic reduction in subsoil pH and release of toxic Al. These
soils are known as ‘acid sulfate soils’ and are fairly common along the Australian coastline as well as along the East African coastline in Mozambique, Tanzania and Kenya.

The various physiological functions of S and symptoms of deficiency are summarized in Box 5.16

**Box 5.16 Importance of Sulfur**

- Sugarcane is capable of removing between 25 to 40 kg/ha per crop. There is increasing support for considering S to be the fourth most important nutrient after N, P and K.
- Sulfur is taken up by sugarcane roots as SO\(_4^{2-}\) ions and transported in the xylem.
- Is important for the functioning of nitrate reductase when nitrate is converted to ammonium, prior to the inclusion into amino acids.
- The amino acids cysteine and methionine are the major end products of SO\(_4^{2-}\) assimilation in plants (Thompson 1967) and can tie up to 90% of the total S (Giovanelli et al. 1980).
- Amino acids in the free state in plants would normally increase the susceptibility of plants to pathogens but, where S has been incorporated into the amino acid structure as in cysteine or methionine, resistance to pathogens was increased.
- Sulfur containing metabolites may be one of the cornerstones of plant resistance to pathogens, and in the case of sugarcane could provide interesting research opportunities for plant pathologists.
- Leaf symptoms of S deficiency are similar to N deficiency, except that symptoms first appear in the top youngest leaves, as a light green to yellowish-green colour which, with advanced deficiency, show purplish margins on both sides of the leaf. Plants tend to be small with thin stalks and maturity is delayed (see Fig 5.18).

**Sulfur leaf deficiency symptoms**

- Similar to N deficiency, except that symptoms appear in youngest leaves
- Young leaves are light green/yellow and may develop faint purplish tinge with advanced deficiency
- Stalks are slender and thin
- Leaves are narrower and shorter than normal
- Critical value of 0.13% commonly used in most countries

Fig 5.18 Main symptoms of Mg deficiency shown in the TVD leaf (after A. Hurney).
5.8 Silicon (Si)

Silicon after oxygen is the most abundant element in the earth’s crust (28.2%) (Wedepohl 1995). In terms of soils the total Si concentration varies from 19 to 32 % for clay soils and 42 to 46 % for sandy soils. Despite these high levels of Si only a small fraction is available for plant growth. For many years silicon (Si) deficiency in crops was relatively unknown and this element was widely regarded as non-essential for plant growth. Ever since the discovery in 1937, that sugarcane growing on highly weathered soils in Mauritius could be rejuvenated, by applying finely crushed siliceous basalt, silicon has emerged as an important nutrient for sugarcane, and a considerable amount of research on the potential agronomic and pest control benefits of Si in sugar cane has been conducted in countries such as Brazil, Florida, Hawaii, Puerto Rico, Australia, Mauritius and South Africa (Savan et al. 1999).

Box 5.17 Important functions of silicon

- With the exception of potassium, sugarcane is known to take up more Si than any other mineral nutrient, with the potential to accumulate up to 400 kg ha\(^{-1}\) in a 12-month old irrigated crop.
- In Puerto Rico, the above ground parts of a 12-month crop contained 379 kg ha\(^{-1}\) of Si, compared with 362 kg ha\(^{-1}\) of K and 140 kg ha\(^{-1}\) of N (Samuels 1969).
- For plant growth the important soluble forms of soil Si are monosilicic acid (Si(OH)\(_4\))\(_n\), also called orthosilicic acid, various polymers and silica gels.
- Mono-silicic acid is for gene expression to control production of phyto-alexins in cucurbits, when infested by fungi (Belanger et al.1995).
- Silicon acquisition by rice is a transporter-mediated mechanism, based on a low affinity silicic acid proteinaceous transporter (Ma et al.2004).
- Silicon is deposited in cell wall and intercellular spaces of root and leaf cells as silica gel or biogenetic opal (Yoshida et al 1969).
- Silicon deficiency is characterized by small circular white to cream spots which coalesce and darken to form a bronze freckle on older leaves.

5.8.1 Reported benefits from silicon treatment

In sugarcane reported benefits from Si treatment include:

- Increased resistance to certain fungal diseases such as eyespot (Raid et al. 1992),
- Resistance to attack by the stem boring insects *Diatrea saccharalis* F. (Pan . 1979, Elawald et al. 1985) and *Eldana saccharina* (Keeping and Meyer 2002, Meyer and Keeping 2005)
- Alleviating soil Mn toxicity in Hawaii (Clements, 1965) and Al toxicity in South Africa (Bishop 1965, du Preez 1970,Moberly and Meyer 1975)
- Aids with transpiration control and tolerance to salinity (Lewin and Reinman,1969 and Wong You Cheong et al. 1972).

The use of Si for controlling plant diseases and pest infestation is gaining rapid acceptance with other crops for inclusion in IPM strategies facilitating reductions in fungicide and pesticide use.
5.8.2 Soil Si source/sink pools

In general, most soils have appreciable amounts of primary silica (Si) minerals (quartz) and aluminosilicate clays present in the solid phase as well as a number of amorphous forms such as plant phytoliths. In the liquid or soil solution phase, Si is present as monomeric silicic acid (Si(OH)$_4$), which is the main form taken up by plants with a direct influence on crop growth. Polymeric silicic acids, silica gels as well as complexes with inorganic and organic compounds and Si adsorbed onto sesquioxide surfaces, are important as sources/sinks of Si that can replenish the soil solution with Si following crop use (Fig 5.19). These secondary forms of silicon can also have a significant effect on improving soil aggregation, increasing soil water holding capacity and increasing the exchange and buffering capacity of soils (Matichenkov and Bocharnikova, 1999).

![Diagram](image)

**Fig 5.19 Source/sink factors impacting on Si availability in the soil solution. Savant et al., 1997**

Typically soil solutions contain between between 2 to 35 mg soluble Si/L but polymerisation of Si occurs when concentrations approach 50 mg Si/L. Si availability is largely controlled by the dominant soil minerals present, particle size, soil pH, organic complexes, the presence of aluminium, iron and phosphate ions, temperature, exchangeable/dissolution reactions, and soil moisture and the amount of Si lost through desilification as a result of weathering.

5.8.3 Managing silicon nutrition

Both acid and neutral extracting solutions have been used to estimate plant available soil Si including 0.005 M, 0.02M and 0.05M sulfuric acid, 0.01M calcium chloride, 0.5 M ammonium acetate (pH 4.8) and 0.5 M acetic acid. Hayesom and Chapman (1975) reported threshold values of 10 and 100 mg/kg respectively for the neutral calcium chloride and acid sulphuric acid methods. Kidder and Gascho (1977) used a value of 100 mg/ dm$^3$ for the ammonium acetate method. More recently, Kanamugire et al (2006) recommended using a sliding scale of threshold values based on soil texture that ranged from 45 mg/kg for sandy soils(<15% clay), 65 mg/kg loamy sands to sandy clay loams (15 to 30% clay) and 100 mg/kg for clay soils (>30% clay), based on the 0.05N sulfuric acid extractant.

Due to the large number of factors that can influence the concentration of Si in the soil solution, the soil test method for Si may not always be a reliable estimate of the ‘plant-available’ soil Si and
should be supplemented with foliar diagnosis that can be more universally applied to sugarcane growing over a wide range of soil conditions. It is generally recognized that the level of Si accumulated by the plant is a more reliable reflection of the amount of plant available soil Si than a soil test (Anderson et al., 1991; Deren et al., 1993). Top visible dewlap (TVD) leaf Si concentration has been strongly correlated with sugarcane yield response to silicon treatment (Bair, 1966; Meyer, 1996). In Florida, response to silicon is likely when leaf silicon is <1.0% (Kidder and Gascho, 1977), but a more conservative target of 0.5% was subsequently adopted to predict economic yield responses to calcium silicate slag treatment. Tissue levels of silicon as low as 0.1% have been found in Australia in an experiment on a silicon deficient soil and where application of a filter mud /boiler ash mixture elevated leaf silicon to 0.49% and raised cane yield by 27 tonnes /ha (Kingston, unpublished data).

5.8.4 Silicon fertilizer sources for sugarcane

The application of silicate materials to soils low in plant available Si has produced marked cane and sugar yield responses in many countries, including Hawaii, Mauritius, South Africa, Puerto Rico, Florida and China (Fox et al., 1969; Samuels, 1969; Meyer, 1999; Wong You Cheong and Halais, 1970; Elawad et al., 1982a; Wang and Liang, 1999).

Before any material can be considered suitable for application to sugarcane, it must meet a number of criteria, such as high solubility, high content of Si, suitable physical properties, low cost and free of heavy metal contaminants (Gascho, 2001). Solubility is one of the most important criteria, and often the most difficult to achieve. Invariably the most concentrated and soluble sources such as potassium silicate are too costly for general use. Potassium silicate is used as a foliar spray for disease control in some high value crops and sodium silicate has been used to supply Si in research. Calcium silicate slags have emerged as the most important agricultural sources for soil application. The literature clearly shows that calcium meta-silicate (wollastonite, CaSiO₃) has been the most effective source and has been applied widely to Everglades muck soils and as well as sands planted to sugarcane and rice. In the South African sugar industry a calcium silicate slag, a waste material from stainless steel production, is widely used as both a lime and silicon amendment. Thermophosphate, a commercial fertilizer used in Brazil to supply P, Ca, and Mg, has also been shown to be a useful source of silicon. Sugar mill wastes such as bagasse ash, may also contain more than 20% silicon, but only a small fraction of the total silicon is plant available. Such wastes are applied at rates of 25-50 dry tonnes /ha, as opposed to rates of 4-6 t/ha for calcium silicate or cement. (Berthelsen et al., 2001). Important sources of plant available silicon are summarised in Table 5.1

| Table 5.11 Range of silicon content for selected silicon fertilizer materials |
|-----------------------------------|----------|----------------|
| **Source (dry matter basis)**     | **%Si**  | **Solubility** |
| Potassium silicate (solution)     | 24.5     | High           |
| Cement                            | 9-23     | Moderate to high |
| Calcium silicate (Wollastonite)   | 21-24    | Moderate       |
| Blast furnace slags              | 7-18     | Moderate to low |
| Thermophosphate fertiliser       | 10-15    | Low to moderate |
| Sugar mill boiler ash            | 30-40    | Low            |
| Filter mud / sugar mill fly ash mix | 10-30   | Low            |
5.9 Micronutrients

Micronutrients are elements essential for plant growth and are taken up by sugarcane in extremely small amounts relative to the uptake of macronutrients. The main micronutrients for sugarcane are zinc, copper, iron, manganese, boron, chlorine and molybdenum. Cobalt and nickel have been established as essential elements for other crops while there is increasing evidence that sodium, selenium and vanadium could have a physiological role in other crops as well. Micronutrient uptake can vary widely and in terms of abundance in sugarcane may be ranked in descending order from high in the case of iron to a low for molybdenum (Fig 5.20).

Unlike the macronutrients, the micronutrient requirements of sugarcane have not been widely researched. Some of the first deficiency symptoms were produced by Martin (1934) in "controlled" nutrient culture solutions. Since these pioneering investigations, instances of micronutrient deficiency have been reported from a number of cane producing countries. In recent years more formal investigations have been carried out on the requirement for micronutrients such as Zn, Fe, Mn and Cu (Anderson 1956, duToit 1956 and 1962, Evans 1959, Malavolta 1961; Bowen, 1975; Gascho 1978, Meyer et al 1999; Anderson and Bowen 1990, Reghenzani, 1990, Reuter and Robinson, 1997).

![Figure 5.20. Average micronutrient uptake (average of pooled data shown in Table 5.1)](image)

Factors that influence micronutrient availability in soils include climatic conditions, landscape, parent material, degree of weathering, organic matter status, clay mineralogy and content and pH. A summary of the main functions, visual symptoms of deficiency and recommended treatments for the more common micronutrients is given in Table 5.11 below:
Table 5.11. Summary of main functions, visual symptoms of deficiency and treatment of selected micronutrient deficiencies.

<table>
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<th>Micronutrient</th>
<th>Function</th>
<th>Visual symptoms of deficiency</th>
<th>Treatment</th>
</tr>
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<tr>
<td><strong>Zinc (Zn)</strong></td>
<td>Younger leaves affected</td>
<td>Zn is acquired by plant roots mainly as Zn(^{2+}) ions and is transported in the xylem as Zn(^{2+}) ions. Involved with chlorophyll formation, regulation of plant growth and the efficient use of water. An essential component of metallo-enzymes and any deficiency will interfere with carbohydrate metabolism and synthesis of proteins.</td>
<td>Soil: Apply 50kg/ha Zinc sulfate or a suitable zinctated fertilizer mixture in the furrow for plant cane or banded on row for ratoon. Foliar: Apply 1% zinc sulfate (or chelate equivalent) and a suitable wetter, using a knapsack spray at a rate of 250 l/ha</td>
</tr>
<tr>
<td><strong>Iron (Fe)</strong></td>
<td>Younger leaves affected</td>
<td>Roots take up iron as Fe(^{2+}) from the cell membrane to the cytoplasm. Essential for chlorophyll formation Is a constituent of metallo-proteins and enzymes. Active in oxidation / reduction reactions and electron transfer and in nitrate reductase for reduction of nitrate to the ammonium.</td>
<td>Soil: Apply 20-30 kg/ha ferrous sulfate in the furrow or top dress on row for ratoon cane. Foliar: Spray chlorotic cane with a 0.5% solution of ferrous sulfate and a suitable wetter using a knapsack spray at a rate of 250 l/ha</td>
</tr>
<tr>
<td><strong>Copper (Cu)</strong></td>
<td>Younger leaves affected</td>
<td>Catalyzes several plant processes Major function in photosynthesis Indirect role in chlorophyll production Major function in reproductive stages Granite derived soils and high organic matter soils, and sandy soils are more susceptible to Cu deficiency.</td>
<td>Soil: Apply 40kg/ha copper sulphate top dressed on row. Foliar: Apply 0.4% copper sulfate and a suitable wetter, using a knapsack spray at a rate of 250 l/ha</td>
</tr>
<tr>
<td><strong>Manganese (Mn)</strong></td>
<td>Younger leaves affected</td>
<td>Mn in the plant is mainly as the reduced Mn(^{2+}) ion. Uptake is likely to be passive and transported in the xylem as a free ion. Assists chlorophyll synthesis. Assists molybdenum in nitrate reductase activity. High pH soils (&gt;8.0) most prone to Mn deficiency.</td>
<td>Soil: Apply 20-30 kg/ha manganese sulphate in the furrow or top dress on row for ratoon cane. Foliar: Spray chlorotic cane with a 0.5% solution of manganese sulfate and a suitable wetter.</td>
</tr>
<tr>
<td><strong>Boron (B)</strong></td>
<td>Younger leaves affected</td>
<td>Essential for seed and cell wall formation. Promotes maturity. Necessary for sugar translocation. Affects nitrogen and carbohydrate. High pH or high organic matter soils most prone to boron deficiency.</td>
<td>Soil: Boron is best sprayed at a rate of 1kg B/ha on soil areas where B deficiency is suspected. Borax (11.3% B), Boric acid (17.5% B) or Solubor (20.5% B) are common carriers. Foliar application has not been successful.</td>
</tr>
</tbody>
</table>
5.10 Good management practices for minimizing environmental impact

The four principles to guide sustainable fertilizer application to ensure high yields with minimal off-farm impact include using:

- **Right amount of N, P and K and lime**: Follow the correct nutrient recommendation based on a soil analysis, for the right crop (plant or ratoon), using an achievable target potential, cultivar and soil type. Guidelines for taking a representative soil sample are given in Appendix 2.

- **Correct placement**: Placement close to the row is the most efficient but this can vary according to fertilizer carrier. Splitting fertilizer can minimize off-farm impacts under certain conditions (see Boxes 5.18 to 5.20).

- **Correct timing**: Timing of particularly N fertilizer application should, for ratoon cane, ideally be synchronized with the pattern of N uptake by the crop according to season, cultivar, whether rainfed or irrigated and soil type. Where the crop is harvested in a favorable season, the nitrogen and potassium should be applied within 2 weeks of the previous harvest. Where the crop is harvested at the beginning of an unfavorable season, where growth could be limited by reduced heat units, sunshine hours or moisture supply (if rainfed), then a strategy of splitting should be considered as specified under chapter 5.2.8.3

- **Foliar diagnosis**: Obtaining a representative soil sample in a field or paddock with highly variable soils is seldom achieved, and the ensuing fertilizer recommendation will also not necessarily reflect the fertilizer requirements of the crop. Under these conditions the ratoon crop should always be leaf sampled as per recommendations given in Appendix 2 to ensure that the nutrient requirements have been met and if not then corrective action can still be taken. More specific advice for reducing losses of N and K fertilizer is given in boxes 5.18 to 5.21.

**Box 5.18 Minimizing volatilization loss of N with urea**

- Know your soil and follow the previously discussed soil specific fertilizer recommendations
- In plant cane the first N split is always buried with the setts, and the balance buried in a band alongside the cane row. In ratoon crops, urea should be buried in a narrow band alongside the stools or knifed into the centre of the stool, behind a coulter disk.
- If burying urea is not possible, then broadcast the urea uniformly rather than banding the recommended rate.
- In a favorable climatic cycle apply urea during rapid crop growth, to coincide with moderate irrigation or rainfall. This improves fertilizer entry into the soil and crop uptake. In an unfavorable cycle, split the urea application.
- In irrigated cane incorporate the urea with immediate irrigation of ~20-25 mm. Delays of > 24 hours render this action ineffective.
- Avoid using urea on cane trash or on newly limed ratoon; more stable alternatives such as LAN, ASN or ammonium sulfate are more tolerant of high soil surface pH and trash.
- Split the N application according the recommended practice.
- Apply dissolved urea slurries with KCl and P fertilizers. Dissolved urea slurry alone is ineffective.
- Fertigate the urea through drip irrigation systems.
- Conduct annual leaf sampling to check for any nutrient imbalance, especially nitrogen.
Box 5.19 Reducing leaching loss of N and K in soils prone to leaching

- Use recommended soil specific N and K application rates.
- Split N and K fertilizer application on sandy and low cation exchange soils (Arenosols, Fluvisols, Regosols).
- For fields that have been ridged or hilled up, apply nitrogen on the crest of the ridge. Ridging reduces the amount of water leached through the row and improves early nitrogen uptake.
- Time fertilizer application to avoid periods of high infiltration and, for irrigated cane, adjust where possible the amount of irrigation rates to avoid deep drainage.
- Foster extensive and healthy root systems by practicing crop rotation, reducing soil compaction, increasing soil organic matter and controlling root pests and diseases.
- Conduct annual leaf sampling to check for any nutrient imbalance, especially nitrogen.

Box 5.20 Reducing denitrification loss in high risk Gleysols

- Avoid high nitrate concentrations by not applying excessive nitrate fertilizer.
- Ensure that fields are laser leveled to avoid ponding.
- Rake trash from the row of fields harvested green to reduce waterlogging and improve shoot emergence.
- Use split nitrogen applications in areas subject to regular waterlogging. Avoid fertilizer application during periods of excess rainfall.
- Place fertilizer on the better drained, raised rows on ridges, not the low, poorly drained interspace areas.
- Conduct annual leaf sampling to check for any nutrient imbalance, especially nitrogen.
- During wet season fallow periods use a cover crop to take up any residual nitrate.

Box 5.21 Strategies for reducing fertilizer inputs in cane cultivation systems

- More site-specific assessment of fertilizer requirements (Thorburn et al. 2003).
- ‘Replacement’ strategy (grower aims to replace the N lost from the previous crop, rather than aiming to fertilize the coming crop) (Thorburn et al. 2003).
- Nitrogen stabilization packages composed of calcium chloride, magnesium chloride, and a urease inhibitor.
- Cultivation of leguminous green manure crops during fallow periods, followed by relatively deep ploughing (Bakker 1999).
- Biofertilizers (inoculation of soils with nitrogen fixing microorganisms such as Azotobacter chroococcum, Azospirillum brasilense and Acetobacter diazotrophicus). Bangar et al. (1993) estimated that nitrogen fixing bacteria and organic amendments could reduce N fertilizer requirements by 25 %. Dobereiner et al. (1995) and Kannaiyan (2002) estimated that nitrogen fixing bacteria could reduce N fertilizer requirements by 20 %.

In addition to these measures, it has been suggested that various wastes from cane processing (and other organic wastes/manures) can be applied to the soil to help maintain soil quality. However, such materials may generate pollution risks, similar to those associated with poorly managed use of inorganic fertilizers. Sugarcane processing wastes (filter cake, effluent) and other organic wastes (chicken manure, kraal manure, abattoir wastes) should be used as soil amendments only with caution, and after obtaining professional advice and guidance.
5.11 General conclusions

More than ever before, there is the need for growers to use soil and leaf analysis in order to balance nutrient uptake and maximize sucrose production, and to reduce unnecessary fertilizer wastage. Fertilizer use in excess of recommendations is not only wasteful but will be more ‘expensive’ under new cane payment systems based on recoverable sucrose. Clearly to avoid the risk of over-fertilization it will be important to continue using aids such as soil and leaf sampling. The use of DRIS in interpreting leaf analysis will provide a means of monitoring nutrient balance. Another potential tool in the future will be the use of real time crop growth soil system models to determine nutrient requirements by computing nutrient balances in the soil. An example of such a model is the Agricultural Production Systems Simulator (APSIM, McCown et al. 1996) which is a modeling system that describes the dynamics of crop growth and soil water, N and C. It has been successfully used to describe production and N dynamics in sugarcane systems in the Australian sugar industry (Thorburn et al. 1999, 2000). APSIM is currently being configured to represent subsurface trickle irrigation and will be used to provide a more detailed analysis of fertigation programs under long term sustainable management systems.

The relationship between nutrient uptake patterns in commercial cane cultivars and sucrose contents needs to be investigated. It is possible that high sucrose cultivars may be associated with inherently low N, P and K profile uptake patterns. In Louisiana, it was suggested by Irvine (1978), that minimizing excessive K uptake by cultivar selection and judicious fertilizer management might be an effective low cost method of improving molasses exhaustion. The effect of management practices on non-sucrose content and the characterization of non-sucrose constituents will need to feature more prominently in future research programs, given the change in emphasis in the cane payment system.
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# CHAPTER 6 IRRIGATION - MIKE COPELAND

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6. IRRIGATION

Introduction
In many hot, dry areas, irrigation is the single most important aspect of growing sugarcane. An irrigation development must not only provide good economic returns to guarantee long term sustainability, but must ensure a balance between the many resources and factors employed in production and the environment. There are many factors beyond just hardware that must be considered for sustainability.

These include:

- **Physical factors** such as water availability and quality, soil quality, drainage, salinity hazard, flood hazard, water rights, topography.
- **Human factors** (e.g. labor – availability, skills, experience and education, level of automation required).
- **Economic factors** (e.g. investment capital, interest rates, cash flow requirements, insurance, uncertainty, services).
- **Social factors** (e.g. legal constraints, political issues, environmental issues, health issues local cooperation and support).

This chapter will focus mainly on two main aspects: water supply and water application. The former is dealt with in 6.8 and the main chapter covers aspects of water application.

6.1 Sugarcane water demand

6.1.1 Crop water requirements (CWR)

Reference Evapotranspiration (ETo) can be defined as the evapotranspiration rate from a reference surface – equating to an actively growing extensive surface of green grass of uniform height, completely shading the ground and with adequate water. The only factors affecting ETo are climatic – and therefore ETo can be computed from weather data and does not consider crop characteristics and soil factors (Allen et al. 1998). It can also be estimated by use of the USDA Class ‘A’ Pan and a variation in Australia known as the “evaporation minipan’.

Crop evapotranspiration (ETc) comprises the largest water-use portion of an irrigated crop. The crop water requirement (CWR), equivalent to ETc, is defined as water lost from a crop through evapotranspiration and is derived from the effect of climate and crop specific characteristics. Climatic effects are estimated using ETo and crop characteristics by the crop coefficient (kc).

\[
\text{ET}_c = k_c \times \text{Eto}
\]  

(6.1)

Many techniques are available to estimate ETc. These range from evaporation pans to climate based simulation models. Crop yield is strongly correlated to evapotranspiration, and Etc is the principal factor in irrigation planning and scheduling. A number of models designed to simulate cane growth have been devised, and most have ETC estimates as a principal sub-routine. Inman-Bamber et al. (2007) stated that CANEGRO (South African) and APSIM-Sugarcane (Australian) had captured the “current state of knowledge of the workings of important parts of the sugarcane cropping system [using the Penman-Monteith approach]. Most deficiencies in the models are deficiencies of our knowledge not the models themselves.” It is clear that modeling has achieved a high level of competency.
The FAO compiled computer program CROPWAT is designed for irrigation planning and is based on evapotranspiration computations (Allen et al. 1998). This program can be successfully used for sugarcane water requirement calculations and scheduling. Like the others, the program is based on estimating reference evapotranspiration. Work carried out by McGlinchey and Inman-Bamber (2002) compared the FAO system to CANEGRO and APSIM models in respect of Etc and found that it was similar except for the Kc value during the final stage of development of the crop.

Other programs such as ZIMsched and CaneSim were originally devised for water budgeting.

**Box 6.1 Calculating crop water requirement**

In general, it is recommended that CWR be calculated using CANEGRO or APSIM sugarcane derived from the Penman-Monteith method – which gives good results over a wide range of climatic conditions. Crop factors for sugarcane (kc) as reported in Allen et al. (1998) are:

| Kc (initial) | 0.40 |
| Kc (mid season) | 1.25 |
| Kc (late season to end) | 0.75 |

Crop water requirement (CWR) is the starting point to determine the capacity of an irrigation scheme. Gross irrigation requirement (GIR) comprises CWR plus expected losses which comprise conveyance losses, soil evaporation and drainage losses. Gross irrigation is expressed as a depth (mm).

\[ \text{GIR (mm)} = \text{Management allowable deficit (see 6.2.4)} \]

Overall Irrigation Efficiency

System capacity (SC) or irrigation scheme capacity is equivalent to GIR in terms of water applied per unit time (important in pump and irrigation system design). SC is usually expressed as a flow rate (m$^3$/h or liters/s).

**6.1.2 Irrigation requirements in relation to the soil water balance**

Sugarcane water requirements comprise consumptive and non-consumptive elements. Consumptive use includes crop evapotranspiration (beneficial) and evaporation from supply infrastructure, spray losses etc (non-beneficial). Non-consumptive use includes water for leaching (beneficial), excess deep percolation and excess surface runoff (non-beneficial), (Heermann and Solomon 2007). GIR is made up of the CWR and all other beneficial and non-beneficial consumption

\[ \Delta \text{SWC} = P + I - R - D - E - T \] (6.3)

Where P is precipitation, I is amount of irrigation, R is surface run off loss, D is drainage loss, E moisture loss through evaporation and T through transpiration
Figure 6.1. Schematic representation of the soil water balance (change in soil water capacity).

6.2 Influence of soils on irrigation

Knowledge of the soils in an irrigation development area is essential for economic and technical reasons. The high development costs of irrigated agriculture require justification through the assessment of the risks and benefits. A detailed knowledge of the soils and their potential effect on irrigated farming is important in quantifying risk (Doorenbos and Kassam 1986).

Sugarcane performs best in soils that are more than 1 m deep. The soil should be well aerated (after heavy rain the air-filled pore space should be >10-12 %) and have a total available moisture content of 15 % or more. When there is a groundwater table it should be more than 1.5-2.0 m below the surface (Doorenbos and Kassam 1986).

Management of irrigation is dependent to a large extent on soil characteristics. These include infiltration rate, pattern of moisture release, saturated and unsaturated hydraulic conductivity and effective rooting depth. Further aspects of soil properties, mainly in relation to dryland sugarcane, are dealt with in Chapter 2.

6.2.1 Soil morphology

Soil morphology is defined as the physical constitution of a soil, particularly the structural properties of its profile as demonstrated by the arrangements and characteristics of the horizons, and by texture, density, porosity, consistence and color.

Soil classification systems, e.g. USDA 7th Approximation Soil Taxonomy system, the World Reference Base (which has superseded the FAO System) and the Soil Taxonomic System of South Africa use morphology and other characteristics to describe and allocate soils into the many different pedological groupings (e.g. Orders, Families, Forms, Series, etc.) (see Chapter 2).

With regard to irrigability, the horizons as identified and described in the classification systems can be good indicators of suitability. This is particularly so with respect to wetness where permanent or seasonal waterlogging can readily be identified by color, including mottling, the presence of a pale eluviated A2 horizon underlying the topsoil, and consistence.
Exposure of a soil profile and examination of its horizons (during project planning or during investigations into poor cane performance) is a critically important exercise. An exposed profile will also reveal probable effective rooting depth, texture differences, structural changes, indurated horizons and possible sodicity, and will also give a good indication of water holding capacity and permeability. Much of this will require confirmation at a soils laboratory, but visual inspection is always a worthwhile exercise (see Chapter 2).

6.2.2 Soil physical properties affecting irrigation

The moisture content where drainage flow ceases can be defined as its maximum retained moisture level, or Field Capacity (FC). The minimum ‘acceptable’ soil moisture level, on the other hand, is a predetermined level generally referred to as the permanent wilting point (PWP). The available water capacity (AWC) of a soil (or total available moisture (TAM)), describes the moisture retained by a soil between the FC and PWP multiplied by the effective rooting depth. The AWC constitutes the soil moisture reservoir, considered to be readily available to plants. AWC is an important design and management factor and should be measured for all major soil groups found on an irrigation farm. The effective rooting depth (ERD) comprises the depth of soil within which the root system can freely exploit its moisture and nutrient requirements without any other factors limiting root development.

**Box 6.2 Estimating effective rooting depth in the field**

A good estimate of effective rooting depth for sugarcane grown in deep sandy loams is 1.2 m and 0.8 m for soils with high clay content (>40 % clay). If a barrier occurs within this depth then effective rooting depth is reduced to the depth of the barrier. The barrier may be due to physical factors, for example a hard compacted zone, a water table and chemical factors, such as salinity or Al toxicity.

Soil texture is important in determining AWC. A good correlation has been found between clay percentage and FC and PWP (van Antwerpen et al. 1994). Other factors such as silt percentage and type of clay also play a role. Table 6.1 shows representative moisture holding capacity values for a number of different soil textures. It should be noted that these values are not definitive, and that different values are given in many texts.

**Table 6.1. Volumetric soil moisture content (%) at field capacity, permanent wilting point and available water capacity (AWC) for various soil textures.**

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Field capacity (FC) (%)</th>
<th>Permanent wilting point (PWP) (%)</th>
<th>Available water capacity (AWC) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>10</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>16</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>21</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Loam</td>
<td>27</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Silt loam</td>
<td>30</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td>36</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>32</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>Clay loam</td>
<td>29</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>28</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Silty clay</td>
<td>40</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Clay (mainly 1:1 lattice)</td>
<td>40</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Clay (mainly 2:1 lattice)</td>
<td>40</td>
<td>26</td>
<td>14</td>
</tr>
</tbody>
</table>
Box 6.3 Calculating total available water

Example:
A soil sample submitted to a laboratory showed the following results:
Field capacity (FC) = 36 %
Permanent wilting point (PWP) = 20 %

Step 1: Calculate available water capacity (AWC):
\[ \text{AWC} = \text{FC} - \text{PWP} = 36\% - 20\% = 16\% \]
Conversion to a depth: \[ 16\% \times (1000 \text{ mm/m} / 100\%) = 160 \text{ mm/m} \]

Step 2: Calculate total available water (TAW):
Effective rooting depth (ERD) = 0.8 m (field determined)
\[ \text{TAW} = \text{AWC} \times \text{ERD} = 160 \text{ mm/m} \times 0.8 \text{ m} = 128 \text{ mm} \]

Infiltration rate is important in determining the amount of water that can be applied during a fixed time period. The rate of infiltration is dependent on the percentage of pore space occupied by the wider pores in the soil surface. The stability of these pores is important and any surface wash, for example with furrow irrigation, will plug them. Rain or sprinkler drops cause surface damage and particles are dislodged, leading to similar plugging problems. Swelling clays also seal off the surface and reduce intake rate. In most cases, infiltration rate declines with time to reach a basic or steady state rate; this is taken as the design intake rate.

A table of typical values is shown in Table 6.2. These typical or representative values are often used in design but the range, also indicated in the table, is important, in that variation can be seen to be significant and underscores the problem of relating soil physical properties to texture only.

However, a good correlation has been found between clay percentage and FC and PWP (van Antwerpen et al. 1994). Other factors such as silt percentage and type of clay play a role, and research work in this area is regularly undertaken.

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Representative infiltration rate (mm/hour)</th>
<th>Normal range of infiltration rates (mm/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>50</td>
<td>20 – 250</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>20</td>
<td>10 – 80</td>
</tr>
<tr>
<td>Loam</td>
<td>10</td>
<td>1 – 20</td>
</tr>
<tr>
<td>Clay loam</td>
<td>8</td>
<td>2 – 15</td>
</tr>
<tr>
<td>Silty clay</td>
<td>2</td>
<td>0.3 – 5</td>
</tr>
<tr>
<td>Clay</td>
<td>0.5</td>
<td>0.1 – 8</td>
</tr>
</tbody>
</table>

Apart from textural grouping, soil infiltration rates can be allocated to classes or infiltration categories of differing basic infiltration rates (BIRs) and to suitability for various irrigation methods (Table 6.3).
Table 6.3. Classes allocated to different basic infiltration rates and suitability for different irrigation methods.

<table>
<thead>
<tr>
<th>Class</th>
<th>Infiltration category</th>
<th>Basic infiltration rate (mm/h)</th>
<th>Irrigation method suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very slow</td>
<td>&lt;1</td>
<td>Basin</td>
</tr>
<tr>
<td>2</td>
<td>Slow</td>
<td>1 – 5</td>
<td>Basin/furrow</td>
</tr>
<tr>
<td>3</td>
<td>Moderately slow</td>
<td>5 – 20</td>
<td>Furrow/drip</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
<td>20 – 60</td>
<td>Furrow/sprinkler/drip</td>
</tr>
<tr>
<td>5</td>
<td>Moderately rapid</td>
<td>60 – 125</td>
<td>Sprinkler/drip</td>
</tr>
<tr>
<td>6</td>
<td>Rapid</td>
<td>125 – 250</td>
<td>Sprinkler*</td>
</tr>
<tr>
<td>7</td>
<td>Very rapid</td>
<td>&gt;250</td>
<td>Sprinkler*</td>
</tr>
</tbody>
</table>

*Sprinkler includes center pivot and linear systems

Other soil physical properties related to texture are important in irrigation planning. Surface irrigation design requires certain factors to be determined in order to compute advance and recession rates and contact time required to complete the irrigation successfully.

6.2.3 Soil texture as a factor in choice of irrigation method

Most irrigation systems perform reasonably well on soil textures ranging from loam to clay loam, especially where these soils are deep and well drained. Furrow irrigation is recommended on medium to heavy soils only, sprinkler including center pivot on medium to light soils and both sprinkler and drip on soils of medium texture. Good management techniques are critical where heavy soils are irrigated.

A particular problem arises with heavy ‘cracking’ clay or vertic soils (vertisols). These soils crack widely and deep when dry, but swell and seal tightly when wet. They therefore have very low basic intake rates and slow hydraulic conductivities, making irrigation management difficult. Sprinkler irrigation on these soils can lead to droplet-induced breakdown of the surface peds and a rapid sealing of the wetted surface. This usually happens before a full irrigation can be applied, with dry soil at depth being a consequence. With drip irrigation, the very slow hydraulic conductivity of a vertisol can be a problem and may lead to pockets of de-aerated soil close to the emitters.

Although furrow irrigation is the preferred irrigation system on vertisols, it can have other problems. During the advance phase, water tends to move rapidly into cracks, giving extremely high infiltration rates. Whilst this does fill the soil profile the advance flows move erratically, making scheduling and cycling more difficult to monitor and control. Eventually the surface layer seals and the basic intake rate drops dramatically, usually to less than 1.0 mm/h. This is accompanied by de-aeration of the surface soil, which may lead to root respiration problems. Only re-cracking will open the soil up to further air inflow. Nevertheless, vertisols are fertile soils and with good irrigation management can be highly productive, as witnessed on many large sugar estates in Africa such as Kenana Sugar in Sudan, Nakambala Sugar Estate in Zambia, in the Zimbabwe sugar industry and the Burdekin in Queensland.

Drip irrigation can be a problem on light, sandy soils where the gravity component of water movement or flux is dominant and lateral movement is relatively small. This is particularly problematic with germination where excessive quantities of water might have to be applied before sufficient capillary water is enabled to move from the emitter to the cane stool. Nevertheless, drip irrigation is often recommended for sandy soils due to its capability for frequent, light irrigations.
which counteract the limiting effect of their low water holding capacity and minimizes moisture stress. Against this positive aspect, however, should be balanced the intrinsic poor fertility of light soils – leading to lower yields and probably less ratoons. From the design point of view, light soils require closer dripper spacing and higher flow rates (to encourage lateral water movement), with shorter set times or shifts (Yaron et al. 1973).

6.2.4 Management allowable deficit

It is generally accepted that the soil moisture reservoir or AWC (effective depth multiplied by the soil water holding capacity) should not be allowed to empty before irrigation is applied. As a soil dries out the energy expended by a plant to extract moisture, which is held ever more tightly by the soil, leads to a progressive reduction in growth rate.

The limits of high and low soil moisture content can be defined. The moisture content where drainage flow ceases can be defined as its maximum retained moisture level, or its field capacity (FC). The minimum ‘acceptable’ soil moisture level, on the other hand, is a predetermined level referred to as the ‘critical point’ (CP). Between the FC and CP levels, soil moisture is usually considered to be ‘readily available’ to plants. The optimum CP should correspond to the highest water use efficiency (WUE). WUE concerns the crop yield resulting from the application of a unit volume of water.

Management allowable deficit (MAD), can be defined as the percentage of the available soil water that can be depleted between irrigations without serious plant moisture stress and is important in determining irrigation interval (cycle time). This can be expressed as:

- The percentage of the AWC that a soil can hold in the root zone.
- A soil water deficit (SWD) in mm.
- An allowable soil moisture tension level (-kPa).

Soil texture has a major influence on MAD. Some recommended MAD (%) values include:

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>MAD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy soils</td>
<td>40</td>
</tr>
<tr>
<td>Medium/loamy soils</td>
<td>50</td>
</tr>
<tr>
<td>Light or sandy soils</td>
<td>60</td>
</tr>
</tbody>
</table>

MAD should be evaluated according to the crop’s needs and adjusted during the growing season to account for change in root depth, crop growth factor and yield response sensitivity to moisture stress at different growth stages (Anon 1997). The concept of MAD can be part of a deficit irrigation strategy whereby reduced water applications are planned with the understanding that this reduction would not lead to a proportional reduction in yield. Deficit irrigation is covered in 6.5.3.

6.2.5 Moisture extraction patterns

The crop extracts moisture unequally down the soil profile. In a relatively homogenous soil, moisture extraction can be considered as occurring in four approximately equal depths – extraction being progressively 40, 30, 20 and 10 % of total available moisture for each quarter, reflecting root density variation with depth.

Variation of abstraction with depth complicates irrigation scheduling in that the surface horizons may suffer moisture stress before the next irrigation. The bottom ‘quarter’, on the other hand, might still be relatively moist, and may lead to deep percolation losses when the irrigation water eventually reaches that quarter. Variations in the moisture profile can be monitored through the use of soil
moisture measuring instruments (e.g. tensiometers, neutron probes and capacitance probes) with sensors being located in each ‘quarter’. This allows irrigation scheduling to be adjusted accordingly, so minimizing both deep percolation losses and moisture stress.

Wide irrigation cycles (typically used in furrow irrigation) encourage deeper rooting, and a more even abstraction of water with depth. This can be seen as potentially improving water use efficiency. However, where water replenishment is inadequate over such wide cycles, the ideal abstraction distribution becomes distorted, with progressively more water being absorbed at greater depths as the surface ‘quarters’ dry out. This will result in some moisture stress, because the root density pattern does not shift proportionally with the drying pattern.

Frequency of irrigation also has a marked effect on the pattern of abstraction with small, regular irrigations encouraging shallow rooting. This applies particularly to drip irrigation where frequent, light irrigations are applied to replenish the small moisture reservoir (which approximates the upper quarter of systems applying larger irrigations).

6.2.6 Soils and water quality

The most important aspects of water quality are salinity and sodicity, which are dealt with in Chapter 7. However, it is advisable to carry out regular complete chemical analyses of irrigation water for nutrients as it may lead to savings in fertilizer requirements. Examples are that the White Nile River contains sufficient K and the Usuthu River in Swaziland contains sufficient S to supply all crop requirements.

6.3 Irrigation application systems

There is a large range of irrigation systems available to growers. Some characteristics of the most commonly used irrigation systems are outlined below.

6.3.1 Low pressure systems: surface irrigation

Basin irrigation for sugarcane is mostly found on smallholder schemes. The main requirement for basins is level land and, in areas suitable for gravity irrigation, basins are capable of high distribution uniformity and efficiency levels.

In general, larger farms and estates have adopted furrow irrigation. Topography is critical for furrow irrigation, with flatter lands with gentle gradients being ideal and steep or broken terrain being excluded. Where field slopes are between 0.5 and 0.05 % (1:200 and 1:2 000) furrow irrigation is feasible. In higher rainfall areas, slopes should not exceed about 0.3 %, (1:330) due to erosion risk. Very flat grades (1:1 000 to 1:2 000) may lead to drainage problems.

Vast areas of mixed cropping are efficiently irrigated by furrow in California, and this is the most widely used irrigation system for sugarcane in Queensland (Anon 2000).
Box 6.4 The relative merits of furrow irrigation

Advantages:
- Relatively inexpensive to operate.
- Very low energy costs, increasingly important as energy costs rise.
- The soil surface is only partially wetted (less evaporation and weeds).
- The system is relatively simple, having few mechanical parts.
- Once the land has been shaped, requires minimal annual maintenance.
- Easy to discharge and fertigate vinasse.
- Relatively low carbon footprint due to the low reliance on energy.

Disadvantages:
- Relatively labor intensive (± 20 h/ha/an), except where automated.
- Requires a high level of land shaping in most situations.
- Not suited to light soils.
- Requires high system capacity (including balancing dams) as night irrigation is seldom employed.
- Efficiencies can be low, with losses to runoff and deep percolation, but varies enormously depending on management and, in some areas like the Burdekin, most lost water is recaptured and used to recharge aquifers.
- Not suited to precision fertigation.

Limitations for furrow irrigation include the time required for water to reach furrow end (which should not be excessive), a non-erosive furrow flow and the need to prevent furrow overtopping (due to steep side slopes or high flow rates). The ‘contact time’ down the furrow must be long enough for the design irrigation application to infiltrate. In general, soils should have medium to heavy texture; very light soils are not suitable, as deep percolation losses can be high.

Discharge rates per furrow are generally in the range 1-6 L/s, and depend mostly on soil texture, furrow length and slope grade. Generally, the highest non-erosive discharge is recommended; this has special relevance on steep land. In a trial on steep land, Torres et al. (2010) reduced the typical flow rates to 0.1-0.3 L/s and achieved good yields. This was also considered to be a low cost alternative to sprinkler irrigation.

Runoff at the end of a furrow (tail-water) is a major factor lowering irrigation efficiency. On flat land, small furrow flows reduce tail-water losses but increase deep percolation losses. Large flows advance rapidly over the field but have the risk of significant runoff. Large flows do, however, have the potential for greater uniformity and less deep percolation losses. Such practices as cut-back and surge irrigation are management techniques designed to reduce these losses (Burt 1995).

Irrigation efficiency with furrow irrigation is greatly improved through land forming (leveling, see Appendix 4) (Fig. 6.2). Any major soil leveling should be done at the time of scheme implementation, but it is good practice to re-level with a land plane at regular intervals between following ratoons.
A furrow design approach that has some support is to irrigate alternate furrows only. This technique has been found to reduce the total amount of deep percolation in high infiltration rate soils. Two reasons for this are suggested: (i) a reduction of wetted surface area (which reduces infiltration opportunity) and (ii) larger furrow flow rates are used (which are needed to achieve the design application). Surface evaporation is also minimized. However, lateral movement of water from the wetted furrow is needed to reach the stool, so that this technique will only be effective on certain soils. Also, under hot dry conditions, alternate furrow irrigation may not be able to supply the required amount of water. Raine et al. (1997) reported that application efficiencies of 75% were achieved using alternate furrow irrigation and water savings of up to 50% have been recorded.

Furrow irrigation is usually limited to daylight operation only, because of poor visibility after dark. Unfortunately this results in the necessity for high capacity delivery infrastructure due to the limited irrigation time (i.e. larger canals and balancing dams). Labor requirements are generally higher for furrow irrigation schemes than pressurized schemes, although some degree of automation is being introduced to furrow irrigation in North America and Australia. Where long lines are feasible, this helps to reduce labor requirements.

With a furrow system, water is typically diverted into canals at the head of the irrigation land and is discharged into the furrow through siphons or spiles (fixed pipes through the canal bank). An alternative is the ‘lay-flat’ system widely used in the Burdekin in Australia, which comprises a large diameter (usually 300-450 mm), thin-walled plastic pipe aligned along the upper boundary of a field. Outlet tubes are attached either every row or second row. The outlet tubes are closed after irrigating a group of furrows, before moving on to the next group. At the end of the season, the lay-flat pipes can be rolled up and removed – to allow harvesting or land preparation activity. A five year useful life for lay-flat tubing is common. Lay-flat enables a higher level of efficiency as it can significantly reduce seepage losses from the header canal.

Detailed design procedures for basin and furrow irrigation can be found in FAO Irrigation and Drainage Paper 45 (Walker 1989) and The Surface Irrigation Manual (Burt 1995).

### 6.3.2 Medium pressure systems: drip irrigation

Drip irrigation – surface and sub-surface systems – is classified as a medium pressure irrigation system because, although the required emitter pressure can be as low as 100 kPa (1 bar), the pressure needed to ensure satisfactory filtration increases the overall pressure requirement to more than 200 kPa. Drip irrigation is designed to replace abstracted moisture within the upper root zone within a minimum time period, so curtailing any moisture stress. Adding small amounts of water
directly in the root zone also improves application efficiency in comparison with other irrigation systems; there should be no deep percolation losses or runoff and minimum surface evaporation.

Figure 6.3. Left: Laying of subsurface dripper lines using a two row application system at Mhlume sugar estate, Swaziland. Right: Drip filter station

Drip irrigation in sugarcane mostly comprises buried (thin walled) laterals or ‘tape’ and is usually known as subsurface drip irrigation (SDI). The drippers can be pressure regulated to cater for rolling topography. There are many modifications of the basic types on the market. The dripper tape, which may vary from 10-25 mm in diameter, comprises a polythene tube with 0.3-0.4 mm wall thickness and with emitters spaced every 650-1,000 mm. Depth of insertion of the tape is usually 200 mm below the surface and is located in the center of a ‘bed’, in a tramline configuration. Emitter discharge usually ranges between 1-4 liters per hour. The design ‘set’ or application period with SDI is usually short, 3-8 hours, and cycle times are 1-3 days. The short set times enable three or more irrigations to be applied each day – to different lands – with the same pump and filtering equipment. This flexibility also enables scheduling to be more precise and some systems are automated in this regard, allowing irrigation applications to be linked to an automatic weather station or soil moisture monitoring system.

All drip irrigation faces the hazard of blockage, owing to the fine passages in the emitters. This necessitates the need for filtration of the irrigation water. Well designed filtration is critical and back-flushing must be timed so as to clear accumulated particulates before filter performance is affected. Should the filtration system fail and significant amounts of ‘dirt’ enter the laterals and drippers, the system will be seriously compromised.

Box 6.5 Relative merits of drip irrigation (SDI)

**Advantages:**
- Can be fully automated.
- Capable of very high efficiency levels.
- Minimum surface evaporation.
- 24-hour irrigation application time is possible.
- Not affected by wind.
- Not limited by topography – with pressure regulated drippers.
- Relatively low pressure requirement.
- Weed infestation is minimized.
- Minimal or no runoff losses.
- Low labor requirement (± 3 h/ha/an).
- Suited to fertigation.
Disadvantages:

- Very high capital cost, with break-even achieved only after the 8th or 9th ratoon.
- Dripper lines normally must be replaced at each plough-out.
- Designs must be of a particularly high standard – especially where chemigation is practiced.
- Emitter clogging is a significant problem and good filtration is a necessity.
- There are few visual indicators that emitters are actually operating.
- Not well suited to light soils due to poor lateral moisture movement.
- Rainfall is not used effectively, due to the continuous high moisture content of the soil. This works against the inherent high efficiency of SDI.
- Root disease may become a problem due to the permanently wet root zone.
- Root intrusion may occur.
- Chemical treatment for root intrusion and blockages can be environmentally unfriendly.
- Back-flushing water requires disposal.
- Requires particularly high management and operator skills.
- Equipment is often complex, requiring high levels of maintenance.
- The extraction and disposal of tape from within the field every ratoon has cost and environmental implications.
- Restricted plant root development.
- Difficult to dispose vinasse in mainly ethanol based cane production systems.
- Length of run may be limited.

A useful ‘back-up’ blockage prevention system comprises the use of flushing valves. These are located at the end of the laterals, with usually 10 tubes being connected to one valve. The valves are usually flushed every day (depending on water quality) and this enables particles that have passed the filtration banks or coagulated and settled matter, to be flushed out with the higher velocity water from the open tubes.

Crop establishment with SDI relies on unsaturated water movement from the buried tape to the stool. The soil’s lateral hydraulic conductivity is critical in determining the maximum distance a cane row can be located from the dripper tape. Ratoon cane roots, however, will usually be found to be concentrated near the emitters or wetted strip.

Spacing between SDI lines has largely been standardized in southern Africa and Australia at 1.8 m, and this is usually implemented in combination with ‘pineapple’ or tramline planting. The cane rows would then be 400 mm apart (two per bed). Drip design must ensure that a wetted strip is formed whereby lateral spread from one dripper will overlap with the next. Row spacing in all cases must be coordinated with the mechanization and harvesting equipment.

Where soils are very light or very heavy, SDI can give problems. On light soils water movement is dominated by the gravity component, with downward movement exceeding lateral movement; this can lead to poor germination. Heavy soils have low hydraulic conductivity, and germination under SDI can be badly affected. SDI has its greatest potential where soils are ‘medium’ in texture (sandy loams to sandy clay loams) with stable surface crumb structure, good drainage and adequate aeration. Lateral movement of moisture in these soils is generally good and germination is not inhibited. The high capital cost of SDI can be best offset against the high yield potential of this type of soil.

Some growers incorporate a portable sprinkler irrigation unit to overcome germination problems, but this is costly and may require a parallel irrigation network to be installed with separate pipelines, hydrants, valves and even pumping equipment. A survey in California found that less than 10 % of
growers used their buried drip systems to establish a crop; all others opted for sprinkler aided establishment (Charlesworth and Muirhead 2003). Although this work was not done on sugarcane, it is indicative of similar germination problems experienced by cane growers. In Swaziland, pulsing irrigation to achieve greater lateral movement has been observed to improve germination (Ndlovu 2000).

6.3.3 Medium pressure mechanized systems: center pivots

Center pivots used for sugarcane generally employ low pressure nozzles (0.8-1.5 bar). Extra energy is required, however, to allow for friction along the pivot structure, strainers/filters, control valves, etc. and they are therefore defined as medium pressure systems. Irrigation is normally carried out over 24 hours (Fig. 6.4).

The low pressure nozzles have a wetted diameter of about 18 m. This relatively small wetted diameter increases instantaneous application rates, and pivot speeds may need to be increased in order to minimize runoff. Soils and topography can also be a problem with center pivot irrigation; high application rates on heavier soils can lead to runoff, as is the case on steep land. Good design and regular maintenance are essential and proper scheduling must be carried out in order to fully realize a pivot’s benefits (Magwenzi and Nkambule 2003).

As the pivot increases in size, the capital cost per unit size decreases markedly. However, larger pivots run the risk of applying excess water at the periphery leading to significant runoff, poor efficiency and localized erosion.

Figure 6.4. Left: Center pivot at Mhlume and Right: Group of pivots at Tabankulu, Swaziland.

Center pivots for sugarcane should be high-clearance machines to allow for crop height (4.5 m above ground level). The nozzle assemblies can be hung close to the crop canopy and adjusted upwards as the crop grows, resulting potentially in a higher application efficiency as wind drift effects are reduced. Efficiencies of 85% are normally expected, especially with pivots having low pressure sprayers hung close to the crop canopy.

The main losses under pivots are due to evaporation off the bare soil after planting/ratooning. Green cane harvesting and trash bedding reduces evaporation losses due to the shading effect and soil capillary movement being curtailed.

Planting of cane beneath a pivot can either be ‘with’ the circle, tangential to it or a mixture of both. Straight or circular rows have advantages and disadvantages, and both are found within the industry. Surface drainage is often the deciding factor – with circular rows often leading to breakthrough’s – unless waterways are included at low points within the circle. With straight rows, the furrows must
be angled to encourage good drainage, but not steep enough to cause erosion. In some circumstances, where terrain slope variance is pronounced, the pivot land is split in half, with the rows in each half angled differently so as to better cope with the differences. Circular planted cane can cause difficulties during harvesting (especially towards the center), and is a problem when breakdowns occur and vehicles have to be extricated (towing across the rows).

In most cases, it is recommended to construct gravel paths for the pivot’s wheels as they tend to sink into wet soil, especially where clay content is high. Surface drainage is critical in all configurations, and waterways should be incorporated within the pivot land to remove ponding and water flowing along the circle or behind the wheel track paths.

There have been recent developments in pivot design intended to overcome the problem of wheels sinking in wet soil. This includes load spreading tracks attached to the wheels, or using double wheel configurations, thus increasing the footprint and reducing the tendency to sink.

<table>
<thead>
<tr>
<th>Box 6.6. The relative merits of center pivot irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages:</strong></td>
</tr>
<tr>
<td>• Can be easily automated.</td>
</tr>
<tr>
<td>• Very low labor requirement (± 1.0 h/ha/an).</td>
</tr>
<tr>
<td>• Relatively low pressure requirement.</td>
</tr>
<tr>
<td>• Capable of high efficiency levels.</td>
</tr>
<tr>
<td>• Suitable for fertigation.</td>
</tr>
<tr>
<td>• Capital cost per hectare is relatively low with the larger machines (&gt;60 ha).</td>
</tr>
<tr>
<td>• Can be installed rapidly, advantageous for new developing projects.</td>
</tr>
<tr>
<td><strong>Disadvantages:</strong></td>
</tr>
<tr>
<td>• Some filtration is required as the nozzles can be blocked by debris from the pumping plant.</td>
</tr>
<tr>
<td>• Not well suited to heavy soils as runoff can be high and wheels may sink into the wet soil.</td>
</tr>
<tr>
<td>• The circular shape of the pivot creates ‘outfall’ areas which require additional irrigation systems, rainfed cropping or re-vegetation.</td>
</tr>
<tr>
<td>• Capital cost per hectare is relatively high with the smaller machines (&lt;50 ha).</td>
</tr>
</tbody>
</table>

6.3.4 Medium pressure mechanized systems: linear systems (moving laterals)

High profile linear move systems have been used successfully in irrigated cane developments. Although at present they comprise only a small percentage of installed mechanized irrigation systems, they are increasing in popularity. Water supply to the moving lateral is the biggest problem; choice is mainly between a pressurized pipeline with outlet hydrants laid perpendicular to the lateral, or a canal with floating pumping unit, also orientated along the field edge. Fertigation is possible though a piped system, but more problematic with floating pumps.

Topography strongly influences choice. For the floating pump option, long canal reaches with low flow velocities are required, which in turn requires relatively level ground. A hydrant based system has the problem of needing regular connection changes, as the linear machine traverses the field. Some automatic and semi-automatic mechanisms have been developed to facilitate this maneuvering.

Linears have similar problems to center pivot (e.g. requiring graveled tracks) but have lower average application rates (cf. the distal end of a center pivot), which is a comparative advantage. They are
also used on relatively flat land, which also reduces the runoff potential, when making comparisons between systems.

Their main advantage is their coverage of rectangular areas with high land use efficiency, as opposed to pivots, where the outfall or corner pieces are a major problem. Lateral move systems cannot be used on steep or rolling lands. The maximum recommended slope along the lateral should be less than 2%. The movement of the machine back over wet ground in order to commence the next cycle is also seen as a problem, but there are techniques that can be applied that avoid this.

**Box 6.7 Relative merits of moving lateral irrigation**

**Advantages:**
- Low labor requirement (± 2 h/ha/an).
- Relatively low pressure requirement.
- Capable of high efficiency levels.
- Suitable for fertigation.
- Does not have the problem found in pivots, of outfall areas.
- Even application along the ‘boom’, unlike pivots.

**Disadvantages:**
- Some filtration is required as the nozzles can be blocked by debris from the pumping plant.
- Water supply to the travelling machine is a major problem.
- Does not lend itself to automation.
- Not well suited to heavy soils as runoff can be high and wheels may sink into the wet soil.
- Capital cost per hectare is relatively high.

### 6.3.5 High pressure manually moved systems: impact sprinklers

All manually moved systems are characterized by the use of small to medium sized impact sprinklers (with nozzles in the range 3-6 mm) attached to sprinkler assemblies (3 m risers mounted on a portable tripod) and connected to a pressurized pipe system. Portable 6-9 m long aluminum and light steel pipes (50-75 mm diameter) with short hydrants have been the most common infield lateral distribution network, but are now largely superseded by buried plastic pipes with above ground hydrants.

In all cases the spacing between sprinkler operating positions – whether the sprinkler is fixed or is moved as a cycle progresses – is design specific; the most common spacing in sugarcane being 18 x 18 m.

A disadvantage of sprinkler systems as opposed to pivots and linears is that they are generally operated at higher in-field pressures (350-450 kPa). Lower pressures mean smaller coverage, lower discharge rates, and poor uniformity at the spacings commonly used with sugarcane. Manually moved sprinkler systems often require night moves (depending on design and system capacity), which is unpopular with both operators and management. Apart from solid-set systems, they all have relatively high labor requirements – moving sprinklers every set.

Manually moved sprinkler irrigation schemes can be categorized relative to the number of position changes necessary per hydrant. A ‘fixed position’ or ‘solid set’ system has one sprinkler per hydrant position; it is therefore the most expensive system but has very low labor requirements.
Examples of high pressure systems include:

- **Solid-set** (semi-permanent) system has fixed sprinklers with no sprinkler changing necessary. Cycling is carried out off-field through on/off control valves at each lateral. This is the simplest to operate of all the sprinkler systems, has the best application efficiency and has the lowest labor requirement. However, it is also the most expensive in terms of capital cost, owing not only to the laying of lateral pipes (with in-line hydrants) every 18 m throughout the lands but to the number of static sprinkler positions, each with a semi-permanent sprinkler and riser (Fig. 6.5). The sprinklers are removed before harvesting.

  ![Solid-set sprinkler system](image)

  **Figure 6.5. Solid-set sprinkler system at Ubombo, Swaziland.**

- **Semi solid-set** system has portable sprinkler assemblies attached to hydrants via short plastic hoses (1-2 m long and 20-25 mm in diameter) and requires an operator to move the sprinkler assembly along a lateral every set or shift; hence its alternative name of a ‘hop-along’ system. A 6-day cycle may require twelve positions per sprinkler (at two moves per day). Semi solid-set sprinkler irrigation has been widely adopted by the sugar industry throughout southern Africa.

- **Dragline** system incorporates longer hoses and fewer laterals and hydrants. It requires that the sprinkler assembly and hose remains connected to a hydrant for at least three and up to six positions (shifts), divided on either side of a lateral. Sprinkler assembly and hose are then moved on to the next hydrant. A sprinkler assembly and hose could therefore be attached to one hydrant for three days, if sets are 12 hours or two days with 8-hour sets. This system has a relatively low capital cost but is tedious to operate, with operators having to carry the assembly, dragging its long hose though tall, wet cane, sometimes at night. As with semi solid-set, dragline has a high labor requirement – which has persuaded some people to abandon it. Its one definite niche is with small growers, where capital for initial development may be limited and labor might be available at relatively low cost (family involvement).

The design of manually moved sprinkler irrigation systems can be found in Kay (1988).
Box 6.8 Impact sprinkler irrigation: solid set systems

Advantages:
- Very low labor requirement.
- Can be automated.
- Capable of relatively high efficiency levels.
- Suitable for fertigation.
- Suitable on rolling topography.
- Not as sensitive to wind as portable systems as the whole area is irrigated simultaneously.
- Relatively low maintenance cost as equipment is not moved around.

Disadvantages:
- Relatively high energy requirement.
- High capital cost.
- Cultivation practices are restricted.
- Land is lost due to the permanent infield pipes and sprinklers.

Box 6.9 Impact sprinkler irrigation: portable systems (all variations)

Advantages:
- Relatively low capital cost.
- Efficiency is lower than solid set.
- Suitable for fertigation.
- Suitable on rolling topography.

Disadvantages:
- Relatively high energy requirement.
- Labor intensive.
- Some land is lost where semi solid-set is practiced, due to the permanent infield pipes and hydrants.
- Cannot be automated.
- High and variable winds can reduce efficiency.

6.3.6 Very high pressure self-traveler systems: travelling guns/rain guns

Self-traveler systems are designed to cover relatively large areas with high-discharge large-nozzled ‘rain guns’ (Fig. 6.6). They are mounted on a carriage and towed by tractors from site to site, where they are connected to hydrants attached to buried piping. The self-traveler comprises two mechanical rigs on wheels; the carriage rig which includes a large diameter reel of (usually) 100 mm polythene hose and a winding mechanism. The second wheeled sub-rig is connected to the ‘big gun’ sprinkler. Irrigation commences with the sprinkler sub-rig, being manually dragged down the field to the ‘start’ point – with the hose trailing behind.
During operation a turbine or hydraulic pump on the main rig (driven by pressurized water) rotates and drags the sprinkler back down the field, at the same time rewinding the hose onto the reel. The big gun is capable of spreading water over a radius of 25-60 m, which allows for very wide spacing of infield hydrants, so reducing installation costs. Each unit covers 10 to 30 ha, depending on the length of the wetted strip. As the rigs move under their own power but require a tractor and labor to move them from field to field, they can be classified as a partially mechanized system. Set times are usually between 12-24 hours.

The main disadvantages of these units are the high pressure requirement at the nozzle (up to 7 bar) and the tying up of tractors to provide towing capability. Further disadvantages are the generally low distribution efficiency and the impact damage to the soil of the large water drops. In addition, maintenance costs have been found to be high. These big guns are widely used in Brazil for distributing mainly vinasse at maximum loads of 180 m$^3$ per crop. Apart from potassium in vinasse, fertigation of other nutrients is not commonly used with self travelers, owing to the often poor distribution characteristics.

The design of self-traveler irrigation systems can be found in Roland (1982) and Kay (1988).

**Box 6.10 Merits of self-traveler irrigators**

**Advantages:**
- Relatively low capital cost per hectare.
- Relatively low labor requirement (± 6 h/ha/an).
- Can be used on rolling topography.

**Disadvantages:**
- Very high energy requirement.
- Very sensitive to wind.
- Large drops can damage soil surface structure.
- High application rates.
- Low application efficiency.
- Ties up tractors for moving machines to different positions.
- Cannot be automated.
- Not suited to fertigation.
- High maintenance requirement.
6.4 Choice of irrigation method

There is probably no ideal or universally 'best' irrigation system. The choice of system is influenced by many factors including soil type, labor availability, capital cost, terrain and power availability. Each system has its own advantages and disadvantages in relation to the particular site circumstances.

6.4.1 Economic aspects

The use of a decision support tool, such as Irriecon V2 (Oosthuizen et al. 2005), to assess net returns to irrigation systems, is helpful when comparing and choosing between systems. In combination with a simulation model (required to estimate yield and water usage under the pertaining soil and climatic conditions, e.g. ZIMsched 2), the most appropriate irrigation system and most suitable operating methodology can be identified.

Subsurface drip and center pivot systems are often compared with each other as they are both medium pressure systems with good efficiency, and are capable of automation and fertigation. Lamm et al. (2002) carried out such a comparison and concluded that center pivots generally have an advantage for large field sizes. They found that SDI can generate more gross revenue by having a higher percentage of irrigated area in a given field (influence of shape). However, the much lower cost and assumed longer life for the center pivot was found to offset the higher SDI revenue advantage. The results showed that the comparisons were very sensitive to the size of center pivot, shape of field, life of the SDI system, SDI cost and the higher potential yield of the SDI system.

Armitage et al. (2008) looked at the costs and returns for three different irrigation systems (big gun, dragline and drip) in the Empangeni area in South Africa, and established that the two relatively inexpensive dragline systems resulted in the highest returns per hectare. This was due to their reasonable cane yields and lower fixed costs compared to the other systems. Although the SDI systems had the best agronomic performance, they yielded the lowest margins. The SDI equipment had an expected life of seven years and comprised 61% of the total SDI scheme cost. For the big guns, the lifespan was 10 years and also 61%. For the dragline the expected life of the mains and sub-mains was 20 years and the cost percentage of that part of the scheme was 58%. This demonstrates that expensive water application equipment (with necessary replacement in the short to medium term) can seriously affect the cost effectiveness of an irrigation scheme.

Qureshi et al. (2001) compared irrigation technologies for sugarcane farms in the northern and southern areas of the Burdekin Delta in Queensland, Australia. Three types of irrigation were compared: furrow, center pivot and drip. Furrow irrigation is the most common irrigation system in these areas; it has low capital costs and is simple to operate. Where water is readily available at low cost, growers were found to have little incentive to switch to alternative technologies. However, furrow has the greatest risk of deep drainage losses and may be contributing to rising water tables.

Qureshi et al. (2001) found that the cost of water was a major factor in the comparisons, as was the capital cost of the systems and the permeability of the soil. Groundwater was relatively cheaper than surface water. The results of the study showed that the net present values (NPV) of the southern Burdekin areas were higher than for the northern areas because of the relatively greater input of less expensive groundwater; the furrow system had the highest NPV followed by center pivot and then drip. The analysis showed that low water charges were the major incentive for cane growers to use the existing furrow systems; where water charges were incorporated into the analysis, the picture changed and the more water use efficient technologies became more attractive. The opportunity cost of water is also an important selection factor, especially where water supply is limited.
Labor requirements differ with irrigation method and may be important in choosing the most suitable method for a particular area. Boxes 6.4 to 6.10 contain typical labor requirements for irrigation systems based on time (hours) per hectare per annum (Solomon et al. 2007)(Anon 200a).

Table 6.4 shows the labor requirements on a sugar estate based on labor days/100 ha.

### Table 6.4. Labor requirements for different irrigation systems.

<table>
<thead>
<tr>
<th>System</th>
<th>Furrow</th>
<th>Sprinkler</th>
<th>Center pivot</th>
<th>Subsurface drip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor days/100 ha</td>
<td>72</td>
<td>91</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

#### 6.4.2 Summary of factors influencing the selection of a particular irrigation system

A list of factors affecting the selection of a particular irrigation system in relation to local conditions is shown in Table 6.5.

### Table 6.5. Factors influencing the selection of an irrigation system (Anon 1997).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Furrow irrigation</th>
<th>Portable sprinkler</th>
<th>Solid set sprinkler</th>
<th>Center pivot</th>
<th>Moving lateral</th>
<th>SDI</th>
<th>Rain gun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low AWC soils</td>
<td>−</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>Heavy clay soils</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>−</td>
<td>0</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Saline soils</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Erodible soils</td>
<td>−</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>Steep topography</td>
<td>−</td>
<td>0</td>
<td>0</td>
<td>−</td>
<td>−</td>
<td>0</td>
<td>−</td>
</tr>
<tr>
<td>Undulating topography</td>
<td>−</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>−</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>High sediment water</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>−</td>
<td>0</td>
</tr>
<tr>
<td>Saline water</td>
<td>+</td>
<td>−</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Odd shaped fields</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Ease of management</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Automation potential</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>High winds</td>
<td>+</td>
<td>−</td>
<td>0</td>
<td>−</td>
<td>0</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>Labor shortages</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>High electricity costs</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
</tr>
</tbody>
</table>

Negative (-) indicates factor has a negative influence on selection of the system. Positive (+) indicates that factor has a positive influence on selection of the system. No Effect (0) indicates that the factor should not significantly influence system selection.

A ‘points based’ system can also be used to aid selection, where each factor is given a weighting in relation to its significance in the local context. This can include such factors as irrigation efficiency, energy requirements, potential yield increment, capital and operating costs, labor requirements and management input. Using such a non-subjective system can help make sense of the complex factor interactions.
6.4.3 Energy aspects

A critical factor in choosing an irrigation system is its energy requirement. The pumping cost from water source to field edge and field edge to infield should be quantified. This will give a complete picture, and enable more accurate comparisons to be made when choosing between irrigation systems. Power consumption (kWh/ha/an) should be used as the principal comparisons indicator. Examples of typical power consumption calculations are shown in Table 6.6.

Table 6.6. Power consumption comparisons for a typical irrigation block.

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th>Crop water requirement (mm/an)</th>
<th>Application efficiency (%)</th>
<th>Operating head (m)</th>
<th>Static head (m)</th>
<th>Power consumption (kWh/ha/an)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furrow</td>
<td>900</td>
<td>70</td>
<td>1</td>
<td>20</td>
<td>1 157</td>
</tr>
<tr>
<td>Drip</td>
<td>900</td>
<td>90</td>
<td>30</td>
<td>20</td>
<td>2 044</td>
</tr>
<tr>
<td>Pivot</td>
<td>900</td>
<td>85</td>
<td>35</td>
<td>20</td>
<td>2 424</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>900</td>
<td>75</td>
<td>45</td>
<td>20</td>
<td>3 238</td>
</tr>
</tbody>
</table>

Calculation notes:
- Furrow requires a balancing dam at level 20 m, with 22 h/day pumping.
- Drip, pivot and sprinkler operate for 22 h/day.
- Pumping plant efficiency is assumed at 65%.
- Drip requires a filter with 30 m u/s pressure.
- All systems were taken as 50 ha for comparison purposes.

6.5 Irrigation performance

The assessment of performance is necessary to ensure that irrigation systems are contributing satisfactorily to achieving optimum yields at lowest cost whilst minimizing any damage to the environment. There are several approaches to assessing performance; mostly they comprise indicators of efficiency and uniformity.

6.5.1 Efficiency

Efficiency addresses the division of irrigation water into productive and non-productive fractions as it is distributed from abstraction point to the crop. A number of different efficiency indicators can be identified, each describing a different component of the water supply and usage system. These indicators can be helpful in evaluating irrigation systems and in providing necessary design inputs.

**Conveyance efficiency (CE)** is the fraction of the volume of water delivered to the field boundary relative to the volume of water diverted from the source.

\[
CE = \frac{\text{Volume of water diverted to the field}}{\text{Volume of water diverted from the source}} \quad (6.4)
\]

**Application efficiency (AE)** - is the fraction of water applied and available for crop use, relative to the water delivered to the field.

\[
AE = \frac{\text{Irrigation water available to crop}}{\text{Water received at field inlet}} 
\quad (6.5)
\]
Storage efficiency (SE) or ‘requirement’ efficiency is an irrigation performance indicator relating the volume of water stored in the root zone to the soil moisture deficit. 

\[ \text{SE} = \frac{\text{Volume stored in the root zone}}{\text{Soil moisture deficit}} \]

Storage Efficiency indicates how well an irrigation event meets its objective of refilling the soil moisture deficit. This is important where large parts of a field are under-irrigated – which may be an intended management practice to maximize the use of rainfall. SE may be computed as 100 % whilst the AE might be half this value.

Irrigation efficiency (IE) is the fraction of the volume of water that is beneficially used relative to the volume of irrigation water applied. A high IE indicates that there is little deep percolation.

\[ \text{IE} = \frac{\text{Irrigation water beneficially used}}{\text{Irrigation water applied}} \]

Irrigation efficiency (IE) is the fraction of the volume of water that is beneficially used relative to the volume of irrigation water applied. A high IE indicates that there is little deep percolation. The several water supply, delivery and soil retention efficiencies are important when calculating project/farm water requirements or system capacity.

Conveyance, storage and on-farm losses can comprise more than half of the overall water demand. Designers have to take this into account when planning bulk and irrigation supply capacity. It should be noted that the variability between reported irrigation efficiencies is significant.

Water Use Efficiency

Water use efficiency (WUE) is a concept designed to assess the effectiveness of irrigation water on crop yield. It describes the yield per unit amount of water applied, e.g. tonnes sucrose/m³ water.

\[ \text{WUE} = \frac{\text{Crop yield}}{\text{Water applied}} \]

Both rainfall and irrigation can be included in this equation, depending on the specific objectives. Irrigation can be separated from overall water application and is then termed ‘irrigation water use efficiency’, IWUE.

WUE values are required for water resource planning and for the assessment of irrigation management practices. Improved WUE can also reduce negative environmental impacts by reducing runoff, erosion damage and leaching of agricultural chemicals.

Similar findings in respect of IWUE were found in a Texas, USA study, where optimum water application levels based on evapotranspiration rates for sugarcane growth and yield were examined. It was found that, over a plant and three ratoon cycle, the highest WUE each year occurred at the lowest irrigation level (deficit irrigation) and declined with increasing water application. Thus deficit irrigation may lower yields but may increase the amount of cane produced per unit of water used by the crop (Wiedenfeld 2007).

A list of typical application efficiencies is shown below (Table 6.7). It should be noted that there are other sources giving figures that are outside these values. For example, furrow irrigation with tailwater re-use can greatly improve efficiency. Furrow irrigation with efficiency values of over 90 % has been reported by Mazibuko et al. (2002). It should also be noted that improved management of all
systems will tend to increase the efficiency values. Reasonably high efficiencies can thus be obtained from all irrigation methods. Keller (1965) states that that efficiency depends more on the way the system is managed than the type of system used.

A high efficiency rating does not necessarily mean the system is the most economical one. However, managers need to evaluate efficiency in order to make rational decisions as to whether a system should be modified or replaced by another.

Leclerc et al. (2007), in arguing the case that water balance should be used for evaluation of performance of irrigation and water management systems rather than the standard irrigation efficiency and uniformity indicators per se, commented that the amount of water consumed in irrigation, i.e. the evaporated component, remains little changed at various levels of efficiency – or may even increase – when changing to systems regarded as being more efficient.

Table 6.7. Application efficiency: variation in reported values (after Solomon et al. (2007), Anon (2003) and Anon (2000)).

<table>
<thead>
<tr>
<th>Irrigation system</th>
<th>Reported variation in application efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface irrigation</td>
<td></td>
</tr>
<tr>
<td>Basin</td>
<td>80 – 90</td>
</tr>
<tr>
<td>Furrow</td>
<td>60 – 80</td>
</tr>
<tr>
<td>Sprinkler irrigation</td>
<td></td>
</tr>
<tr>
<td>Manually moved (dragline)</td>
<td>65 – 80</td>
</tr>
<tr>
<td>Solid set</td>
<td>70 – 85</td>
</tr>
<tr>
<td>Center pivot and linear</td>
<td>75 – 90</td>
</tr>
<tr>
<td>Travelling gun</td>
<td>60 – 70</td>
</tr>
<tr>
<td>SDI</td>
<td></td>
</tr>
<tr>
<td>With point source emitters</td>
<td>75 – 95</td>
</tr>
<tr>
<td>With line source emitters</td>
<td>70 – 85</td>
</tr>
</tbody>
</table>

6.5.2 Uniformity

Coefficient of uniformity (CU) is generally applied to pressure systems only, including center pivot, sprinkler and big gun. The Christiansen CU definition, which is the standard concept, gives the absolute mean deviation of the various application depths from the average depth, over the whole field, expressed as a fraction of the average depth. The main factors affecting CU are pressure, wind and the amount and quality of overlap of sprinkler patterns.

Work done by the Swaziland Sugar Association’s Technical Services Department measured CU values for dragline sprinklers as ranging from 68-88 %, depending on wind speed and pressure variation. It was noted that seasonal CU was likely to be greater than a single event because of changes in wind direction and sprinkler positions over time. The same study measured the CUs of 17 center pivots, where the CUs ranged from 72-92 % and 31 drip irrigation blocks, where the SUs (see below) ranged from 56-97 %.The drip variance was ascribed to design differences, with improvements being noted in later designs. It was also noted that most of the drip systems were less than three years old (Anon 2002).

Statistical uniformity (SU) is usually applied to drip irrigation. SU evaluates the evenness of application and is measured by catching emitter flows down the length of a lateral and comparing these to the design flow rate.
**Distribution Uniformity (DU)** is described as the ratio of the minimum depth infiltrated to the average depth infiltrated. Distribution uniformity addresses the evenness of irrigation applications. As such, it is a key indicator of the performance of an irrigation system.

\[
DU = \frac{\text{Minimum depth infiltrated}}{\text{Average depth infiltrated}}
\] (6.6)

Irrigation efficiencies are expressed as functions of the volumes of water directed ultimately towards the crop and the satisfying of crop water requirement. Low irrigation uniformity can result in large variations in crop yield and quality, and is a major factor contributing to low water use efficiency and excessive leaching of nutrients.

It should be understood that DU is not a measure of efficiency because it does not quantify beneficial use or consider runoff water, etc. However, high irrigation efficiency for a fully irrigated field is only possible with a high DU. Should IE be greater than DU, it is indicative of under-irrigation.

IE can approximate DU, however, if surface runoff is collected and recycled, evaporation losses are minimized and good scheduling is practiced (Burt 1995).

The economics of irrigation system design may dictate that less than 100% of the target area be adequately irrigated. This gives rise to the concept of a minimum area that might be identified and examined as to adequacy of irrigation. Most often the under-irrigated area is taken as a quarter of the cropped field, known as the ‘low quarter’ (DUₗq). Where the average of the low quarter is equal to the desired depth of application, approximately 12% of the area of an irrigated field will be under-irrigated (Burt 1995).

This concept is useful in system design. In general, most irrigation fields are over-irrigated, at least for some of the season. This is due in part because irrigators, in an attempt to ensure that all areas receive at least the planned amounts, end up over-irrigating significant portions of the field. Over-watering is not always thought to be a cause of yield decline; on the other hand, under-irrigation is always seen to be counter-productive, unless water shortages exist.

It should be noted, however, that a uniform water application may not necessarily mean the irrigation system is highly efficient, as water can be uniformly over-applied.

Simulations carried out by Lecler and Jumman (2009) showed, however, that there were only small yield benefits to the practice of applying additional water when trying to compensate for uneven irrigation (poor uniformity), particularly as large additional volumes of water were required to achieve this. Furthermore, no matter how much extra water was applied, the yields for the poor DU systems never attained those of the good DU systems, particularly on shallow soils.

The simulations were carried out for varying amounts of applied water to shallow and deep soils and well and poorly designed/maintained irrigation systems (using the simulation model ZIMsched 2.0). Poorly maintained irrigation systems were allocated a CU of 60 % and well maintained 80 %. The shallow soil had a depth of 0.6 m and the deep soil 1.2 m (textures were similar). The results showed that there were substantial differences in sucrose yield for different uniformities and soil depths for the same water application. The impacts of uniformity were not as great on deep soils compared with shallow soils.

Various irrigation systems can be said to have potential DUs due to their intrinsic characteristics. For ‘moderately well designed’ systems applicable to sugarcane, Table 6.8 provides typical values.
Table 6.8. Potential DU values for different irrigation systems (after Burt 1995).

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th>Potential field DU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear move</td>
<td>92</td>
</tr>
<tr>
<td>Center pivot</td>
<td>81</td>
</tr>
<tr>
<td>Contour furrow</td>
<td>89</td>
</tr>
<tr>
<td>Level furrow</td>
<td>87</td>
</tr>
<tr>
<td>Drip</td>
<td>90</td>
</tr>
<tr>
<td>Manually moved sprinkler (square spacing)</td>
<td>75</td>
</tr>
<tr>
<td>Manually moved sprinkler (triangular spacing)</td>
<td>85</td>
</tr>
</tbody>
</table>

6.5.3 Efficiency Improvement

Certain management practices by growers can improve irrigation efficiency. Some of these are mentioned below.

Deficit irrigation

The main objective of deficit irrigation is to increase WUE by eliminating irrigations that have little impact on yield. This is most useful in times of water shortage caused by drought (Ellis et al. 1985). Several authors suggest that increasing the area irrigated with the water saved would compensate for any yield loss. As sugarcane is a perennial crop, this is only feasible with sugarcane if deficit irrigation becomes a long term strategy.

Drying-off of cane is also seen as a deficit strategy through resultant water saving and emphasizes the need to plan drying off in a scientific manner (Lecler and Jumman 1999).

Before implementing a deficit irrigation program, therefore, it is necessary to know cane yield response to water stress, both during defined growth stages and throughout the whole season. Yield response to moisture deficit varies with growth stage. Water deficits during the establishment period and tillering have an adverse effect on yield as compared to water deficit in later growth periods. Water deficit slows down germination and tillering and the number of tillers is smaller. Light frequent irrigations are preferred in the early growth stages of a plant crop. Water deficit during stem elongation and ‘early yield’ formation causes a lower rate of stalk elongation. There is a close relationship between water use during this period and stalk elongation, and adequate water will give the longest internodes and the tallest cane. Water deficit later in the growth cycle forces the crop to ripen. When too seriously deprived of water, however, loss in sugar content can be greater than sugar formation (Doorenbos and Kassam 1986).

Lecler et al. (2005) looked at the interaction between irrigation system capacity and deficit irrigation. System capacity designed to meet maximum crop water requirements would naturally be more costly than a system designed to meet a lower rate of water use. Using data from the Zimbabwe Sugar Association Experiment Station over the period 1975-1992, yields were simulated using the ZIMsched 2.0 model for a number of different system capacity equivalents; these were 4.3, 5.0, 6.0, 7.5 and 10 mm/day. The system with the highest capacity (10 mm/day) gave the best yields. However, from an economic perspective this was not the best system. Should land be limiting (relative to available water), the system with the capacity equivalent of 7.5 mm/day was estimated to give the best returns. Where water was limiting (relative to available land), the system with the equivalent capacity of 5 mm/day gave the best returns.

Soil type is an important factor; lighter soils lead to crop stress more rapidly than deep heavy soils where deficit irrigation is more likely to be successful.
Trash blankets
Evaporation of water from the soil surface is known to comprise a significant portion of crop water usage. Trash blankets, the retention of trash from the previous crop, has been considered a way of minimizing these losses. Trials in South Africa showed a saving of 21% in seasonal crop water use with a trash blanket in comparison with a bare soil. Crop yield was not significantly affected by this reduction in applied water, although there was a definite slowing of growth rate in the young cane. Trash blankets could comprise an important water saving strategy in water deficient areas (Oliver and Singles 2007).

Cut-back furrow irrigation
With furrow irrigation, a large flow rate at the start of an irrigation set is required to obtain a rapid advance. Once the water reaches the end of the furrow, runoff will occur. The supply rate can then be seen to be greater than the average instantaneous intake rate in the furrow, and this will increase with time. If irrigation is not stopped the majority of water will eventually pass out of the end of the furrow. Some runoff is inevitable, however (hence low efficiencies are common for furrow irrigation).

Cut back systems are intended to reduce this out-flow. It is common practice to cut back the original discharge at some time before the advancing water has reached the end of the furrow, and to continue using this new discharge for the remainder of the irrigation. A common technique is to cut back the irrigation when the advance has reached 25% of the design period for that irrigation. The flow is then cut back to about one third or one half of the original flow. This fine tuning can only be successfully done by trial and error. Cutting back is difficult if the original design does not allow for multiple canal outlets, e.g. two or three siphons.

Tail-water reuse
Tail-water reuse is a technique used to improve efficiency through the collection of runoff water at the bottom of a field and either pumping it back to the top or cascading it through other fields further downslope. Some collection or storage system is usually included so as to ensure that reasonable quantities of water accumulate before being transferred back to higher levels or used on lower fields.

One of the main reasons for low furrow irrigation efficiency is runoff loss, so reuse can be an important improvement. On heavy soils in particular, where runoff is usually the major cause of low efficiency, runoff recycling is of particular importance. In the Burdekin area of Australia, improvements in application efficiency of approximately 20% have been demonstrated through tail-water recycling (Raine and Bakker, 1996).

Taken in terms of water balance on a basin scale, however, runoff or return flows may be less of a negative than on a farm or estate scale.

Banked furrow ends
In the absence of tail-water reuse, another common technique is to block the end of the furrow; flows are cut off early and the excess water is then allowed to pond. Banking at the furrow end allows irrigation to be shut off earlier as water moving down the furrow can recharge the end without spill. However, this practice can lead to over-irrigation at the furrow end (Lecler and Griffiths 2003).

Water measurement
Measurement of irrigation water flows from abstraction to application is a critically important aspect of water conservation and management. Without regular measurement there is no dependable
feedback and irrigation scheduling becomes inaccurate. If there are leakages in the system, measurement of flows should identify where this is taking place and to what extent.

Water meters should be installed at pumping plant and measuring flumes with depth recorders on open channels. Van der Stoep et al. (2005) have carried out a major review of the subject.

For pipes, mechanical meters (turbine, impeller and propeller types) are robust, easy to use and have low capital cost, but they are susceptible to blocking and have moderate accuracy (better than 10%). Non-intrusive electromagnetic flow meters cause no obstruction to water flow, have a high degree of accuracy (0.5 to 2%) but are moderately expensive and require specialized technicians for repairs. A third type (acoustic or ultrasonic flow meters) is also non-intrusive, very accurate (2%) and is well suited to portable (clamp-on) models, but is more expensive than electromagnetic meters.

For open channel measurement, it is important to have a long approach canal without turbulent flow. Sharp-crested weirs (metal plates with gauges) are popular for small channels, with V-notch preferred for low flows. They are cheap to install but can get blocked with debris or silt which affects the calibration. For larger flows, short-throated flumes, typically the Parshall flume, are widely used both in concrete lined and earth canals. Portable cut-throat flumes are useful for flow measurement of small channels in fields. Mechanical current meters are portable and used for larger channels and rivers; the river cross-section and depth must first be established.

Modern irrigation systems have increasingly made use of telemetry to transmit real time flow data measurements to a central control center, where scheduling is managed.

**Pumping plant**

Power costs are often the largest expense in irrigation. Efficiency can be markedly improved by: the installation of power factor correction equipment: typical correction from 80 to 99% reduces costs by around 20%. This equipment also needs to be installed at the electrical sub-station. Up to half the monthly power costs may be accounted for by maximum demand charges; the use of ‘soft’ starters also assists. In some countries, on-peak/off-peak tariffs are imposed and it becomes important to minimize (or eliminate) power usage during these limited daily periods. Control of energy costs is an important part of the Irrigation Manager’s duties.

Specifications during Initial design should require a minimum pump efficiency level – which on the larger units (>100 kW) should include a pre-delivery test certificate. Motor design should be specified as close to full load current as possible, to improve efficiency. Pump impellers wear away over time, which lowers efficiency. It is therefore worthwhile either to install an efficiency monitor on pumping plant or to implement a regular efficiency testing program.

**System maintenance**

Considerable wastage of water can occur in poorly maintained irrigation schemes. Leakages in pipelines, canals, storage reservoirs, etc. can be significant. Worn sprinkler nozzles are an important cause of low efficiency. Wearing causes an enlargement of the orifice. A 10% enlargement of the orifice will result in an increase of about 20% in discharge, a 20% increase in power consumption and possible over-watering.

Simulations carried out by Lecler et al. (2007), showed that reductions in non-beneficial water balance components were affected more by design and management considerations than by the type of irrigation system. Good management of a poorly designed system may have better results than poor management of a well designed system. Avoidable losses account for the largest portion of water wastage in irrigation farming.
System evaluation
System evaluation involves taking in-field measurements and then using scientific and engineering principles to assess these measurements in the light of performance standards (Griffiths and Lecler 2001).

The authors reported that the objectives of irrigation evaluation include:

- Determining whether the system is working according to grower assumptions and design specifications
- Determining how much variation there is in the amounts of water applied and whether this is impacting on yield
- Determining the causes of the variation and recommending cost effective remedial intervention
- Assessing whether the conveyance system is efficient and correctly sized
- Checking the efficiency of power usage
- Making recommendations to improve the system and so maximize the efficient use of water.

Dlamini (2007) describes a number of practical methods for the evaluation of furrow, sprinkler, center pivot and drip irrigation which was done in Swaziland. Areas of concern included deep percolation in furrow irrigation (cut-back techniques were recommended). With drip irrigation large variations in pressure in the system were found, and corrective actions such as acid treatment were recommended; worn nozzles and leaky pipes were a problem in sprinkler irrigation, with replacement being the recommended remedy. With center pivot, blocked nozzles were found, and cleaning and replacement were the solution. It was concluded that evaluation is an extremely important exercise in order to ensure good investment returns.

The use of the various efficiency and uniformity ratios during evaluation enables the investigator to compare the results with industry norms and highlight areas where interventions are necessary. It should be noted that an irrigation system can have a high application efficiency and have a poor DU, i.e. a large portion of the crop may not be receiving an adequate water supply even though the water is being efficiently used – with minimum losses. Crop stress may be occurring over a significant area. This underscores the importance of using all the indicators, as the full picture is not revealed when some of them are omitted from the evaluation (Ascough and Kiker 2002).

Benchmarking
Benchmarking is a system which can be effectively used in irrigation evaluation. Benchmarking is a process of learning from past performance in the pursuit of continuous improvement. Two methods apply: on-farm investigations and industry wide analysis; the two combined will determine the benchmark. Irrigation performance indicators should be used to compare test results with previous levels of performance and desired future targets or with other irrigation projects or farms. Industry norms and standards can be used as additional benchmarks.

Greaves et al. (2008) used a benchmarking approach to adjudge the performance of a conveyance system in KZN, South Africa, and to rank associated farms in terms of yield and irrigation water use. The conveyance system was considered as being very efficient, with only 10% losses as compared to a standard national benchmark of 20% losses. At the individual farm level, a large amount of variation in results was found. An envelope of high and low expected performance was used as the comparative benchmark. Possible reasons for the varying performance were identified and the comparisons with the expected results were seen as a good example of how benchmarking can be useful in such evaluations.
6.6 Scheduling

Irrigation scheduling can be defined as a program of irrigation determining the amount of water and timing of application (Olivier and Singles 2004). It is generally accepted that the adoption of appropriate irrigation scheduling practices can lead to increased yields and greater profit for growers, significant water saving, reduced environmental impact and improved sustainability. Scheduling methods aim to maintain the soil water content in the optimal range by direct soil moisture monitoring or by estimating the soil moisture content through water budgeting. In general, soil moisture is found to be at an optimum level only for a short portion of the growing season.

Many scheduling systems are available. In general, meteorologically based systems are best served by automatic weather stations (AWS), which can be set up on a farm, group of farms or an irrigation area with broadly similar climate. An AWS can be linked to on-farm scheduling systems and near real-time data can then be used for manipulation of water application management.

Schedules can be classified as fixed – with the amount and cycle fixed for the entire growing season, semi-fixed – with the amount and cycle changed a few times to accommodate rainfall and major changes in age related crop water demand, and flexible – where the amount and cycle are changed daily or weekly according to a calculated water budget based on pertaining crop and weather conditions (Olivier and Singles 2004).

Fixed irrigation scheduling is largely practiced on gravity based surface irrigation schemes, where water is rotated according to delivery cycles defined mostly by canal capacity. Flexible systems are the only ones to be considered here.

Some scheduling methods are described below:

- **Evaporation pan**
  Using a ‘profit and loss’ system of control, widespread use has been made of the USDA Class ‘A’ Pan and the Australian Minipan. Anon (2000) describes the latter as the simplest and cheapest scheduling tool available, providing good accuracy and reliability. The success of the Minipan can be attributed to its simplicity and the fact that growers can easily calibrate Minipan to individual soil types. Responses ranged from 10 to 25 % increase in cane yield compared with unscheduled irrigation.

- **Soil water potential system**
  Several systems are available, mostly measuring soil moisture potential indirectly; and therefore requiring calibration for different soil types. Tensiometers target a single horizon per device. Neutron probes can measure a number of points as the probe is lowered or raised in the access tube. Capacitance probes usually have three to five sensing points which are aimed at points of interest down the soil profile (e.g. 300 mm where most water is abstracted, 600 mm which often coincides with the B horizon and can be used to determine rates of infiltration and 1 200 mm, which gives information as to potential over-watering). The capacitance probe is ideally suited to data transmission via a telemetry network and can deliver near real-time data to a control sensor.

  A continuous soil water monitoring system (capacitance probe) was used to indicate under- and over-watering of cane in a KZN study area in South Africa. Over-watering in the early season was identified, as well as under-watering during the peak growth period. Adjustments to these anomalies could result in water saving and/or increased yield (Jumman and Lecler 2009).
• **Time temperature threshold (TTT) system**

Using a center pivot, an automatic scheduling system was tested using an infrared thermometer (mounted on the pivot) to remotely examine crop canopy temperature. The system, termed a time temperature threshold (TTT) scheduling system, recorded canopy temperature and, where a threshold canopy temperature was exceeded for longer than a predetermined threshold time, an irrigation was triggered (Peters and Evett 2006).

• **Web-based systems**

Singels (2007) reports that decision support service (DSS) using computer and web-based models sending data by mobile phone text messages have been developed over the years but have largely proved unsuccessful in South Africa, with a disappointing uptake by farmers, being often impractical and complex. The adoption of DSS based on growth models has also been slow in parts of Australia (Inman-Bamber et al. 2007). However, the rapid progress of communications technology including the internet, may enable this technique to take off in the future.

### 6.7 Potential impact of irrigation practices on the environment, communities and health

Irrigated sugarcane developments have a profound influence on the environment. Where irrigation is introduced on a large scale, it is likely that a relatively dry environment will change to one having water surpluses. This is mainly due to runoff, spillage and seepage. In addition, the exploitation of groundwater for irrigation may deplete deep aquifers, affecting wells used for drinking water. The introduction of harmful chemicals, waste waters and increase in soil erosion may adversely affect the natural fauna and flora of the area.

Groundwater levels may rise over time and lead to salinity and waterlogging problems, which has occurred in many areas, notably the Indus basin in Pakistan. Return flows will always need to be monitored for quality purposes (salt content). This is covered in Chapter 7.

Allocation of river flows should always include an environmental component. Local rivers supplying irrigation water may suffer reduced flows, especially during the dry season. Minimum river levels are critical for the breeding of some aquatic species, and local populations may be affected in terms of their livelihood, such as fishing and subsistence irrigation as well as for domestic purposes.

#### 6.7.1 Environmental impact assessment (EIA) for irrigation developments

Economic, social and environmental change is inherent to development and, whilst development aims to bring about positive change, it can lead to conflicts. An EIA is concerned with the negative impacts of irrigation on the environment, and with the sustainability of irrigation itself.

Negative effects include:

- Degradation of irrigated land (including salinization, alkalization and waterlogging).
- Deterioration in socio-economic conditions (e.g. increased incidence of water related disease, increased inequity and weaker community infrastructure).
- Water quality problems for downstream users.
- Ecological degradation such as reduced biodiversity in the project area, and damage to downstream ecosystems due to reduced water quantity and quality.
- Ground water depletion (e.g. dry wells, saline intrusion at coasts, reduced base-flow and wetland damage) (Dougherty and Hall 1995).
Cheesman (2004) lists the following aspects that can mitigate the environmental impacts of the irrigation of sugarcane:

- Improved scheduling to enhance water use efficiency.
- Adoption of water-saving irrigation methods, e.g. drip irrigation.
- Adoption of water conservation methods such as mulching.
- Tail-water reuse.

6.7.2 Environmental Management System (EMS) for sugarcane developments

Maher and Schulz (2003) noted that, in the Noodsberg area of South Africa, environmental issues were becoming increasingly important and that an appropriate system for environmental protection needed to be developed. Consequently an environmental management system (EMS) based on ISO 14001 was formulated and implemented. It was found that prior to this development, good practices for sugarcane were fragmented and no single document existed in the sugar industry containing all the guidelines necessary to protect the environment. They describe the construction of a basic EMS plan for a sugarcane area including a breakdown of the several components, its implementation, management and review. The EMS described could be used as a template for other sugar producing areas.

6.7.3 Effects on communities

Social considerations include the creation of employment opportunities, income distribution and quality of life changes. These can be complicated, for example, changes in cropping patterns (e.g. introduction of irrigated sugarcane), may change the kind of work done by men and women and displace the production of staple foods and grazing areas. It is critical that communication with local people is initiated as early as possible in project development.

Many of these issues were encountered in the Komati Downstream Development Project (KDDP) in Swaziland. This project was initiated to develop small sugarcane growers in the area. The Swaziland Government created an overarching agency to assist KDDP – which facilitated rather than managed the project, enabling the affected communities to control all aspects of their development. The KDDP was an interactive and responsive project that relied on a continuous evaluation process and included social and training teams. Interaction was important as communities raised more complex issues as they pursued increasingly skilled activities. Their philosophy of proactive awareness enabled potential adverse impacts from the development to be converted into beneficial and sustainable opportunities (Login 2001).

Many failures of irrigation projects can be blamed on neglecting the social institutional structures. Enabling and enhancing of organizational capacity is seen as critical in the development of viable projects and good environmental management. The Water User Association (WUA) model has now been widely adopted, and has been important in encouraging community participation and labor mobilization, adoption of improved farming practices, and improved irrigation efficiency (Byrnes 1992).
6.7.4 Effects on health

Introduction of irrigation to an area can bring wealth and prosperity, but also sickness. Many important diseases in the tropics are related to the presence of water, e.g. malaria, schistosomiasis and hookworm. New villages are especially vulnerable to diseases such as filariasis and diarrhoea, which can be linked to raw water rising out of the irrigation development (Kay 1986).

Mosquito borne diseases, of which there are many ranging from malaria to numerous viral diseases, are a global problem which is exacerbated by irrigation and drainage activities. Recommendations to combat this have included the need to expeditiously remove and dispose of irrigation runoff, waste water, seepage and ponding around the irrigation lands.

Land leveling and grading should be implemented to minimize ponding. Vegetation in drainage channels should be cleared as this reduces stream velocity and provides protection for eggs and larvae, and desilting should be implemented on a regular basis. Conveyance channels on low gradients should retain constant levels to encourage predators of vectors.

Kay (1986) suggests that the best way of fighting the main water borne diseases is to interrupt their life cycles. Three ways are put forward: (i) treat infected people, (ii) get rid of the vectors and (iii) separate people from the infected water. Treatment of infected persons is self explanatory. Mosquitoes (the vectors of malaria) and snails (the vectors of schistosomiasis) thrive in similar conditions – shallow, still or slow moving water in canals, drains (with vegetation) and irrigated land. Apart from chemical treatment, actions that can be taken to eradicate these vectors include increasing the water velocity in channels (at 0.5 m/s snails do not survive well), lining of canals, removing the vegetation from the channels, and backfilling ‘borrow’ or gravel pit areas. Periodic drying of drainage ways and balancing dams is also effective, as is sealing of leaking canals.

Separating people from water is important. Fencing should be erected along water structures; foot bridges can be erected over channels and water can be piped past residential areas rather than flowing in open canals. It is also essential to provide a good alternative source of clean water for drinking and washing. This is particularly important where vinasse is distributed through the irrigation system.

6.8 Water supply and hydrology

Prior to the implementation of any major irrigation development, the potential water source should be thoroughly investigated. The following is a list of requirements to verify water availability and suitability:

- Establish contact with Government Water Allocation Authorities, local Water User Associations and/or Water Boards. Obtain national/local regulations pertaining to water usage, environmental requirements and social considerations.
- Determine legal position with regard to water usage – complying with all local and regional legal requirements. Establish licensing requirements and obtain water use charges; identify prior users and their offtake quantities; investigate potential users; consider the international position, if applicable, in respect of new abstractions.
- Obtain water use charges and add these to project economic analysis.
- Identify river gauging station locations and obtain historical data. With established projects, determine water delivery schedules.
- Conduct hydrological study on the river or dam supplying water, carefully assessing dry season flows to establish exceedance levels. Identify river gauging station locations and obtain historical
data. Investigate risk of possible flooding, and determine flood magnitudes and return periods. Relate flood magnitude to project topography and establish the 20 and 50 year flood lines. Consider flood control measures that may be required. Investigate options for off-river storage for low flow periods (on-river storage is generally too expensive and long term for a sugar project).

- Assess water quality in respect of salt content, sediment loading and contamination.
- Obtain water allocation/abstraction permit.
- Obtain national/local regulations pertaining to water usage, environmental requirements and social considerations.

With established projects, determine water delivery schedules. Identify low flow periods of a river and relate them to the farm or project water requirements on a monthly basis. Compute probability of supply (risk of failure) for various low flow return periods – with cognizance being taken of existing and potential users.

6.9 Summary of good management practices

<table>
<thead>
<tr>
<th>Item</th>
<th>System</th>
<th>GMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>System selection and water sourcing</td>
<td>All</td>
<td>Carry out screening of possible irrigation systems to find most appropriate to the local circumstances.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confirm water availability and suitability.</td>
</tr>
<tr>
<td>Irrigation system</td>
<td>Furrow</td>
<td>Carry out land leveling initially and smoothing every plough-out.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Implement a tail-water or lower field re-use system where possible.</td>
</tr>
<tr>
<td></td>
<td>SDI</td>
<td>Monitor dripper discharge; apply chemigation when necessary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ensure regular filtration and flushing is carried out.</td>
</tr>
<tr>
<td></td>
<td>Sprinkler</td>
<td>Check nozzles for wear; replace at least every five years.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>During windy seasons, irrigate at night if possible.</td>
</tr>
<tr>
<td></td>
<td>Center pivot</td>
<td>Check nozzles every year for blockages and wear.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ensure there is no over-watering at terminal sprayers.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max slope across field should not exceed 15%.</td>
</tr>
<tr>
<td>Scheduling</td>
<td>All</td>
<td>Implement weather based scheduling system with soil based systems as confirmatory and back-up.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitor deep percolation to determine wastage.</td>
</tr>
<tr>
<td>Pumping plant</td>
<td>Sprinkler/pivot</td>
<td>Operate at design duty point only where possible.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitor efficiency and energy consumption; maintain at design specification by replacing wearing parts.</td>
</tr>
<tr>
<td>Water measurement</td>
<td>All</td>
<td>Install water meters on pump plant and at drip irrigation valve control centers. Relate flows to required depth of application.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With furrow irrigation, install measuring flumes.</td>
</tr>
<tr>
<td>Trash blankets</td>
<td>All</td>
<td>Green cane harvesting leaving a trash blanket will improve efficiency of all irrigation systems.</td>
</tr>
<tr>
<td>Evaluation</td>
<td>All</td>
<td>Carry out evaluation of irrigation systems every two years to determine efficiency and uniformity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Identify areas where systems are below standard and rectify these.</td>
</tr>
<tr>
<td>Environment</td>
<td>All</td>
<td>Avoid standing water in canals or sluggish drain flow. Remove weeds and silt from drains.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Check for leaking pipes and valves.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Manage over-irrigation – deep percolation and runoff.</td>
</tr>
</tbody>
</table>
6.10 References


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**Further reading**


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7. DRAINAGE, IRRIGATION WATER QUALITY, SALT AFFECTED SOILS

7.1 Introduction

Irrigated agriculture cannot survive indefinitely without appropriate drainage and salt management. How long it can survive depends largely on the hydrogeology and water management of the area concerned.

Crop performance can be affected by inundation and shallow water tables which lead to oxygen depletion and high carbon dioxide concentrations. Inundation also leads to chemical reduction reactions in the soil, denitrification, and a build-up of methane and ethylene gases in the soil solution. The capacity of soils to carry machinery falls steadily as the soil moisture content increases and, at moisture levels above field capacity, soils can only bear light loads without being damaged. Access to lands is impaired and field operations cease.

Dissolved salts can have detrimental effects on plants and soils. At certain salt concentrations in the soil water, cane yield begins to decline. One reason is that high salt levels increase the osmotic pressure across the soil root interface, making moisture less available to the root system. Specific ions in saline waters can also be injurious. Sodium in particular is harmful in that it can be toxic to root growth and cause soil structural damage when it dominates the soil’s colloidal exchange complex.

Excess chloride can also be toxic to root growth, while bicarbonate can be harmful by precipitating soluble Ca from the soil solution and indirectly increasing the impact of sodium through an increase in both the Exchangeable Sodium Percent (ESP) and Sodium Adsorption Ratio (SAR) of a soil solution.

The rate of salt accumulation in the soil is determined by the salinity of the applied waters, the in situ salinity of the soil profile and the rate at which salts are leached out of the root zone. If impermeable layers are present near the soil surface, salt accumulation and waterlogging develop within a relatively short time, decades or less. If no restricting layers exist and the vadose region (soil volume extending from the ground surface to the water table) has a large water storage capacity, irrigation may be practiced for a long time, perhaps centuries, before salinity or waterlogging become a threat (Oosterbaan 1994).

7.2 Drainage of agricultural lands

Sugarcane is a ‘special case’ in respect of agricultural drainage as the drainage infrastructure has to be in place before the crop is planted, but must continue to perform adequately for all the ratoon crops, which might be many years. Opportunity for any major infield cultivation or drainage is limited by the presence of the growing crop.

Agricultural drainage concerns the control and management of excess water as it impacts on the root zone of a growing crop or erosion damage to land surfaces. Drainage may be the result of, for example: runoff from badly designed sprinkler/pivot irrigation where application rates exceed the infiltration rates of the soil, from uncontrolled end-spillage with furrow irrigation causing subsurface seepage or from over irrigation of drip on a light soil, leading to deep percolation or naturally high water tables.

7.3 Types of drainage

Agricultural drainage can be divided into surface and subsurface systems as shown in Box 7.1:
Box 7.1 Types of drainage

**Surface drainage:**
Surface drainage is designed to channel excess water or runoff – usually following rainfall – away from the cultivated land as soon as is possible. A further function is to collect and dispose of water coming out of subsurface drains. Surface drainage comprises networks of ditches and waterways. Within the fields, variously spaced ‘tertiary’ ditches and waterways collect and divert runoff to secondary and main drains and eventually into a natural water course or stream.

Interceptor ditches capture and divert water away from the upper slopes of a field (primarily as a flood protection precaution). Where a surface drain terminates at a point lower than the natural stream, the lower boundary of the land is usually diked (against river flood waters) and the collected drainage water is pumped out over the dike.

**Subsurface drainage:**
Subsurface drains are designed to ensure that the water table remains below the root zone for most of the growing season.

- They comprise a network or grid of perforated pipelines buried at a target depth. These drains discharge into deep open surface drains or ditches.
- Mole drains are a special case of subsurface drainage; they comprise relatively short-lived soil-channels formed in a clay subsoil using a mole plow. The life of a mole drain depends on a number of factors that will be considered later in the chapter.
- Tubewell or vertical drainage is another sub-drainage system but is not in common use. It comprises a series of wells drilled into the aquifer to some tens of meters; the pumped water is then discharged into open surface drains. Water table height can be controlled, but spacing between wells is critical and costs – capital and operational – are high.

7.3.1 Internal drainage of soils

The internal drainage of soils concerns the existence and control of water tables. The three internal soil drainage problems below can be recognized.

**Permanently waterlogged conditions**
Here the gleyed subsoil and geological strata remain continuously saturated below the water table. The soil may be permeable, but groundwater has built up above deeper geological formations to reach the surface. The water tables in these lands may fall slowly in the dry season, but return to shallow depths with rain or irrigation. Where the soil is permeable, the method of dealing with this problem is to install subsurface drains to peg the water table at the required design level. Due to the permanent nature of the waterlogging, mole drains are not recommended.

**Perched water tables**
These occur where an impermeable layer in the soil profile or underlying strata prevents downward movement of water, causing it to build up towards the surface. The impermeable layer can be quite shallow. These water tables are usually seasonally present, draining naturally during the dry season. If the problem is caused by a shallow plow pan, subsoiling can be used to break up the pan and, if the soil below this is permeable, the drainage problem could then be solved.

If the impermeable layer comprises heavy clay subsoil, subsoiling should not be employed. If the surface soil is relatively permeable, a subsurface drainage system will probably be effective, but may
need a porous envelope to be included if the drainage pipe is located in a heavy clay subsoil. Supplementary mole drains may be effective in some clay soils provided the depth of the clay subsoil is within 300 mm of the surface.

Very heavy or dense hydromorphic soils
Where the soil profile has a very low hydraulic conductivity rate due to the presence of a firm gley at depth, water movement will be very slow and may lead to waterlogging and surface ponding and runoff. In these heavy soils, the drainable porosity can be as low as 0.5 % and any water movement is usually only in the topsoil or over the surface. Subsoils may be relatively dry when the surface soil is moist. Lands with heavy clays are usually fairly flat, or at valley bottoms which exacerbate the situation, as there may be slow natural drainage over the surface. Subsurface drainage would require very close spacing of the pipes to be effective – which would probably be uneconomic.

Mole drains may be a solution, depending on clay content (> 40 %), the type of clay (preferably non-swelling non-sodic clays) (SAR < 6 for grey duplex soils) and the topography (slope 2-5 %). Drainage of these heavy soils depends largely on the removal of surface water via an effective waterway and ditch system coupled with shaped and graded lands.

Other than pumping to remove water accumulated at a low lying collector point, drainage systems rely on gravity to move water. (Tubewell drainage is the exception.) The rate of flow in all drains must be fast enough to move water away from the cropped land in a reasonable time period, but not at velocities that would cause erosion. Flow rates in subsurface drains should be rapid enough to entrain silt and carry it to an outlet structure.

Drain maintenance is important; surface drains require regular desilting, devegetation, reshaping of ditch sides and occasional land smoothing. Piped drains require desilting (using high pressure hoses), cleaning out of outfall boxes and repairing of exit structures where collector pipes discharge into open drains. Mole drains require to be re-pulled after plow out, and can be installed as a ratoon management strategy, e.g. every three crops.

7.3.2 Inundation
One of the most important factors in drainage design is the length of time that a crop can be inundated without sustaining significant yield decline or death. Inundation describes the total saturation of the soil profile, but may not necessarily include standing water. Roots do not thrive in a saturated environment and will degenerate over time.

In addition, if the water table remains elevated for extended periods during early crop development, crop roots may not develop deep enough to prevent subsequent moisture stress during low rainfall periods. Moisture may be present at depth but roots are too superficial to exploit it.

Carter (1976) carried out water table experiments at Louisiana to evaluate the tolerance of sugarcane to a saturated root zone during the growing season. It was found that setting the water table at the surface for up to seven days had little effect on cane and sugar yield. Inundation longer than seven days was not advised, as yields were progressively affected. The soil used in the trials was a silty clay.

Narine, as reported by Ooosterbaan (1994), when working with sugarcane in Guyana defined the term High Water Days (HWD) as the number of days per season during which the water level in the drain collectors exceeded a specific level. Taking the drain level as 0.9 m, he found that HWD greater than seven days resulted in a definite decline in cane yield.
Soil strength is also reduced when saturated and this will affect mechanical operations. Working the soil at water contents at field capacity or higher gives rise to mechanical difficulties and destroys soil structure, especially in clay soils (Oosterbaan 1994). There is a narrow range of soil water content that is optimum for working and trafficking the soil, and this narrow range is less than field capacity. However, with an adequate drainage system the average water content of the topsoil, even in humid areas, seldom rises much above field capacity.

There is an apparent dearth of research work on the effects of inundation on yield as influenced by the interaction of soil texture, temperature, stage of growth, age and variety. A ‘rule of thumb’ that drainage engineers have adopted in surface drainage design is that all residual surface water should be removed from the field within 48 hours.

### 7.3.3 Aeration

The displacement of air during inundation has important consequences in respect of root growth, shoot growth and yield. (It is of interest that oxygen diffuses 10 000 times faster through a pore filled with air than with water.) Soil aeration influences many soil reactions and therefore many soil properties. Reduced oxygen constrains root respiration, which negatively affects water and nutrient uptake. Both low oxygen and high carbon dioxide cause a decrease in ion uptake in the order K>N>P>Ca>Mg (FAO/UNESCO 1973). In general, it has been estimated that the pore space in the top 1.0 m of soil contains a supply of oxygen sufficient to meet the respiratory demand of crops for about 3-4 days without replenishment.

In most soils microbiological activity and plant growth are severely inhibited when the air-filled porosity falls below 20% of the pore space (about 10% of the total soil volume). Soil microorganisms responsible for the breakdown of organic matter are inhibited. In anaerobic conditions the decay is slower, resulting in the accumulation of products of partial decomposition, such as ethylene gas, alcohols, etc., many of which are toxic to plants.

Temperature is also important as it affects the rate of oxygen use; during the hottest months of the year, oxygen requirement in the root zone is greatly increased.

Texture and structure are important; a lack of oxygen is common in heavy clay soils and also those with compacted, saturated or otherwise impeded subsurface drainability. Yield reduction of crops grown in heavy clay soils has been partly attributed to depletion of oxygen in the root zone.

Most of the air entering a soil whilst draining takes place through the macropores, underscoring the importance of structure – especially so in soils with dense clay horizons. Sodic soils with dispersed particles contain few macropores and suffer significant de-aeration, which is one reason for poor crop growth on those soils.

### 7.4 Water table management

The term ‘water table management’ (WTM) concerns the manipulation of a water table for both drainage and sub-irrigation purposes. Sub-irrigation is possible where a water table is positioned at a level within the soil profile such that capillary rise can meet all or some of the crop’s transpiration requirements. It is critical that the water table does not inundate the field to very shallow levels, causing deoxygenation. Because the water for irrigation rises through capillary action, the larger pore spaces are aerated and a moisture status close to field capacity exists. The high moisture potential minimizes stress, and yield potentials are good.
Managing the water table position should provide the opportunity to increase the in situ crop water use, which should result in improved irrigation efficiency. The closer the water table is to the bottom of the root zone, the better will be the opportunity for in situ crop water use (Ayars et al. 2006). With WTM, water tables are raised or lowered by a combination of natural and artificial actions; water is removed (water table lowered) by crops transpiring or by gravity through a subsurface piped drainage system. Water is raised by allowing water to flow back through the subsurface drains, the water level being raised by pumping water into the outlet channels of the sub-irrigation network as needed. This is termed sub-irrigation.

WTM is only appropriate where there is a restrictive layer at a reasonably shallow depth and the lands are relatively flat, mostly less than 0.5 % slope. When an effective subsurface drainage system is not in place, where the topography is more undulating or where the soil profile is unrestricted to depth, the water table cannot be easily manipulated and WTM as such cannot apply. As with a ‘normal’ subsurface drainage system, the timely removal of water then becomes the most important requirement, with water tables having to be maintained below a minimum depth.

Dissolved salts do rise with the fluctuating water table and can concentrate within the root zone, requiring that lower salinity waters be applied periodically to the surface for leaching. This is mostly in the form of rain water during the wet season.

The WTM system requires outlet level control structures as well as an irrigation supply system. The level control is usually a manually adjusted weir but automatic valve systems with water level sensors are also employed. When excessive rainfall occurs, the water level at the weir can be lowered to allow the system to function as a conventional subsurface drainage scheme; lowering the water level hastens drainage out of the field. When sub-irrigation is required, the outlet weir is raised and irrigation water can be pumped into the main drainage system as needed, or rainfall ‘collected’. This raised water level will cause the shallow water table to rise and supply capillary water to the root zone.

It is probable that many irrigation projects benefit (albeit unknowingly) from a natural sub-irrigation at some point in the growing season. WTM systems are widespread in Florida (USA) plantations, for example, but could be employed elsewhere as an energy and water saving strategy and an environmentally friendly management policy. It should also be noted that there are certain cane varieties that have been selected on the basis of their good performance under high water tables.
### Box 7.2 Examples of high water table management with sugarcane

Pitts *et al.* (1993) examined the effect of water table depth on cane growth and management. The effects of a high water table (HWT), a declining water table (DWT) and a low water table (LWT) were examined on a sandy soil in a Florida trial. The HWT was 0.45 m from the surface and the LWT 0.75 m. The DWT table began at 0.45 m and then reduced at a rate of 0.15 m/annum (plant plus two ratoons). Average cane and sugar yields from the HWT did not differ significantly from the cane and sugar yields from the DWT, but average yield from both the HWT and DWT treatments were significantly greater than those from the LWT. It was apparent that the majority of the crop’s ET requirements were being met by the capillary rise from the water table – as sub-irrigation.

The sandy soil used in Pitt’s work had limited capillary rise, and required a water table depth of 40-50 cm to be fully effective; finer soils, however, can be sub-irrigated from greater depths. In all treatments it was found that the majority of roots were located in the surface 300 mm and that longevity of cane was not affected by the high water table on the sandy soils.

Using a silt loam soil in Assumption Parish, LA, USA, Carter *et al.* 1988, found that a sugarcane crop responded well to WTM. Over a three year period, the WTM plots yielded 15 % more cane and 22 % more sugar than the control plots. Crop production was enhanced, since the amount of sugar produced by the area without WTM could be produced with 18% less land if WTM had been used. The under-drainage was spaced at 15 m and a water control pump allowed water to be removed as drainage or introduced as sub-irrigation.

Christen and Ayars (2001), report on a proposal described by Manguerra and Garcia (1997), where a series of alternating drainage and no-drainage cycles are described. In their proposal, after a leaching event, the drains are closed and no drainage is permitted until the water table rises to a predetermined depth or until threshold soil salinity levels are reached. At this time the drains are opened and the drainage and leaching process begins.

Ayars and McWhorter (1985) showed that when crop water use from shallow groundwater was included in the drain design, the total flow from the drainage system was reduced by nearly 60 %. Incorporating crop water use in the design also resulted in wider lateral spacing than was otherwise indicated. The crop water use effectively reduced the drainage coefficient.

In arid and semi-arid areas (with high evapotranspiration rates) where the purpose of drainage is mainly to control salinity, maintaining a shallow water table for irrigation via capillary water would appear to be counterproductive. However, projects in India and Pakistan have shown that salts accumulating in the root zone from the shallow groundwater were easily leached before the following cropping season; a heavy rainfall period is, however, a necessity – e.g. monsoon rains (FAO 2002).

WTM has significant environmental implications. It can effectively reduce drainage effluent and so save water for other beneficial uses. Maintaining a high water table significantly decreases the loss of nutrients in the drainage water, especially nitrates, as a result of both load reduction and an increase in denitrification. It also helps reduce the presence of pollutants into the drainage water.

Water balance studies would quantify the net gains or losses of WTM to the larger basin or catchment area.
7.5 Drainage methods

7.5.1 Surface drainage

Surface drainage design should ensure that surplus rainfall, in excess of soil storage capacity, is removed before anaerobic conditions set in, and should ensure rapid access to wet lands; the sooner the surface dries out the sooner access will be possible. An open surface drainage system can remove large quantities of water quickly and efficiently, provided the land surface is conducive to surface flows.

On fairly steep ground, surface drains are tied in with soil conservation planning such as contour banks, terracing, grassed waterways and stormwater drains. The main concern is erosion control, and high water tables and inundation are usually not a problem. Where the topography is not flat but gently undulating, land smoothing will also have to be considered as a primary operation (see Chapter 3).

Four types of surface drainage ditch can be identified: tertiary, secondary, main and cut-off drains.

Tertiary or infield drains
These drains, which include shallow waterways, are designed to collect excess water running off the land surface. They are not deep and are arranged to fit in with the roads and irrigation blocks. They are located either on the periphery or as waterways within a field. They usually have shallow side grades (e.g. 1:8) to permit the passage of traffic within or into and out of a field. They are not designed to carry large flows.

Secondary drains
Secondary drains act as collectors and receive water coming from tertiary drains (Fig. 7.1). They are deeper than the tertiary drains and require culverts or bridges to cross them. Secondary drains are also positioned where the collector drains from a subsurface drainage system emerge, which is typically at 1.5-1.8 m requiring the secondary drains to be up to 2.0 m deep.

They are usually built with a uniform cross section and are standardized across a plantation as much as possible. Secondary drains discharge into the main drainage system, which may comprise a natural stream. The number and extent of secondary drainage ditches has an impact on mechanization, as cane rows are usually aligned perpendicular to the secondary drains. Drain spacing is based on topography, irrigation system layout and the runoff capacity from the lands they service. There needs to be a compromise between harvesting operations, which favor long cane rows and drainage design, which requires a rapid disposal of surface flows.
The gradient of secondary drains may be steep as they are usually aligned down a slope. This may require the installation of gabion weirs (Fig. 7.2) along the drain or where it discharges into the main drain, to dissipate velocity and reduce erosion.

**Main drains**
Main drains are required to collect and transmit all surplus water off the farm or estate as a controlled non-erosive flow. They will progressively increase in size as they accumulate flows from secondary drains and other runoff points. However, the size increase should be in width only as it is important that main drains are not deeper than the secondary drains or the terminal outlet points.
Cut-off and interceptor drains

Cut-off drains are designed to protect cultivated land from runoff water arising from higher ground. These drains are usually located above cane fields, and are designed to discharge into the secondary or main drainage systems.

An Interceptor drain, which is a special case of a cut-off drain, is placed where seepage arising from higher ground impacts on fields lower down a slope. The seepage may be from a natural spring, from water infiltrating up-slope and creating a down-slope water table – especially where an impervious layer in the soil rises close to the surface.

They should also be included where free water is maintained at levels higher than the surrounding fields (e.g. balancing dams or canals built in fill) to control seepage problems. The interceptor drain should be excavated to reach an impervious layer, or be at least 1 m in depth.

Where gradients are steep and erosion is likely in secondary or main drains, an in-channel protection system such as gabion weirs with stilling basins and/or stable vegetation protection plantings, such as Vetiver grass, should be considered.

7.5.2 Subsurface drainage

Subsurface drains are used to suppress water tables and, in conjunction with a leaching program, are used to control salinization.

Sugarcane is sensitive to anaerobic conditions in the root zone caused by inundation from a high water table. Where soils are light to medium in texture it is usually possible to control water table height through an artificial or subsurface drainage system. A lower water table will also increase the efficiency of precipitation (increased soil storage volume) and in the same way increase the efficiency of irrigation.

With relatively flat land, a subsurface drainage system comprises networks of parallel buried drainpipes spaced apart at designed distances. Alternatively, pipes can be laid to drain specific wet areas, separate from each other.

The spacing between parallel laterals is important as the shorter the distance the more expensive the scheme. Spacing between parallel drains depends on the required rate of removal of water (drainage coefficient), the allowable water table height, the hydraulic conductivity of the soil and the depth to an impermeable layer. An impermeable layer is defined as one that has an HC of less than one tenth of that of the soil above it. There are a number of mathematical formulae used for determining the required drain spacing (Oosterbaan 1994).

Obtaining values for some local data (e.g. hydraulic conductivity) may be difficult however, and in many cases a spacing of 40 m is used in the absence of the necessary measured values. This is often satisfactory for permeable soils, and allows for a subsequent halving of the spacing if a higher level of protection is found to be necessary. Nevertheless, there is no economic advantage to be gained in spacing drains closer than necessary. As long as the root zone is aerated for longer than the critical period, yield potential will not be compromised (Carter and Camp 1994).

Filters may comprise a surround of well graded granular material or, more common in recent times, a geo-membrane (e.g. non-woven, needle punched polyester type material). Filters are designed to establish a stable interface between the drain and the surrounding soil. Geomembranes are meant to retain finer particles moving towards the drain without reducing the permeability of the drainage
system. Fine particles that do enter the SPP are liable to compact through successive wetting and drying cycles, causing premature blockages and dysfunction.

Filters are indicated where the soils have particles mostly in the 50-100 micron range (equivalent to silt to very fine sand textures). The clay:silt ratio is also important, and where this exceeds 0.5, silting is unlikely to be a problem. Plasticity index (PI) is also a good indicator: With a PI > 12, there should be no tendency to silt up. With a PI of 6-12 there may be limited silting, and with PI < 6, silting can be significant. Soils which have a good spread of particle sizes ranging from clay to coarse sand generally do not have major siltation problems, and filters may not be necessary (FAO 1984).

When a granular surround is in place, the velocity of the fluid streamlines and is increased as it approaches the SPP (lower energy losses). This acts to lower the water table more rapidly as drain water has fewer constraints to entering the SPP slots. Lateral spacings can be increased if a sand envelope is included as drain response time is reduced; this has most relevance in heavier, dense soils.

### Box 7.3 main components of a subsurface drainage scheme

A subsurface drainage scheme involves the installation of a series of perforated pipelines, laterals, buried at design depths and grades. Many materials have been used for this purpose, including clay tiles, pitch fiber pipe, flexible corrugated plastic pipe, semi-rigid slotted plastic pipes, etc. The slotted plastic pipe (SPP), in 6.0 m lengths, is the most common at present because its many advantages include its ease of transport and loading, ease of installation – being light and incorporating bell and spigot joins (unglued), its durability and its being relatively easy to clean.

Laterals are linked to larger collector pipes orientated at a steeper grade; these in turn discharge into an open, secondary surface drainage system. The laterals are usually installed at 1.2-1.5 m deep at gradients paralleling the field slope. The SPP laterals join the collector pipes at a junction box which also enables inspections and cleaning. The laterals can be installed in a trench excavated to grade or by using specialized trenchless machinery (the latter are more suited to flexible corrugated pipe systems).

Drainage efficiency over the long term is affected by silt accumulation in the pipes. In order to prevent or slow this down, it has been common practice to surround the pipe during installation with a filter system. This can be an expensive practice and the relevance should first be established.

A general requirement for the efficacy of sand envelopes is that the HC of the granular material should be 10-100 times the HC of the dense soil horizon (FAO 2007).

Granular material can also be used to improve the drainability of soils with heavy subsoils but which have lighter, freely draining surface horizons. The SPP is laid in the heavy subsoil at design depth; the trench is then backfilled with granular material, so connecting the SPP with the permeable surface horizon. Narrow trenches are obviously more economical but it is, nevertheless, an expensive operation that depends greatly on the availability, proximity and cost of the granular material.

SPP drains should last at least 15 years before replacement is needed. Regular drain cleaning is, however, imperative to ensure a reasonably long life. Cleaning is carried out using high pressure jets of water from a nozzle attached to a hose.
The nozzle is propelled up the drainpipe until it reaches the end, with any silt being flushed back down to the inspection box. High pressure jets can break off roots and remove most of the silt, but some deterioration of the drain does take place over time. Compacted silt, root penetration, collapse and blocking of filter material are some of the factors that gradually reduce the effectiveness of SPP.

7.5.3 Mole drains

On very heavy soils (HC < 0.1 m/day) the design spacing for subsurface SPP drains becomes too close to be economically viable where, for example, recommended spacings of <10m are indicated. The solution to draining heavy soils is mainly at the surface level; a strategy to ensure good runoff, collection and disposal of water has to be put in place. On flat lands, this may require land shaping in order to ensure a positive grade.

Another solution is mole drainage. A mole drain is basically an unlined ‘soil pipe’ or channel which usually discharges into a system of permanent pipe drains installed at fairly wide spacings. These semi-permanent mole channels are drawn through the soil at depth by a cylindrical 75 mm torpedo-shaped steel foot with expander piece attached to a shank or leg and pulled through the soil by a 65 kW+ tractor to form a circular channel or soil pipe.

Mole spacings are commonly between 1.5-3.0 m apart – usually dictated by tractor width. The cost of installation is not usually a major factor even at such close spacing – being < 10 % of a normal subsurface system. Moles are drawn at relatively shallow depths, usually between 450-700 mm deep, and are drawn parallel to the cane row. They vary in length from about 30 m to 100 m.

Mole drains are designed to be drawn through a moist clay layer – with more than 35 % clay. The intention is to compress the soil at depth and to shatter the soil in the upper profile. In order to promote shattering or fissuring and to ensure adequate traction, the moling operation must be conducted when the surface soil is relatively dry. The subsoil must however be in a moist state, i.e. at the lower plastic moisture limit, in order to facilitate the forming of the mole channel.

Mole drains are used primarily to increase the drainage rate of slowly permeable soils and not for combating permanently high water tables. Saturated soils should not be moled as there must be air filled pore spaces in the subsoil to enable this compaction. The clay type is important, with Smectite clays generally not responding well to moling, as the channels are prone to collapse especially if the subsoil tends to be sodic. However, in the South African sugar industry, mole drains in vertisols have lasted for up to five years and longer in some cases.

The gradient of the mole drain is usually that of the average gradient of the soil surface. If there is submergence of the channel for any length of time, however, the mole will collapse. Grades of less than 1:100 can lead to ponding in the drain and more than 1:40 will lead to erosion, both situations resulting in premature collapse. Reverse grades must also be avoided. The land surface must be flat to ensure moles are pulled at an even, regular grade; thus installation should not follow a rough cultivation operation. The mole usually runs down the maximum slope, but can be angled so as to avoid erosive velocities.

On very flat areas where the natural grade is shallow, an artificial grade has to be introduced. This can be done by gradually and progressively increasing the depth of the mole plow from entry to exit. The length of the mole drain is then dependant on the length of the mole plow leg, the chosen grade and the power (capability) of the tractor.
The mole plow (Fig. 7.3) is usually inserted at a drainage ditch or trench excavated for the purpose, and where moling can be initiated at the design depth. A particular mole drain can be drawn the whole length of a field, but periodically discharging into collector drains located at intervals down the slope.

![Figure 7.3. Rear view of a mole plow.](image)

Collector drains or drain-lines are usually excavated ditches (150-200 mm wide) backfilled with sand or gravel and with a perforated plastic pipe installed below the level of the mole. The connection is effected simply by drawing the mole plow across the drain-line. No other form of connection is needed between the mole channels and the collector system. The spacing of the drain-lines equals the mole drain length. A network of collector drains takes the form of a normal subsurface drainage system – but with permeable connection up to the mole drain level.

Over long slopes, several drain-line collectors may cross the field, perpendicular to the moles. They are effectively permanent infield structures, but cultivation equipment can easily ride over them. Alternatively, with smaller fields or with longer mole runs, the collector trench can be left open at field edge and the field sized according to the length of the mole run. Collector drain-lines discharge into the secondary field edge open drainage system at appropriate points.

If constructed under the right conditions, mole drains should be effective for at least five years and in some cases up to 10 years, their life being a product of the consistency of the clay, slope gradient and degree of inundation. With sugarcane, ratoon length usually coincides with the time that moles are re-pulled. After harvesting, the mole drains are re-formed with the mole plow operating between the rows of cane (Dewey et al. 1987).

### 7.6 Drainage design

#### 7.6.1 Surface drainage design

Drainage of excess surface water is important, and surface drainage and irrigation planning should be carried out at the same time. The following discussion on surface drainage mainly concerns land with less than 0.5 % slope.

There are two initial requirements for surface drainage. Firstly, the land must have a definite graded slope towards the drainage ditches and disposal channels, and ponding and reverse-grades must be leveled out. This may require land shaping and smoothing operations, using graders, scrapers and finally land planes (Fig. 7.4).
Secondly, the fields must channel surface runoff in a definite direction in line with the crop planting rows. The typical ridge and furrow method used with sugarcane is a good system. Runoff water breaking though wrongly aligned rows having significant cross-slopes can lead to serious erosion and possible damage to infrastructure, e.g. infield roads and dripper tape lines. These initial requirements are best achieved at the time of project commencement but can be improved where necessary as a maintenance activity at plow out.

Land slope is important; the design for sloping areas (> 0.5 %) is usually based on control of peak discharge (due to erosion risk) and for flat land, control of the average of high discharges.

The drainage capacity or drainage factor is the amount of water that must be discharged over the design disposal period. It is calculated on the basis of coping with a flood discharge having a particular return period; a 24 h rain event with a 1:5 year return period is commonly used (20 % probability of occurrence).

The standard practice is to design runoff to be cleared within 48 hours – termed the rainfall period. The disposal time should not exceed the rainfall period. Subsurface drains will deal with the excess infiltrated water (as the water table rises) but, especially on heavy soils, surface water must be cleared within the design rainfall period. The capacity of the drainage network is based on the drainage factor flow rate, in terms of L/s/ha or mm/24 h day.

With a 1:5 year 24 h rainfall of 150 mm on a sugarcane plantation in Tanzania with a 0.2 % slope, the drainage factor was calculated to be between 5-7 L/s/ha (Euroconsult 1989). The antecedent moisture of the soil or the evaporation amount for this work was not given.

Surface storage, infiltration and evaporation will reduce the drainage factor. Evaporation can be measured. On flat ground, surface storage can be taken as approximately 10 mm and infiltration into an already saturated field as approximately 5 mm. It is recommended that drainage capacity rate be adjusted accordingly during design.

Figure 7.4. Scraper used to shape lands to a definite, even grade.
As an example: taking a 40 mm rainfall event occurring within the 24 h rainfall period, and with:

- the soil being saturated due to previous rains, so allowing only 5 mm of infiltration,
- evaporation over the disposal period being measured as 5 mm, and
- the soil surface storage being taken as 10 mm,

The drainage capacity is then calculated to be 2.3 L/s/ha.

Where soils are heavy, it is important that the tertiary, secondary and main drainage system can handle the drainage capacity runoff and have the capability to transmit this water as a controlled non-erosive flow (FAO 2007). The slope of surface drains mostly follows the general slope of the land, but may need protection if the flow approaches erosive velocity (e.g. gabions or Vetiver grass).

When laying out a sugarcane plantation, it is often desirable to form several fields into one contiguous group, with the facility for machinery to pass directly from one field to another. Equipment can thus operate up or down the length of several fields before turning. This increases field efficiency, especially important with respect to harvesting. A ‘break’ between each field in the group permits the provision of a runoff-collection tertiary drain and a field access road.

The tertiary drain should be wide and shallow and ‘vee’ shaped, with side slopes graded to no steeper than 1:8. The road and drain complex provides protection against the fire hazard, and allows full cane transporters during harvest to exit the fields at regular intervals. Tertiary drains at field breaks flow into the secondary drainage system. Drop structures may be necessary at each outfall, as the vertical height difference can promote gully formation. Inlets from the field to tertiary drains must be free-flowing and small shoulders created by plowing and field wash-out, etc. must be removed periodically.

There is usually a compromise necessary between having many infield surface drains (which take up productive land and shorten cane rows but ensure a relatively rapid removal of drainage water) and fewer surface drains (which frees-up productive land and allows longer rows, but can lead to significant downtime as the soil takes longer to dry out), with often no clear-cut answer. Irrigation system design usually becomes the deciding factor (e.g. furrow irrigation cannot have long rows on light to medium soils, and drains between centre pivots are fixed by the size of the machine).

Secondary drains should be excavated to a level below the design water table level where they can receive water from subsurface drains without submergence. During very high rainfall events the subsurface drain outlets may be flooded for a period, but the water levels should drop to normal within 24 h if the drains have been correctly designed. Being excavated below the field level and below the subsurface drain outlets (if applicable), secondary drains act to influence the general height of the water table in the cropped area through seepage from adjacent lands, especially as they are normally unlined.

Secondary drains require regular maintenance – desilting and weed clearance, so there should be a service road on either side for excavator access. Shoulders must also be periodically removed. Shoulders are created during desilting operations, where soil is deposited next to the drain rather than carted away. Whilst secondary drains are designed to only link with tertiary drains, general surface runoff during high rainfall periods can spill directly into the drain along its length, which is an effective disposal system. Shoulders cut off this spillage and may lead to overwhelming of the tertiary drains during flood events.
The main drain depth should not be deeper than the secondary drains and should join the regional drainage system at a gentle gradient without promoting headwall erosion. Main drains may need to be considerably widened to accommodate these requirements whilst carrying the accumulated floodwaters.

Side slopes can be based on one of two criteria, depth and soil type; the shallower slope of the two possibilities should be adopted. Examples of each approach are given in Tables 7.1 and 7.2 below (FAO 2007).

### Table 7.1 Minimum side slope ratios for various depths of earthen channels.

<table>
<thead>
<tr>
<th>Channel depth D (m)</th>
<th>Minimum side slope ratio: horizontal/vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>D = &lt; 1</td>
<td>1.0</td>
</tr>
<tr>
<td>1 &lt; D &lt; 2</td>
<td>1.5</td>
</tr>
<tr>
<td>D = &gt; 2</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### Table 7.2 Minimum side slopes for earthen channels in different soil materials.

<table>
<thead>
<tr>
<th>USC group symbol</th>
<th>Typical names</th>
<th>Minimum side slope ratio: horizontal/vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>Gravely clays and gravel-sand-clay mix.</td>
<td>1.0</td>
</tr>
<tr>
<td>ML</td>
<td>Silts, fine sands, clayey fine sands</td>
<td>1.5</td>
</tr>
<tr>
<td>CL</td>
<td>Clays of medium to low plasticity. Sandy clays and silty clays.</td>
<td>2.0</td>
</tr>
<tr>
<td>SC</td>
<td>Sandy clays.</td>
<td>2.5</td>
</tr>
<tr>
<td>CH</td>
<td>Clays of high plasticity.</td>
<td>3.0</td>
</tr>
</tbody>
</table>

USC = Unified Soil Classification system

All roads traversing cross-slopes should have drains on the upslope side. Culverts should be installed to take this upslope water under the road to join secondary or main drains where they are encountered.

Crest roads should be drained on either side with miter drains being constructed at regular intervals to divert the drainage water into surrounding non-arable areas or secondary drains. Drainage design should take note of the need for infield equipment to cross drainways and enter into fields or to join other access roads.

Surface drains are relatively cheap to build, using a backhoe or excavator, and are usually easily maintained. However, large amounts of soil have to be disposed of. This soil can be used, where suitable, to construct dams or protective dikes, construct roads, fill low spots, etc.

### 7.6.2 Subsurface drainage design

Subsurface drainage design is not an exact science because of the great variability that exists in the natural soils. Furthermore, rainfall is not constant and irrigations are not perfectly uniform.

Certain soil properties are important in subsurface drainage design, these include:
Hydraulic conductivity (K)
Soil hydraulic conductivity (K) is the main factor in deciding whether a subsurface drainage scheme is feasible. K is defined by the volume of water that will pass through a unit cross-sectional area in unit time having a unit difference in water potential.

Saturated hydraulic conductivity applies to drainage design; unsaturated hydraulic conductivity has much slower flow rates and applies more to the soil moisture status at and below field capacity. Initial K rates are high as the larger pores drain; when the water content is reduced to field capacity, K reduces to between 1/100 and 1/1000 of its initial rate at saturation.

Low K values put the economics of subsurface drainage in question. Low K values are found in silty loam soils and heavier, although some sandy clay loams can have similarly low K values (see Table 7.11). Heavier soils such as clay loams, silty clay loams, silty clays and clays can benefit from subsoiling, and sometimes mole drains as opposed to subsurface drains. Where soils have K values greater than 2.0 m/day, they generally do not require subsurface drains.

Drainable porosity (drainable pore space, storage coefficient, air capacity)
Drainable porosity (DP) can be defined as the ratio between the change in the amount of soil water and the corresponding change in the level of the water table; i.e. the difference between saturation and field capacity. It thus approximates the volume of air that can replace water draining under gravity. If the drainable porosity of a soil is 10%, adding another 10 mm to a soil at field capacity will cause the water table to raise 100 mm, as described by equation 7.1:

\[
\text{Rise in water table} = \frac{\text{water application}}{\text{DP}}
\] (7.1)

Drainable porosity is an indicator of the stability of the macropores – the number of which has a major influence on the total soil air space as well as the gaseous exchange and biochemical reactions.

Texture
Texture influences hydraulic conductivity and drainable porosity. In general, the lighter (sandier) the soil, the faster it will drain and the higher the drainable porosity. The heavier (clay) soils have slower hydraulic conductivities and smaller drainable porosities (Table 7.3).

Soils with strong structure, which are heavy, have high K values and may rely entirely on their structural pores for their conductivity. Vertic soils high in montmorillonite clays have high K values initially but swell when wet and the K value drops to very low values.
Table 7.3 Approximate relationships between texture, structure, drainable porosity and hydraulic conductivity.

<table>
<thead>
<tr>
<th>Texture, Structure</th>
<th>Drainable porosity (%)</th>
<th>Hydraulic conductivity, (m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>26-35</td>
<td>&gt;12</td>
</tr>
<tr>
<td>Medium sand</td>
<td>22-26</td>
<td>6-12</td>
</tr>
<tr>
<td>Loamy sand, fine sand</td>
<td>Medium crumb, single grain</td>
<td>15-22</td>
</tr>
<tr>
<td>Fine sandy loam, sandy loam</td>
<td>Coarse, sub-angular blocky and granular, fine crumb</td>
<td>12-18</td>
</tr>
<tr>
<td>Light clay loam, silt, silt loam, very fine sandy loam, loam</td>
<td>Medium prismatic and sub-angular blocky</td>
<td>6-12</td>
</tr>
<tr>
<td>Clay, silty clay, sandy clay, silty clay loam, silt loam, silt, sandy clay loam</td>
<td>Fine and medium prismatic, angular blocky and platy</td>
<td>3-8</td>
</tr>
<tr>
<td>Clay, clay loam, silty clay, sandy clay loam</td>
<td>Very fine or fine prismatic, angular blocky or platy</td>
<td>1-3</td>
</tr>
<tr>
<td>Clay, heavy clay</td>
<td>Massive, very fine or fine columnar</td>
<td>1-2</td>
</tr>
</tbody>
</table>

**Design drainage rate**

The amount of drainage water to be removed by the subsurface drainage system is described as a depth or volume per unit area per unit of time (mm/day) and is known as the design drainage rate or drainage coefficient (q). This has the same units as hydraulic conductivity. If salinity control is required, the leaching fraction must be added to the drainage coefficient. Water to be removed from the system can then be stated using equation 7.2.

\[
Q = \frac{ET[(1-SF)(1-LF)]}{SF}
\]  

(7.2)

where

- \( Q \) = the drainage coefficient (using same units as ET)
- \( ET \) = crop evapotranspiration – the rate of use per day or the depth of water consumed over a specific period of time
- \( SF \) = the fraction of the infiltrated water that is stored in the root zone
- \( LF \) = the leaching fraction.

\( SF \) can be computed from equation 7.3.

\[
SF = \frac{ET}{[IWi(1-RF)-ET(LF)]}
\]  

(7.3)

where

- \( IW \) = irrigation water
- \( RF \) = fraction of the irrigation water that runs off.

Alternatively, where outside influences are included, equation 7.4 can be used:
\[ Q = RW + SC + SI - DN \] (7.4)

where

- **RW** = the on-farm recharge to ground-water i.e. leaching water, rainfall, and deep percolation resulting from excessive water application or non-uniform irrigation
- **SC** = canal seepage
- **SI** = in-seepage, i.e. groundwater flow into an area to be drained (e.g. artesian inflow)
- **DN** = natural drainage, i.e. groundwater flow out of the area.

Typical drainage coefficients found in practice are shown in Table 7.4

### Table 7.4 Range of drainage coefficients found in practice.

<table>
<thead>
<tr>
<th>Drainage coefficient (mm/day)</th>
<th>Soil-climate-crop interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1.5</td>
<td>Soils with low infiltration rates.</td>
</tr>
<tr>
<td>1.5 – 3.0</td>
<td>Most soils; with higher rate for more permeable soils and where cropping intensity is high.</td>
</tr>
<tr>
<td>3.0 – 4.5</td>
<td>Applies to extreme conditions of climate, crop and salinity management, and under poor irrigation practices.</td>
</tr>
<tr>
<td>&gt; 4.5</td>
<td>Special conditions; humid areas or very light soils.</td>
</tr>
</tbody>
</table>

Source: FAO (1986)  Note: 3.0 mm/day = 0.35 L/s/ha.

The drainage coefficient is used in drain spacing calculations. Examples of the computations used for drain spacing under steady state and transient state conditions are given in FAO, 2007 and King and Willardson 2007.

**Drain depth**

The design water table level can be achieved by a range of depth and spacing combinations. In general, the deeper the drain, the wider the spacing can be. (See FAO (2007) for theoretical explanation, models and equations.)

Initially the maximum allowable water table height is chosen for the design crop, which is equivalent to the required root zone depth mid-point between two laterals; the design sugarcane root zone is usually specified as 1.0 m, which commonly gives a drain depth of between 1.2-1.5 m.

Drain depth is influenced by soil characteristics, the outfall elevation in relation to the secondary drainage system (where sufficient freeboard is needed), the drain gradient, machinery available, etc.

Interceptor drains must be sunk into a less pervious layer, and a minimum depth of 1.0 m is recommended.

**Drain spacing**

Drain spacing is influenced greatly by economics as the closer the spacing, the more expensive the scheme. Where K values are relatively high, e.g. > 1 m/day, calculations will indicate comparatively wide lateral spacing. Deep and wide spacing increases the volume of soil to be drained and also the amount of salt removed. Excessive drainage water volumes may result, including increased downstream salinity levels. The closer together drains are spaced the higher will be the drainage coefficient and the faster the drain-out will be. However, where K values are below 0.1 m/day, very
close drain spacings are required; should the K value be too ‘slow’ drain spacings will be too close to be economic and mole drains might be indicated.

**Drain Gradient**
Mostly the lateral will be laid parallel to the land surface. Ideal gradients range between 1:150 and 1:250. On flat land the gradient can be as little as 1:800, and on steep land, gradients of 1:50 are possible. Laterals can be laid at an angle to the general land slope in order to increase or decrease flow velocity.

Gradient and pipe sizing are related in this respect; pipes must be sized to provide a minimum velocity so that self-scouring or self-cleaning takes place. With soils prone to silting, a minimum velocity in drainage pipes of 0.45 m.s\(^{-1}\) is recommended. For more stable soils, a minimum velocity of 0.15 m/s is suggested. Gradients below 1:250 are prone to silting.

**Pipe sizing**
The maximum amount of water a drainage pipe can carry – its capacity – depends on its internal diameter, land slope and material. Plastic pipes of 70-90 mm in diameter are the most common laterals and 110-200 mm the most common collectors. Recommended sizes are computed at the design stage using standard flow diagrams provided by manufacturers.

**Available pipe materials**
There are a range of different pipe materials available, each with its advantages and disadvantages, e.g. clay tiles, semi-rigid slotted plastic pipes, flexible, perforated plastic pipes and pitch fibre pipes. Clay tiles are seldom used today, mainly due to the high labor requirement for installation. Plastic pipes are the most common, with flexible pipes used in conjunction with trenchless installation machinery and rigid pipes with excavated trenches.

**7.6.3 Pumped outfalls**
Where the exit points of a surface drainage system cannot discharge through gravity, a pumping system is required to lift the drainage water to a higher elevation before disposal. Many cane growing areas are located along a river, near the sea or adjacent to low lying swampland where there are often embankments to be crossed to gain access to the off-farm regional drainage network.

Examples are the presence of levees along a river bank where the river level is higher than the field level during high flow periods, or where plantations are located on reclaimed swamp-land which may be periodically flooded.

Castle *et al.* 1984 and Wijdieks and Bos 1994 describe the design requirements of pumped drainage, e.g. the sizing and type of pumps, location of exit points, storage requirements, etc.
7.7 Flood control

Flooding is of particular importance in low lying areas where heavy rainfall can cause a rapid rise in surface water level. High tides can have a similar effect, raising river levels in delta areas and through hydraulic backwater effects.

The main function of flood control is to prevent land from being flooded by excess water from adjacent areas, rivers, etc. This is achieved by constructing dikes surrounding limited areas of cultivation, called polders.

Factors to be taken into account in determining the crest elevation of a dike:

- Extreme high water levels
- Wind setup
- Wave run-up
- Embankment settlement after construction
- Expected maintenance quality.

Furthermore, where the dike is built to protect against a river flood, the dike should be located beyond the meander belt of the river and also located some distance from the river channel to provide peak discharge capacity between the dikes in times of flood.

Once flood control is assured, draining a polder requires evacuation of excess rainfall (FAO/IPTRID 2001). Evacuation can be by pumping or by ‘flap-gates’, which allow water to flow out of the polder whilst restricting inflow.

Pumping out of the polder may also be required as a routine operation in order to lower the water table – in combination with a standard surface and subsurface drainage system.

The dike should incorporate a filter and drain on the inside to control seepage induced embankment collapse during high water levels.

Flood control is expensive and should be designed with a clear understanding as to the benefits that might be realized, more especially when compared to the cost of damage (to cane fields, infrastructure and particularly human life) caused by periodic flooding. Good maintenance is important to avoid, for example, catastrophic breeches due to embankment failure.

7.8 Water quality

All water from natural sources contains some amount of dissolved salts. In irrigated areas, evapotranspiration of applied water leaves behind ever increasing salt concentrations. If the irrigation water has a high level of dissolved salts it can lead to rapid salinization. The principal constituents of saline waters are the dissolved salts of the inorganic ions Na, Ca, Mg, K, HCO$_3$, SO$_4$ and Cl. Of the anions, HCO$_3$ is particularly troublesome, as it combines with soluble Ca to form calcium carbonate. The reduction in the soil solution Ca will indirectly lead to an increase in the SAR level of the soil.

Salinity of water is expressed in terms of either electrical conductivity (EC) in dS/m (deciSiemens/m), or as the mass of dissolved salts in the water (mg/L). Approximately 1.0 dS/m is equal to 640 mg/L of dissolved salt.
Water with an electrical conductivity of 0.3 dS/m, which is considered to be suitable for all crops, contains approximately 200 mg/L of salt (its salt loading).

**Box 7.4: Salt loading**

Applying 900 mm of water with an electrical conductivity of 0.3 dS/m will add 1.8 t salt each year to the soil. With the same amount of water applied, irrigation water having an electrical conductivity (ECiw) of 1.1 dS/m will deposit approximately 9.8 t/ha of salt per hectare. Water with a conductivity of 1.1 dS/m will result in a significant decline in cane yield (see section 7.18, Salinity, sodicity and cane yield).

Saline water in general and Irrigation water in particular can be classified according to their EC and dissolved salt concentrations, as shown in Tables 7.5 and 7.6.

**Table 7.5 Classification of saline waters.**

<table>
<thead>
<tr>
<th>Water Class</th>
<th>Electrical conductivity (dS/m)</th>
<th>Salt concentration (mg/L)</th>
<th>Type of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-saline</td>
<td>&lt; 0.7</td>
<td>&lt; 480</td>
<td>Drinking and irrigation water</td>
</tr>
<tr>
<td>Slightly saline</td>
<td>0.7-2.0</td>
<td>480-1 500</td>
<td>Irrigation water</td>
</tr>
<tr>
<td>Moderately saline</td>
<td>2-10</td>
<td>1 500-6 500</td>
<td>Primary drainage water and groundwater</td>
</tr>
<tr>
<td>Highly saline</td>
<td>10-25</td>
<td>6 500-16 000</td>
<td>Secondary drainage water and groundwater</td>
</tr>
<tr>
<td>Very highly saline</td>
<td>25-45</td>
<td>16 000-30 000</td>
<td>Very saline groundwater</td>
</tr>
</tbody>
</table>

After FAO (1992)

**Table 7.6 Hazard of use classification of irrigation waters.**

<table>
<thead>
<tr>
<th>Irrigation water class</th>
<th>Electrical conductivity (dS/m)</th>
<th>Salt concentration (mg/L)</th>
<th>Irrigation hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>&lt; 0.25</td>
<td>150</td>
<td>Low</td>
</tr>
<tr>
<td>C2</td>
<td>0.25-0.75</td>
<td>150-500</td>
<td>Moderate</td>
</tr>
<tr>
<td>C3</td>
<td>0.75-2.25</td>
<td>500-1400</td>
<td>Medium high</td>
</tr>
<tr>
<td>C4</td>
<td>2.25-4.0</td>
<td>1400-2 500</td>
<td>High</td>
</tr>
<tr>
<td>C5</td>
<td>4.0-6.0</td>
<td>2 500-3 800</td>
<td>Very high</td>
</tr>
<tr>
<td>C6</td>
<td>&gt; 6.0</td>
<td>&gt; 3 800</td>
<td>Excessive</td>
</tr>
</tbody>
</table>

After Richards (1954)

Saline water can also affect leaf tissue, which is sometimes a problem with sprinkler irrigation. The maximum ECiw in respect of sugarcane leaf effects is 2.2 dS/m. Higher ECs have been shown to result in leaf burn (Johnson 1980).

Another source of salinity is from groundwater, where salts are carried into the root zone though a fluctuating water table and via its capillary fringe. Many groundwaters are highly saline, emanating from minerals dissolved from the local geology or seepage of salty water from higher ground. Testing water for its dissolved salt content is an important requisite in planning and operating irrigation projects.
Certain divalent cations, particularly calcium, are important in ensuring soil structural stability. Low salinity waters (less than 0.5 dS/m and especially below 0.2 dS/m) tend to leach soluble salts from the soil surface. Without calcium and other dissolved divalent cations, the soil disperses, with the finer particles filling many of the soil pores, sealing the soil surface and reducing infiltration rate. Excessive sodium in the irrigation water also promotes soil dispersion and structural breakdown, but only if the sodium exceeds calcium by more than a ratio of about 3:1. The infiltration rate generally increases with increasing salinity and decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium.

Sodium content of water is measured in terms of the Sodium Adsorption Ratio (SAR) – which determines how the dissolved sodium will impact soil properties.

The sodium hazard is usually expressed as the SAR, and is defined in Equation 7.5:

\[
\text{SAR} = \frac{\text{Na}}{(\text{Ca} + \text{Mg})^{0.5}}
\]  

The USDA (Richards 1954) has arranged the sodicity of water in groups of increasing hazard, as shown in Table 7.7, with comments from the SASRI Information Sheet 5.6.

**Table 7.7 USDA classification of sodicity hazard of irrigation water.**

<table>
<thead>
<tr>
<th>Sodicity Class</th>
<th>SAR of irrigation water</th>
<th>Sodium Hazard of Water</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>&lt; 10</td>
<td>Low</td>
<td>Can be used on almost all soils with little danger of the development of harmful levels of exchangeable sodium.</td>
</tr>
<tr>
<td>S2</td>
<td>10-18</td>
<td>Medium</td>
<td>May present a moderate hazard in fine textured soils with high CEC. Can be used on lighter soils with good permeability.</td>
</tr>
<tr>
<td>S3</td>
<td>18-26</td>
<td>High</td>
<td>Generally unsuitable for continuous use. May produce harmful levels of exchangeable sodium in most soils and will require good drainage and leaching. Organic matter and chemical amendments recommended.</td>
</tr>
<tr>
<td>S4</td>
<td>&gt; 26</td>
<td>Very High</td>
<td>Generally unsuitable for irrigation except at low or medium salinity levels where it may be used in conjunction with gypsum or other ameliorants.</td>
</tr>
</tbody>
</table>

Managing salinity in irrigated agricultural land is a major challenge for sustainable sugarcane production especially in the dryland areas of East Africa and Pakistan, where irrigation water quality is increasingly being driven by alkalinity issues. High levels of residual sodium bi-carbonate (RSC) will cause precipitation in near soil surface water. This will enhance the effective SAR of water and may cause destruction of soil structure at the soil surface and result in poor water infiltration.

A computer model named WATSUIT developed by staff from the University of California (USDA 2006, [http://www.envisci.ucr.edu/faculty/wu](http://www.envisci.ucr.edu/faculty/wu)), can be used to assess the likely long term impact of irrigation water suitability on soil quality. This model calculates the concentration of the major cations (Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\), and K\(^+\)) and anions (Cl\(^-\), HCO\(_3\)\(^-\), CO\(_3\)\(^{2-}\), and SO\(_4\)\(^{2-}\)) of soil water based on the composition of irrigation water under various management practices, including the leaching fraction as well as amendment additions to the water. The model does not use the depth (or volume) of applied water as an input, rather it uses leaching fraction. The output is expressed in terms of ion concentrations as well as the concentrations of precipitated or dissolved salts because the depth or volume of applied water is not used.
7.9 Water blending

One solution to the disposal of excess water and which is applicable to all drainage systems is to implement a pumped return scheme, pumping drainage water back up to the head of the irrigation infrastructure, e.g. balancing or storage dams or the main canals, for blending and re-use. This blended water will contain more salts than the irrigation water but may still be below the threshold value of salinity induced yield decline. Provided that the blended water is sufficiently low in total salinity and toxic ions, this is the most economic and environmentally acceptable means of disposing of drainage water (FAO/ICID 1997).

It may be that only a portion of the drainage water can be safely returned, or that only certain fields (with cane at a low stress stage) can be irrigated with the blend. The downside of this approach is that the drainage water eventually returned to the regional system will be of lower quality than the original drainage water. Depending on the dilution capacity of the regional system this may well be acceptable.

Pumping in respect of disposal and/or returns of drainage water requires careful planning and engineering design in order to gain maximum benefit. Depending on the distance of the drain exit from the regional drainage system, the exit point distance from irrigation dams and the elevation differences between all these points, there are a range of possible solutions that can optimize the pumped disposal of drainage water.

At certain times of the year ‘returned’ drainage water may comprise an invaluable contribution to irrigation. However, the salinity values of the drainage water, blended water and original irrigation water must be continually monitored and application to the fields managed accordingly.

It should be noted that the plant roots experience the average salinity of the root zone and that critical EC values are based on the EC of the saturation extract of a soil, ECe. Table 7.4 shows the relationship between ECiw and ECe.

An alternative to blending water with an unacceptable SAR or Residual Alkalinity (RA) levels may be to ameliorate with acids to neutralise most of the RA (Miyamoto et. al., 1975) or with gypsum to adjust RA and SAR to regional thresholds (Ham et. al., 2000). Calculation of acid requirement is facilitated by a calculator developed by Whipker et. al., (1996).

7.10 Water table depth

Where a water table is close to the surface, the upward flow of groundwater through capillary action and its subsequent evaporation at the soil surface will lead to salinization. Similarly, a crop utilizing groundwater during transpiration will gradually increase salinity in the root zone if upward flow continues and there is insufficient leaching. Irrigation water having a high salinity level and applied in excess will raise the water table and have the same affect.

Over the long term, a net downward flow of water through the root zone and below it is required to control salinization and sustain cane productivity. Lowering a water table from the surface to a depth of about 1.0 m, without a net downward flux, has little benefit in most soils due to capillary rise. Upward flow rates in heavy soils can exceed 2.5 mm/day in lighter soils. If the groundwater is fairly saline and rainfall and irrigation amounts are relatively low, capillary rise will lead to a gradual salinization of the root zone. Capillary rise potential for different soil textures is illustrated in Table 7.8.
Table 7.8 Capillary rise in different soils.

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Grain size (mm)</th>
<th>Potential capillary rise (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>0.5-1.0</td>
<td>135</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.2-0.5</td>
<td>246</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.1-0.2</td>
<td>428</td>
</tr>
<tr>
<td>Very fine sand</td>
<td>0.005-0.01</td>
<td>1 055</td>
</tr>
<tr>
<td>Coarse silt</td>
<td>0.002-0.005</td>
<td>&gt;2 000</td>
</tr>
</tbody>
</table>

Where a subsurface drainage system is in place, rainfall and irrigation can dissolve the salts and control salinization. This is possible where rainfall and irrigation water together are sufficient to provide both the CWR and leaching requirement. The leaching requirement is an amount of water – additional to the CWR – applied during irrigation to ensure dissolution of salts and their removal in the drainage water.

Leaching irrigations can be applied through surface applications (furrow, sprinkler, drip, etc.) or via the manipulation of a fluctuating water table, with the addition of intermittent rainfall. This is described under 7.5, Water table management.

Box 7.5 Water table depth impact on yields

Work carried out in Queensland, Australia, by Rudd and Chardon (1977) and reported by Oosterbaan 1994, shows that where the water table was shallower than 500 mm, there was a definite decline in cane yield the longer the water table remained at that level. Where the water table was held at 500 mm for varying time periods, yields declined on average as follows: for 40 days the yield was 80 t/ha, for 120 days it fell to 60 t/ha and for 180 days, 20 t/ha.

Gayle et al. (1987) used a stress-day index (SDIW) to relate stresses caused by excessive water conditions on sugarcane yield. The SDIW for a given period is determined as a product of a ‘crop susceptibility’ (CS) factor and a ‘stress day factor’. For his work he used an ‘excess water level’ of 450 mm as the stress day factor. Stresses were then quantified as the number of days where the water table was above the 450 mm mark. The CS factor was taken for three growth stages: (i) dormant to early growth CS=0.6, (ii) mid-season CS=0.4 and (iii) maturity CS=0.01. A regression equation was derived where relative yield (YR) was computed for varying SDIW in centimeter-days (Equation 7.6).

\[
YR = 100 - (0.029)SDIW
\]  

(7.6)

For example, for a one-week duration and SDIW of 316 cm-days, the relative yield was 91% of potential, and for two weeks at SDIW 632 cm-days, it was 83% of potential.

Gosnell (1968) working in Zimbabwe, established that root growth ceased 50-100 mm above a water table. He further determined that water table levels of 250 mm had a serious deleterious effect on cane yield, being worse with ratoon cane (Gosnell 1971). At 500 mm a negative effect was still found, with salinization occurring 200-300 mm above the water table. It was concluded that water tables should be maintained below 1.0 m. It was also established that a lower water table could increase the number of ratoon crops.
7.11 Salt affected soils

Dissolved salts can have damaging effects on plants and soils and on the surrounding ecology. Salt affected soils and river waters with high salt content are confined mainly to those areas receiving a mean annual rainfall of less than 800 mm, where irrigation is essential. For instance, in parts of the Pakistan sugar industry, Iran, the Burdekin and the Ord in Australia, and Egypt, Sudan, Ethiopia, Malawi, Zimbabwe, Mpumalanga and Swaziland in Africa.

<table>
<thead>
<tr>
<th>Box 7.6 Different types of salt affected soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A saline soil is defined as a soil with a high salt content, with calcium and magnesium salts predominating over sodium. The pH is generally below 8.5 and soil structure is not affected.</td>
</tr>
<tr>
<td>• A saline-sodic soil also has a high salt content but sodium is the dominant exchangeable cation. pH is generally &lt; 8.5 and soil structure is usually affected.</td>
</tr>
<tr>
<td>• A non-saline sodic soil has low salt content, and sodium is the dominant exchangeable cation. pH is &gt; 8.5 and soil structure is very poor, due to swelling and dispersion of the clay. Permeability of the soil by air and water is very low.</td>
</tr>
</tbody>
</table>

7.12 Salinity dominated soils

When salt concentrations in the soil solution increase cane growth is progressively reduced due to induced water stress. The high salt content of the soil solution results in a high osmotic pressure which retards water uptake by cane roots. Typical symptoms are curling of the youngest which can advance to being scorched with restricted growth as evidenced by shorter internodes and in severe cases when death of the plant when an upper threshold level is reached. These effects may take place even though the soil is apparently moist.

Limits or threshold values for salinity have been determined for sugarcane where, beyond a certain level, yield decline will commence.

7.12.1 Origin of saline soils

Saline soils originate from natural sources such as the local geology including salt deposited from the ocean during soil formation, groundwater fluctuation due to poor drainage, seepage from unlined water conveyance systems and dams, saline irrigation waters, fertilizers, etc. In terms of topography salts will accumulate at the lowest point in the landscape (Fig. 7.5).
7.1 Measurement of salinity

Soil salinity is usually expressed in terms of the electrical conductivity of a saturation extract of the soil, ECe, in dS/m (deciSiemens/m).

In general, the ECe values of a soil are significantly higher than that of the applied water, depending on the soil depth, frequency of irrigation and the amount of water applied. When an irrigation is applied to a partially depleted soil, it displaces most of the pre-existing soil solution downwards, taking the place of the previous solution; a phenomenon known as ‘miscible displacement’. Therefore the corresponding volume of displaced solution contains higher concentrations of dissolved salts than present in the applied water. Consequently, the salt concentration in the root zone increases as the leaching fraction decreases.

Usually the concentration of salts in the topsoil (up to 300 mm) is about 2-3 times that of the irrigation water but may increase by a factor of 5-10 at greater depths. A plant is therefore exposed to changing salinities; at the surface it is that of the irrigation water (ECiw) but progressively it increases to the salinity of the drainage water (ECdw) at the lowest part of the root zone. However, the plant responds to the average root zone soil salinity and not to the extremes of either the upper or lower zones; a crop root system will extract progressively less water with increasing depth – due to both root density decreasing with depth and salt concentration increasing with depth. Thus in a saline environment, scheduling of irrigations should be influenced mainly by the soil water potential in the upper root zone, where most water is abstracted.

At a commercial level, large estates such as Kenana in the Sudan, TPC in Tanzania and JDW Sugar Mills in Pakistan have established laboratories to routinely monitor soil and water quality. In Pakistan, mill management also conduct earth conductivity surveys using a portable electromagnetic instrument, to classify the salinity risk of cane fields on an ongoing basis. The results are used to guide management decisions for planting cane or to use more salt tolerant crops or to identify fields that need to be rehabilitated. Drainage characteristics of soil and capacity to leach salt must also be considered.

7.1.2.3 Influence of salinity on crop yield

The effect of salinity on crop yield is considered relative to a ‘threshold’ level of the ECe of the soil. A crop shows minimal salinity damage until the threshold level is reached; the threshold level for sugarcane is between 1.7 and 2.0 dS/m.

Grouping of soils in terms of their salinity status and how these groups might affect cane growth was carried out by Johnson 1980. The groups are reproduced in Table 7.9. This work was intended for
computerization of the soil assessment service provided by the South African Sugarcane Research Institute (SASRI) to industry growers. The analysis looked only at the top 60 cm of soil, as this was considered to address the most affected depth where rooting was predominant, and has given good results.

Table 7.9 Salinity ratings according to electrical conductivity values of soil saturation extracts (ECe).

<table>
<thead>
<tr>
<th>ECe (dS/m)</th>
<th>Rating</th>
<th>Effect on cane growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2</td>
<td>Non-saline</td>
<td>None</td>
</tr>
<tr>
<td>2-4</td>
<td>Slightly saline</td>
<td>Slight</td>
</tr>
<tr>
<td>4-6</td>
<td>Moderately saline</td>
<td>Serious</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>Highly saline</td>
<td>Very serious</td>
</tr>
</tbody>
</table>

It is important to be able to obtain local ECe values so as to enable comparison with this threshold value. However, ECe analyses are not always easy to obtain, as measurements are usually carried out in a soil laboratory – which may not be available.

An approximate estimate of ECe can be made, however, using the interrelationship between the applied, soil and waste waters; portable EC meters can be easily used to measure the conductivity of the irrigation water (ECiw) and drainage water (ECdw) if the lands have subsurface drains installed. Assuming, for example, that the percentage water abstraction down the profile occurs in the pattern 40, 30, 20 and 10 % (percentage of root zone depth) and the leaching fraction is in the order of 10-20%, ECe is approximately equal to 1.5 x ECiw. Other relationships, also assuming the same water abstraction pattern and similar leaching fraction have been established, and are shown in Table 7.10.

Table 7.10 Approximate EC relationships.

<table>
<thead>
<tr>
<th>Measured</th>
<th>Concentration</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>conductivity</td>
<td>factor</td>
<td>conductivity</td>
</tr>
<tr>
<td>ECiw</td>
<td>x 3</td>
<td>= ECsw</td>
</tr>
<tr>
<td>ECiw</td>
<td>x 1.5</td>
<td>= ECe</td>
</tr>
<tr>
<td>ECe</td>
<td>x 2</td>
<td>= ECsw</td>
</tr>
</tbody>
</table>

In general, the conductivity of the soil water, ECsw, and drainage water, ECdw, are considered to be the same.

Box 7.7 Other factors that impact on sugarcane’s response to salinity

Soil texture has a strong influence on a plant’s response to salinity. For the same potential evaporation rate, a sandy soil with a low water holding capacity will lose proportionally more water than a fine textured soil, resulting in a more rapid increase in salt concentration in the soil solution and potentially greater damage to the crop. This possible damage can be mitigated by irrigating a sandy soil more often than a clay soil.

Temperature is also a critical factor for crop salt tolerance. High temperature increases the stress level of the crop (either because of the increased transpiration demand or because of the effect of temperature on the biochemical transformations) and is additive to other salinity effects. High humidity tends to decrease crop stress, thus reducing salinity damage.

If natural drainage is not adequate to control salinization, an artificial drainage system must be
installed to maintain productivity under typical rainfall and irrigation conditions. The crop will grow best when the water table is kept at or below the bottom of the root zone. Subsurface drains are generally designed to keep water tables (midway between adjacent drains) from getting closer than about 1 m from the surface.

7.13 Reclamation of saline soils

The only proven method of reclaiming salt affected soils is by leaching. Adequate drainage and suitable disposal of the leaching water are also prerequisites for reclamation. The minimum amount of applied water needed to maintain a salt balance is referred to as the leaching requirement (LR).

Whatever the salt concentration of the irrigation water, some excess water (above the evapotranspiration needs of the crop), is mandatory to leach out salts – the leaching fraction (LF). The leaching fraction is the water passing through the soil profile and accumulating soluble salts as it passes. The leaching fraction must be added in order to keep the soil water salinity below the crop’s threshold value.

Where the ECiw and ECdw are known, the leaching fraction can be established using Equation 7.7.

\[ LF = \frac{ECiw}{ECdw} \]  

(F.7)

Furthermore, the leaching fraction (LF) can be defined as the ratio between the amount of water drained below the root zone (Dd) and the amount applied in irrigation, (Di).  (Equation 7.8):

\[ LF = \frac{Dd}{Di} \]  

(F.8)

Under steady-state conditions, the salinity tends to increase gradually from a level near the soil surface, controlled by ECiw, to one near the bottom of the root zone, which is determined mainly by the LF. Thus by varying the leaching fraction, it is possible to achieve some degree of control over the EC distribution in the root zone (Shainberg and Oster 1978).

Many irrigation systems are inefficient and inadvertently provide sufficient leaching. With furrow irrigation, for example, the leaching requirement is generally accepted as being covered by irrigation losses to deep percolation. But even under the best management, some excess irrigation water is generally applied to pursue maximum yield. The application of additional water (to ensure adequate watering everywhere) can also result in an excessively high water table. Over-irrigation in this manner is costly, however, and equates to a loss of water and nutrients, is wasteful of energy and increases the need for drainage facilities.

In addition, no matter how carefully irrigation is managed, it is inevitable that rain will, on occasion, fall soon after an irrigation and cause leaching. Rainfall should therefore also be included in the leaching requirement calculations. The advantage of rainfall is that it applies water almost uniformly at very low ECs (< 0.05 dS/m).

Soil texture affects the amount of deep percolation through its influence on moisture storage capacity. For example, to displace once the pore volume at field capacity to a depth of 750 mm in a sandy soil requires about 120 mm of water, but for a clay soil 320 mm is required. Therefore an application, say, of 250 mm (irrigation or rainfall) would more than suffice the leaching requirement of a sandy soil, but would be insufficient for a clay soil. King and Willardson (2007), include a table (reproduced below as Table 7.11), which gives approximate values of deep percolation for different soil textures showing, for example, that deep percolation losses in clay soils are relatively small.
compared to light soils. For drain spacing calculations it is recommended that, if the leaching requirement is greater than the deep percolation percentage, the larger value be used.

**Table 7.10 Approximate deep percolation losses for various textures.**

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Deep percolation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loamy sand</td>
<td>30</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>26</td>
</tr>
<tr>
<td>Loam</td>
<td>22</td>
</tr>
<tr>
<td>Silt loam</td>
<td>18</td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td>14</td>
</tr>
<tr>
<td>Clay loam</td>
<td>10</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>6</td>
</tr>
<tr>
<td>Sandy clay and clay</td>
<td>6</td>
</tr>
</tbody>
</table>

After Dumm (1968)

Natural drainage in many instances is insufficient to leach salts from the root zone. Most fine textured soils, soils with compacted layers and soils with layers of low hydraulic conductivity may be so restrictive to downward water movement that an artificial subsurface drainage may be required.

In many irrigation projects, it is not possible (due to system-capacity limitations) to supply both the peak CWR and the leaching fraction at the same time. However, leaching is not required until the accumulated salinity is expected to exceed the crop salt tolerance. Leaching can be done during an irrigation, between alternate irrigations or only during those periods when crop water requirements are low. The timing of leaching is not critical; the only proviso is that the salinity level does not exceed the crop’s tolerance over extended periods. Nevertheless, where leaching is required, a ‘maintenance’ leaching fraction of between 10-20% is commonly applied.

**7.14 Irrigation method and salinity control**

The salinity profile that develops in a soil as water is transpired or evaporated depends, in part, on the water distribution pattern inherent with the irrigation method. Distinctly different salinity profiles develop under different irrigation systems. Each irrigation method has clear advantages and disadvantages for salinity management.

**Box 7.8 Effectiveness of different irrigation systems in controlling salinity**

- With furrow irrigation, leaching occurs primarily below the furrows themselves. Salts tend to accumulate on the ridges due to capillary movement away from the furrow edge. Evaporation will also concentrate salts on the ridge surface. Removal of these salts will be by rainfall unless, or until, the cane is plowed out. Where irrigation water is very saline, it may be prudent to use in-row or alternate-row irrigation.
- Sprinkler irrigation, including pivots and linears, wet the entire soil surface and create a profile that at steady state increases in salinity with depth. Provided that moderate leaching is applied, that applications are uniform and that no shallow saline groundwater is present, this profile will extend to the bottom of the root zone.
- Intermittent irrigation applications by sprinkling (or flooding) is a particularly efficient method of leaching and requires less water than continuous flooding. The amount of
water needed for leaching on heavy soils can be reduced by intermittent sprinkler applications.

- Intermittent ponding requires only about one third as much water to remove 70% of the soluble salts initially present compared to continuous ponding. Another advantage of sprinkler irrigation over gravity systems is that infiltration is controlled by the application rate of the sprinkler rather than the soil surface. Small irrigations can then be applied, e.g. 3-5 mm/applications, as opposed to furrow irrigation where a minimum of 40-50 mm is standard. This improves the efficiency of leaching.

- With drip, high levels of leaching occur near the drippers, and if soil moisture potentials are maintained in the root zone, salinity effects will be minimized. Plant roots tend to accumulate in the leached zone. This allows water of relatively high salt content to be successfully used in many cases.

- Salt levels do build up between dripper/crop rows and this salt will eventually need to be flushed out. Periodic rainfall is the obvious flushing agent and will be successful if it is sufficiently dependable, i.e. if there is a definite, reliable annual rainy season. Light showers can, however, dissolve the salt and the move the saline water into the root zone; but cane planted on ridges will not normally be affected.

For all systems, poor irrigation management and scheduling can result in salts accumulating at the surface and result in a severe salinity problem over time.

### 7.15 Sodicity dominated soils

Salt affected soils that contain sodium as the dominant ion on the exchange complex are referred to as sodic soils due to the implied effect on deflocculating clays in soils and destroying soil structure. At high levels of exchangeable sodium, certain clay minerals (notably smectite, which is common in black clays and the subsoil of duplex soils), when saturated with sodium, swell markedly leading to dispersion of clays. This results in a closing up of the pore spaces and a drastic reduction in infiltration rate.

#### 7.15.1 Impact of saline-sodic conditions on cane growth and the soil landscape

The onset of saline-sodic conditions can be seen as patches of relatively poor cane growth and are commonly found in bottom lands. These patches invariably expand in size as the subsurface water accumulates around them, with cane growth deteriorating and the cane eventually dying (Fig. 7.6).
7.15.2 Measurement of sodicity

The absolute concentration values of the various cations in irrigation water are not sufficient for quantifying the total hazard potential. The EC of the soil solution considers all soluble salts; the sodium hazard is defined separately because of sodium’s specific detrimental effects on soil physical properties. The Sodium Adsorption Ratio (SAR) quantifies the relationship between water soluble sodium and soluble divalent cations which can be used to predict the exchangeable sodium percentage (ESP) of a soil in equilibrium with the solution. SAR is a good estimate of ESP (they are approximately equal between the values of SAR 2 and 30). In general, an ESP of 15 is considered as the threshold value above which a soil is defined as sodic; however, this does not take into account soil type or crop type.

The extent to which the ESP of the soil will increase as a result of adsorption of sodium from the water depends on the ratio of soluble sodium to the divalent cations in solution; the higher the ratio, the higher the sodium hazard.

A high level of exchangeable sodium in the soil causes it to swell and has the effect of reducing pore space. A small reduction in the size of the larger soil pores has a significant effect on soil permeability and infiltration rate. A decrease in infiltration rate can be expected to result in increased surface runoff and decreased moisture availability to the crop. The reduction in porosity, especially of macro-pores, may also result in reduced aeration and gas exchange. It should be noted that soil permeability decreases with the square root of the pore radius.

Box 7.9 Interactive effects of the salinity of irrigation water and soil SAR

The salinity of irrigation water and the SAR have an interactive effect on soil physical properties. Elevated values of SAR result in decreased hydraulic conductivity, decreased aggregate stability, clay dispersion, swelling of expandable clays, surface crusting and reduced tilth. For a given SAR, the adverse impacts on soil physical properties are reduced with increased salinity. Where rain and irrigation are both significant contributors to crop water demand, it is possible for a soil to go from a relatively saline condition, e.g. 3.0 dS/m and SAR 10, to a non-saline condition with EC < 0.5 dS/m in the upper profile after a significant rain. Decrease in SAR will be slower than decrease in EC, which could lead to a potential sodium hazard, with dispersion, surface crusting and decrease in infiltration.

Suarez et al. (2006) found that increases of SAR of irrigation water had an adverse impact on water infiltration for both clay and loam type soils. For the silty clay soil tested, an increase from SAR 2 to SAR 4 resulted in a significant decrease in infiltration rate, whilst for the loam soil the decrease was significant at SAR 6. The decreased infiltration rates with increasing SAR was comparable for both soil types. The main textural components of the silty clay soil were 54 % clay (predominantly smectite) and 45 % silt, and the loam was 46 % fine sand, 28 % silt and 24 % clay. The authors concluded that for regions where rainfall is significant, the Na hazard is considerably greater than that suggested by simple application of the EC-SAR hazard relationships.

Furthermore, when high sodium water is used for irrigation, problems may not occur immediately. During the rainy season, however, when salts are leached from the upper soil horizons, dispersion may then take place. As previously mentioned, the WATSUIT model can be used to evaluate the adverse impact of changing water quality on potential soil salinity/sodicity problems (see 7.8 and http://www.envisci.ucr.edu/faculty/wu)
Different soils react differently to sodicity – which is largely due to the nature of the colloidal fraction, e.g. clay percentage and clay mineralogy, sesquioxide content etc. A study on the effects of exchangeable sodium (measured as SAR) on soil hydraulic conductivity on a range of South African soils showed that soils with smectitic clays were the most vulnerable (Johnson 1975).

Johnson (1980), proposed a guide to sodicity hazard in order to accommodate sodicity effects on a range of different soils commonly found in the South African cane growing areas. He used the mean SARe values from the 0-600 mm soil depth. The different soils varied in their sensitivity to sodium and were therefore assigned different SARe values. When the measured SARe value was greater than the critical SARe value for a particular soil, it was rated as sodic. Table 7.12 gives the three critical-value groupings.

<table>
<thead>
<tr>
<th>Critical SAR 6</th>
<th>Critical SAR 10</th>
<th>Critical SAR 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generally poorly drained, hydromorphic and highly dispersed soils, including gleysoils, duplex, solonetz and solonchaks soils.</td>
<td>Mainly slowly draining swelling clay soils associated with dolerite and heavy basic alluvium, including vertisols and chernozems.</td>
<td>Mainly well drained porous, non-dispersive soils, ranging from apedal to well structured clays, often in upland positions including rhodic luvisols, ferralsols, nitosols and well drained fluvisols.</td>
</tr>
</tbody>
</table>

7.16 Reclamation of sodic soils

When ameliorating a sodic soil, the prime consideration is the improvement or maintenance of soil permeability (Johnson, 1977). Amelioration requires the replacement of exchangeable sodium (with calcium or another suitable cation) and then to leach out the replaced sodium and other soluble salts. Subsurface drainage is a prerequisite in reclaiming sodic soils before any treatments are applied.

The process must take place in that order; otherwise, if the soluble salts are replaced first, the soil structure may deteriorate. I.e. an initial leaching and removal of salts may create sodic conditions and reduce permeability.

Where the soil is impermeable to start with, permeability can be temporarily improved by cultivation, and then more permanently by converting the sodic soil into a saline-sodic soil, if fairly saline water is available; the increase in soluble salts improves structure and hence permeability. However, the reclamation of sodic soils is very difficult and expensive (if not impossible) without the use of chemical amendments to replace sodium by calcium.

Gypsum is the principal ameliorant applied to sodic soils in order to increase calcium levels on the soil exchange complex. Gypsum in granular form is usually broadcast on the soil surface at rates of 5-10 t/ha. It is only slowly soluble so it is common practice to incorporate it into the top 300 mm. Deep plowing (> 400 mm) of sodic soils should only be carried out after removing the sodicity, as there is the danger of collapse of the soil structure.
Trials in South Africa have also indicated that high rates of filterpress mud (150 t/ha) incorporated into the topsoil with an SAR of 25 has proved more effective than gypsum in leaching Na from the top 600 mm of soil. There is some evidence that where capping or crusting of the soil surface is sodicity induced or because of a lack of divalent cations, spreading gypsum on the soil surface can improve infiltration. This is best carried out just before irrigation, and very windy periods of the year should be avoided. Small repeated soil applications may be more effective for water related surface infiltration problems (high SAR waters), whereas single large applications are more effective for sodic soil reclamation (FAO 1985).

Gypsum can also be applied in the irrigation water to deal with an infiltration problem. Amounts of 1-4 me/L calcium have been effective. The low solubility of gypsum is partly overcome by selecting finely ground material (> 0.25 mm in diameter) for application through nozzles in a pressurized irrigation system. Several methods of applying gypsum in irrigation water have been described, e.g. De Bruyn and Grobler (1978), using a sprinkler irrigation system. An alternative is depositing of rock gypsum in an irrigation supply canal.

Other ameliorants, such as sulphur, aluminum sulphate, calcium chloride, etc. can be used, but availability and cost need to be considered in relation to the usually more commonly available and cheaper gypsum. Lime is not an effective ameliorant when used alone, but when combined with a large amount of organic manure it has a beneficial effect, as in the case of carbonitized filterpress mud.

Incorporating organic matter into the soil can act as an ameliorant when irrigating with high SAR water. Firstly, permeability is improved and secondly, the release of carbon dioxide and the formation of organic acids during decomposition lowers the pH, and so releases calcium through the solubilization of calcium carbonate and other minerals. This increases the ECE and encourages the replacement of exchangeable sodium by calcium and magnesium, so lowering the ESP. Including a green manure crop has a similar effect (FAO 1992).

**Box 7.10 Selected examples of successful reclamation trials**

(a) In Zululand in South Africa, soils of naturally poor drainage are the most susceptible to sodicity damage. A saline-sodic soil with heavy subsoil which was affected by a high water table (from an unlined dam) was successfully treated through the installation of subsurface drains and gypsum and sulfur ameliorants. With respect to cane yield, it was found that the detrimental effects of poor physical condition (caused by dispersion following cultivation/desalinization) was less important than that of the high free salt content for that trial (Johnson 1977).

(b) In a trial conducted in Swaziland to assess the effectiveness of some amelioration strategies on sodicity, Henry and Rhebergen (1994) applied three different treatments to a generally saline-sodic duplex (solonetz) soil in Swaziland. The treatments included deep plowing, filter cake incorporation and gypsum either as single treatments or in various combinations. It was found that:

- Surface crusting was improved by spreading gypsum on the soil surface.
- Sodicity at depth was best addressed by combining gypsum application with deep plowing.

Filtercake incorporation improved soil physical properties (e.g. infiltration rate, water holding capacity etc) and could be used as a substitute for gypsum in terms of its calcium content, so addressing topsoil sodicity.
7.17 Salinity, sodicity and cane yield

Different crops exhibit different degrees of tolerance to salinity. There are also varying responses at different growth stages as well as cultivar and management responses (e.g. moisture status). Salinity is expressed as ECe in dS/m.

Salt tolerance can be represented by two parameters: the threshold salinity value (t), which is expected to cause an initial significant reduction in the maximum expected yield; and the slope (s) of the yield decline. Slope is the rate at which yield is expected to be reduced for each unit of added salinity beyond the threshold value, and expressed as slope %/dS/m. YR (the relative yield) is the percentage of the yield of the crop grown in saline conditions relative to that obtained under non-saline conditions. YR is calculated using equation 7.9.

\[ YR = 100 - s \times (ECe - t) \quad \text{where } ECe > t \] (7.9)

Sugarcane is considered to be ‘moderately sensitive’ to salinity (Ayers 1985). The Salinity effect (yield decline) is reported to become evident at an ECe of about 1.7 dS/m (threshold value) and the slope (%) for sugarcane is given as 5.9 dS/m.

Therefore at an ECe of 3.4, the relative yield for cane is expected to be 90 % of the maximum expected yield and at an ECe of 10.0, 50 % of maximum expected yield. In respect of the salinity of the irrigation water, an ECe of 3.4 is approximately equal to water salinity (ECiw) of 2.3 dS/m and an ECe of 10.0 is about equal to an ECiw of 6.8 dS/m.

Soil EC values are usually associated with drainage status. Nour et al. (1989) found that imperfectly drained soil soils had the highest EC values, moderately drained soils were less affected and well drained soils had the lowest values. The amounts of accumulated soluble salts were highest in fine textured soils – where the height of the capillary fringe may be the controlling factor.

Sodicity, whilst mainly affecting a soil’s physical condition can also have a negative influence on plant health. On a calcareous vertic soil in Zimbabwe, it was found that yields were low on areas suspected of irrigation induced salinity and sodicity. Sodicity apparently had the greater effect (many SAR levels recorded were in the range 10-20). Yield decline was reported to be 2.1 t/ha for every 1 % increase in ESP. Amelioration strategies suggested included dealing with the high water table and allowing the vertic soils to dry out (cracking) to encourage leaching (Rietz and Haynes 2002).

Where water resources are scarce and saline conditions exist, there is a potential trade-off between using the limited water to irrigate a larger area (and accept lower yields) or to use that water to leach salts out of a smaller area – with the expectation of higher yields per hectare. Matthews et al. (2010) found that it is more profitable to leach excess salts from the soil once the salinity level has reached the crop’s threshold level – which may result in a smaller area being irrigated.

A larger quantity of saline water must also be applied to maintain a given yield compared to non-saline conditions. Costs associated with installing a subsurface drainage system however, might change the economic benefits of these conclusions.

7.18 Impact of drainage and salinity on the environment

About 25 % of the world’s irrigated land is affected by waterlogging and salinization and it is estimated that an extra 0.5-1.0 million hectares each year are being damaged. On average only
about 60% of water diverted for agriculture is used in crop evapotranspiration, much of the remainder becomes drainage water.

Typical irrigation water contains between 0.1 to 4.0 kg of salts per m$^3$. Irrigations of 1 000-1500 mm are not uncommon, resulting in depositions of between 1-60 t salt/ha/an. Much of this salt content is in flux as the water table rises and falls. Leaching and drainage installations are interventions designed to remove this excess salt and transfer it to other locations.

Drainage installations, however, have a definite impact on their surroundings and it is not uncommon to find that drainage improvements at one place lead to damages in another. It is generally acknowledged that the assessment of drainage needs is not complete if no consideration is given to the adverse effects of its implementation (Ritzema and Braun 1994).

Negative effects of drainage water on the environment are similar to those of an irrigation project – drainage water being usually a result of over-irrigation. Negative effects include degradation of irrigated land (including salinization, alkalization and waterlogging), reduced socio-economic conditions (increased incidence of water related diseases, increased inequity and weaker community infrastructure), poor water quality (reduction in irrigation water quality, water quality problems for downstream users), ecological degradation (reduced biodiversity in the project area, damage to downstream ecosystems due to reduced water quantity and quality) and groundwater depletion (dry drinking and irrigation wells, saline intrusion at coasts, reduced base-flow and wetland damage) (FAO 1995).

Maintaining a water table at a shallower level is one possible method of reducing drainage discharge. Management of drainage water provides an opportunity to control the loss of agrochemicals (including nutrients) as these are carried in surface runoff and subsurface drainage outflows. In one case the annual nitrate loss was reduced by 60% due to the effect of shallower water table (FAO/ICID 1997). Furthermore, drainage water collected to lower the water table can be used for irrigation. This reduces the amount of non-saline irrigation water required and decreases the volume of drainage water needing disposal.

Drainage water can also be used for wildlife and/or constructed wetland sanctuaries. Questions that must be asked in this regard are:

- What constituents are in the water?
- Is the water available when needed?
- Is an adequate volume of water available?
- Is the wetland sustainable?

Where drainage water is derived from surface drainage or tailwater sources only, the water might contain residues of pesticides, etc. which may be toxic to wildlife. The reuse of saline subsurface drainage water for wetland establishment is less problematic with respect to pesticides and herbicides, but it may contain high nitrate levels or soil derived toxicants such as arsenic, boron, cadmium, selenium, etc. These wetlands should be designed to have a sufficient flow-through to minimize concentrations – due to evaporation – of toxic elements.

Evaporation ponds are a further alternative for saline/sodic water disposal. These can also become wildlife sanctuaries – but such water needs to be regularly assessed for potentially toxic constituents, which can accumulate to dangerous levels (e.g. Se).
Seepage from canals and dams has been shown to be the biggest contributor to salinity on a typical irrigation project - requiring that more attention be paid to this source.

7.19 Impact of drainage on health

In tropical and subtropical regions, there is a close link between the presence of excess water (due to inadequate drainage) and the transmission of water related vector-borne diseases – such as malaria, schistosomiasis and lymphatic filariasis. Proper surface and subsurface drainage to remove excess water in a safe and timely manner plays an important role in controlling water related diseases.

It is worth noting that irrigation canals generally receive regular maintenance, have fairly constant flows and have relatively high flow velocities. This militates against conditions that favor disease vectors. Drainage channels are the opposite, with irregular flows with low velocities, high seepage, siltation, low embankment slopes, weed infestation, uncontrolled access and many ponds with still water (usually with minimal maintenance). These are ideal breeding conditions for mosquitoes and aquatic snails. Misuse and lack of maintenance are the two main reasons why drainage structures (including road drainage ditches, culverts, dam site drainage, etc.) are often associated with environmental health problems.

The health issues related to drainage water management can be grouped into three categories (FAO/ICID 1997):

1. Water related vector borne diseases.
2. Faecal/orally transmitted diseases.
3. Chronic health issues related to exposure to residues of agrochemicals.

Drainage can bring significant public health benefits, such as improved sanitation from draining waterlogged areas, control of water related diseases and reduction of the incidence of malaria and schistosomiasis (ASABE 2008). To experience maximum benefits, drainage design must be integrated with the whole water control system – irrigation, flood control, environment preservation and domestic supply and disposal.

Intervention strategies can include:

- Building villages on high ground with a slight or uniform slope to facilitate good drainage. Draining and/or filling in depressions.
- Locating villages away from drainage channels.
- Restricting accessibility to slow flowing waters and dams.
- Reducing the volume of water collected in exposed reservoirs designed for domestic use.
- Providing potable water away from drainage areas.
- Improving sanitation facilities.
- Ensuring drains do not accumulate stagnant water.
- Drying out of waterlogged areas or shallow ponds as often as possible.
- Desilting drains and clearing them of weeds.

7.20 Good management practices

7.20.1 Pre-implementation: survey and planning requirements for drainage

- Obtain the best quality contoured imagery of the development area and carry out the appropriate soil survey, climate and other resource analyses.
• Obtain the long term mean monthly rainfall data for the area and, where possible, peak daily precipitation data.
• Compute expected runoff, considering soil type, slopes, vegetation, precipitation rates etc.
• Compile a general surface drainage plan for the cane farm, highlighting all natural flow paths, wetlands, main drain outlets to the project and consider possible downstream impacts.
• Plan the farm layout as an integrated irrigation and drainage entity with due consideration given to roads, infrastructure, mechanization, etc. Align cane rows so as to be self-draining, with row lengths not too long. Ensure cut-off drains are included above lands and plan for interceptor drains alongside canals and dams.
• Subsurface drains may be indicated where soils are heavy but have a fairly permeable A horizon.

7.20.2 Post-implementation: identification of drainage, salinity and sodicity problems

Where a cane project is operational, drainage problems may become evident with time. These problems are generally concerned with rising water tables and salinity, but runoff erosion may be seen and sometimes sodicity problems can occur.

The symptoms of poor drainage and salinity are often similar and it is not easy to distinguish between them. Sodic soils are a special case. General symptoms within cropped areas of poor drainage include:

**Waterlogging**
- A heavy infestation of bulrushes and sedges, such as *Cyperus*, which prefer wet conditions
- Mottled and gleyed soil profile
- Standing pools of water following rain or irrigation
- Signs of previous ponding – such as the development of a slick surface.
- Moss and algae growth on the soil surface
- Stunted growth with pale green foliage
- Dead cane or areas of no cane growth.

Note that if there is yellow cane in the field but examination of the surface and subsurface soils reveals no mottling or signs of a water table, then the yellow cane was not caused by the lack of adequate drainage.

**Waterlogging and salinity**
- The soil surface shows signs of ponding, capping or has a crust of salts or green algae.
- The natural vegetation has a high proportion of moisture loving or salt tolerant species.
- Patches of yellowish, stunted cane in the field and patches of dead cane.
- White salt encrustations and the development of green algal crusts.
- White crystalline deposits on the sides of canals and especially drainage channels.

**Sodicity**
- The surface of the soil is often discolored by dispersed humus; soils generally have a grey color
- Sparse vegetation; lack of grass cover
- Sheet erosion is a frequent occurrence, with significant surface wash and gullies
- Small sink holes are common
- Often have a sandy topsoil changing abruptly to a dense, impermeable clay-rich subsoil
- Structure of the subsoil is usually columnar or prismatic
- Wet soil has a soapy feel when touched
- Regular patterns of small square shaped cracks on the surface of a dry soil.
7.20.3 Monitoring of drainage, salinity and sodicity problems

- Look for the effects of wrong alignment of cane furrows after a heavy rain; wash-out if too steep and overtopping if too shallow.
- Monitor water table height on a continuous basis – install permanent piezometers at selected sites.
- Monitor drain-ways for silt build-up, weed growth and free flow.
- Scout for wet patches in harvested fields – might be a blocked subsurface drain.
- Check that mole drains are still effective – through appearance of numbers of wet patches.
- Observe crop and soils for signs of salinization and alkalinity.
- Measure salt content of irrigation water and drainage water.
- Where the salinity or residual alkalinity of irrigation water is suspect, make use of the WATSUIT model to assess the long term effects of water application on build up of salts in the soil profile.
- Measure ECe levels in steps of 300 mm down the soil profile (to 1 200 mm) when salinity is suspected.
- Monitor the effect of leaching (changes in EC values in drainage water).
- Check for seepage from dams and canals.

7.20.4 Mitigation measures

Other than good design at project commencement, there are general and specific measures that can be implemented to mitigate drainage problems:

**General measures**
- Prevent flooding from external sources by constructing dikes/levees and installing suitable flap gates.
- Intercept and dispose of seepage.
- Ensure that cut-off drains are in place to divert runoff from higher ground.
- Ensure water table levels are controlled at the design level.
- Control seepage from dams and canals by either lining permeable sections or adding chemical sealants (e.g. bentonite).
- Schedule irrigation scientifically so as to ensure excess water is not causing the water table to rise.
- Higher efficiency irrigation systems (e.g. centre pivot and drip) should be adopted to reduce deep percolation.
- A blended water system might be appropriate to reduce waste water and agro-chemicals – blending drainage water with better quality irrigation water.
- Alternatively waters with unacceptable SAR or Residual Alkalinity (RA) levels may be neutralised with acids or with gypsum to adjust RA and SAR to regional thresholds.
- Where sodicity is identified, amelioration should be undertaken using calculated amounts of gypsum (or other material where necessary) whilst ensuring that permeability is retained and a subsurface drainage system is in place. Sodic soils may also be ameliorated by application of gypsum in irrigation water.

**Surface drainage**

- Ensure that the surface drainage system has adequate capacity (monitor performance during flood routing after heavy rain).
• Shape and grade lands – to improve surface irrigation and ensure positive flow of surplus water to field drains.
• Regularly de-silt drainage channels
• Remove shoulders of tertiary and secondary drains (Fig. 7.7)
• Clear vegetation from drainage channels
• Where infield ponding occurs or where washout or overtopping is significant; mark the affected areas for possible reshaping and/or realignment after plow out.
• Consider using alternate furrows or in-row irrigation where a water table is the problem.

Figure 7.7 Secondary drain showing weed infestation.

Subsurface drainage
• Where a high water table is found to be a problem, and soils are suitable, a subsurface drainage system could be installed. Drain depth, spacing and sizing should be computed using appropriate drainage design formulas and/or proprietary software.
• Where drain spacings are calculated to be uneconomically close, consider a mole drainage system. Mole drains should be re-pulled at ratoon end.
• Leaching may be required, depending on the EC of the irrigation and drainage waters. An appropriate program should be devised.
• All subsurface drains must be cleaned annually.
• Inspection boxes must be de-silted annually and checked for accidental machinery damage.
7.21 References


SASRI Information Sheet 5.6: Soil Water Quality. Published by the South African Sugarcane Research Institute, Mount Edgecombe, South Africa.


# CHAPTER 8 DISEASE CONTROL – ROGER BAILEY

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8. DISEASE CONTROL

8.1 Introduction

Sugarcane is prone to infection by a large number of diseases that can impact significantly on productivity (Rott et al. 2000). This is partly due to the nature of the crop and the manner in which it is propagated, cultivated and managed.

In commercial practice sugarcane is propagated vegetatively, by planting pieces of stalk, termed setts or seedcane. The tillers that emerge from the axial buds on the planted stalk pieces develop into the new crop of stalks. Diseases caused by systemic pathogens (those that occur within the plant tissues) can therefore be readily introduced into a new crop by the planting of infected seedcane.

Sugarcane is also effectively a perennial in that once a new crop is planted; it is harvested repeatedly, usually annually, for up to five to ten years or more. This practice of 'ratooning', which is necessary for economic reasons, permits systemic pathogens to survive and multiply from one ratoon crop to the next.

The perennial nature of the crop and the fact that sugarcane is usually grown as a monoculture (i.e. it occupies most or all of the land within a given area for a prolonged period) also favors the build-up of diseases. These factors also mean that crop rotation, which is an important method of minimizing the build-up of pathogens in many arable crops, is of limited application in sugarcane culture.

An additional factor that contributes to the spread of diseases in sugarcane is that in many industries production is often based on only one or a few predominant varieties (the highest yielding). This increases the risk of disease development, if, for example, the main variety becomes susceptible to a new strain of a pathogen.

The ratooning that is characteristic of sugarcane culture and the need for a system to produce the large quantities of seedcane material that are needed to plant fields (6–10 t/ha) also do not permit sugarcane varieties to be changed quickly by the farmer. This also favors the development of both systemic and non-systemic diseases, such as those caused by foliar pathogens (e.g. brown spot and rust).

Sugarcane is also a relatively low value crop in terms of income per hectare in comparison with many other crops. Costly intervention practices, such as the application of pesticides to the growing crop, are therefore usually not economically feasible.

For all the above reasons the control of diseases is a critically important aspect of the management of sugarcane and must largely be achieved through a policy of prevention. The production and release to sugarcane farmers of varieties (cultivars) that have adequate resistance to prevalent diseases, in addition to the required agronomic and productivity characteristics, is the most important factor in this policy of disease prevention.

A system of producing disease-free seedcane with which to establish new plantings is also essential.

Most of the important sugarcane pathogens are widely distributed internationally. These include the viral diseases sugarcane mosaic virus (SCMV) and sugarcane yellow leaf virus (SCYLV); the bacterial diseases leaf scald (Xanthomonas albilineans) and ratoon stunting disease (RSD, Leifsonia xyli subsp xyli); and the fungal diseases smut (Ustilago scitaminea), brown rust (Puccinia melancephala) and
red rot (*Glomerella tucumanensis*). Hence similar control measures tend to be used internationally. Other important and potentially damaging diseases, including the viral disease Fiji disease (FDV), the phytoplasma diseases green grassy shoot and white leaf, and the fungal disease Pachymetra root rot, may have a more localized distribution. For these, control measures may have to be developed locally.

### 8.2 Sugarcane quarantine

The interchange of cultivars between sugarcane-producing countries is a common practice. It is necessary for the introduction of possibly superior hybrids for commercial production and also for the exchange of germplasm between institutes that conduct sugarcane breeding programs.

The method by which cultivars may be imported (i.e. whether as setts or tissue culture-generated plantlets) and the details of the quarantine protocols are usually determined by national governments. Importation is only permitted according to the terms and requirements of Import Permits issued by the appropriate government department.

Most countries where sugarcane is grown require that any introduced material in the form of setts must first be grown in isolation in some form of quarantine. This is necessary to reduce the risk of exotic pests and diseases, which might otherwise be a threat to local varieties, being introduced in the imported plant material and spreading to local varieties. In countries that lack sophisticated facilities ‘quarantine’ may simply mean that the introduced varieties are grown in areas remote from areas of commercial sugarcane, either in the field or in shade houses.

Most importing countries, however, require that the imported cultivars are grown in specially constructed quarantine glasshouses, designed to prevent any pests and pathogens escaping into the local environment (Bailey and Bechet (1988) before being released for further propagation outdoors.

Within the quarantine facility the imported material is usually grown for two plantings, including a ratoon crop stage, according to protocols that usually include hot water treatment (HWT) to eliminate any bacterial or fungal pathogens. Frequent inspection by skilled plant pathologists is necessary to identify any disease symptoms that might appear. Increasingly, quarantine protocols include the examination of samples by immunological and DNA-based diagnostic tests to identify any viral, phytoplasma and bacterial pathogens. The development of such tests has greatly increased quarantine security because these pathogens often do not express symptoms that can be recognized by visual examination.

Increasingly, varietal material that is exported from countries with technologically sophisticated sugarcane industries first undergoes a ‘pre-export quarantine’ process to minimize the possibility of exporting infected material. This process might include the ‘mother plants’ being subjected to serological or DNA-based diagnostic tests to ensure freedom from selected pathogens followed by multiplication via tissue culture (TC) to produce disease-free plantlets. Cultivars that are exported in this form might be approved for planting directly into the field in the importing country.

Comprehensive standards and detailed procedures for the export and import of sugarcane germplasm, as approved by the International Society of Sugar Cane Technologists (ISSCT), were published by Frison *et al.* (1993). These were updated by Bailey *et al.* (2000).
8.3 Integrated disease control in sugarcane

Although the planting of resistant cultivars is the best means of controlling most sugarcane diseases in the long term, in the short term, before adequately resistant, agronomically suitable cultivars become available for planting, other methods of disease control might have to be applied. A combination of these methods may be applied together in an integrated control system.

In addition to a degree of resistance to diseases in the cultivar disposition, an integrated system usually includes seedcane health and thorough eradication of the old crop before fields are replanted. It may also include the roguing of infected plants from fields and other cultural methods of control. These other methods of control are described in later sections.

In the case of RSD, for which there is little varietal resistance compared with most other serious diseases, the application of an integrated system of control offers the only means of minimizing the effects of this potentially damaging disease.

8.4 Varietal resistance

As with most crops, the planting of cultivars that are resistant to the spectrum of pathogens that occurs in a cane production area is the ideal means of controlling diseases. Through appropriate crossing and selection procedures, all sugarcane breeding centers aim to produce new commercial hybrids that have adequate resistance to those diseases that are thought to present a risk to production.

As resistance to most diseases is at least partially heritable, the parent varieties used in crossing programs are partly chosen to improve the proportions of progeny that are resistant. Over time, the accumulation of data on the frequency of resistance in the progeny, together with data on the agronomic and yield performance of the progeny, permits the identification of the most suitable male and female parent varieties to be used for crossing.

A number of sugarcane industries, particularly smaller industries, do not have their own crossing and selection programs. These industries rely on the importation of new cultivars from other industries in the form of seedcane setts or on the importation of ‘true seed’ (fuzz), on which to base a selection program. The importation of disease-free plantlets of foreign cultivars derived via tissue culture is an increasing practice.

Following crossing or the importation of new cultivars, the new genotypes are selected over a period of up to ten years or more in field trials, during which they are exposed to naturally occurring pathogens. Those that exhibit undesirable disease susceptibility (or other undesirable traits) are rejected.

For some diseases, particularly the more important ones in terms of the hazard they present, or if naturally occurring levels of potentially hazardous pathogens are low, the new selections may be ‘screened’ by exposure to artificially boosted levels of pathogens or they may be inoculated. For example, in South Africa new selections are screened for resistance to mosaic by being interplanted with stools of mosaic-infected ‘spreader’ plants. Similarly, for detecting resistance to smut, new hybrids are often inter-plantet with spreader plants of infected susceptible cultivars (Bailey and Bechet 1982).

For a number of important diseases for which a high level of resistance is essential, new hybrids undergoing selection are inoculated with the pathogen in question. Inoculation methods differ
according to the pathogen. For example with the fungal disease smut, setts of the genotypes under test may be dipped in a suspension of spores of *U. scitaminea* (Bailey and Bechet 1982). For leaf scald, a suspension of *X. albilineans* bacteria may be sprayed on to the cut ends of young shoots (Bechet et al. 1992). In Australia, screening for resistance to Pachymetra root rot is conducted in the glasshouse, where the hybrids undergoing selection are exposed to the fungal pathogen *Pachymetra chaunorhiza* under conditions that favor the infection process (Croft 1989).

Such inoculation techniques are often applied as early as possible in the selection process to maximize the number of new hybrids that proceed to later stages of selection for determination of yield and agronomic characteristics. Clearly, it is important that the results of any artificial screening process have a high degree of correlation with the susceptibility of cultivars under field conditions, hence the accuracy of such tests requires confirmation in calibration trials, otherwise there is a risk that unnecessarily stringent screening will limit the number of new cultivars that might be agronomically useful.

While a number of control options are possible for systemic diseases, including seedcane health, avoidance of volunteer regrowth and roguing, varietal resistance is the only practicable means of control for the many foliar diseases of sugarcane.

Because of the risks inherent in sugarcane production in an area being based on only one or a few cultivars (for example, a predominant variety may rapidly succumb to a new strain of a pathogen), it is generally recommended that a number of cultivars are grown. This can be done without unduly prejudicing productivity because most sugar industries require different cultivars suited, for example, to early, mid and late season harvesting and to different soil conditions.

8.5 Seedcane health

Because there are many important diseases caused by systemic pathogens that are readily spread by the planting of infected seedcane, the procurement of healthy seedcane is a prerequisite for the successful production of sugarcane. Internationally, the most important of these systemic diseases include RSD (*L. xyli* subsp *xyli*), smut (*U. scitaminea*), red rot (*Glomerella tucumanensis*) and sugarcane mosaic virus (SCMV). Other systemic diseases may be very important locally, such as the phytoplasma disease green grassy shoot in eastern Asia (Pliansinchai and Prammanee 2000).

The need to procure healthy seedcane for planting is widely understood among sugarcane growers worldwide and most operate some form of seedcane production system that includes treatment of the seedcane to eliminate pathogens and pests and the subsequent planting of the treated seedcane in carefully managed ‘seedcane nurseries’ to produce the healthy seedcane used for commercial planting.

The initial treatment of the seedcane often includes the routine application of thermotherapy, such as hot water treatment (HWT), to eliminate fungal and bacterial pathogens as well as pests. The treatment time and temperature is a compromise between the need to eliminate pests and pathogens without severely impacting on the subsequent germination of the treated seedcane. The standard treatment in most sugarcane industries is 2 h at 50 °C, which has been shown to achieve a high degree of elimination of the RSD pathogen *L. xyli* subsp *xyli* (Davis and Bailey 2000). HWT is usually followed by a fungicide dip to prevent infection of the treated seedcane by soil-borne diseases after planting (Girard and Rott 2000).

Variations on the standard treatment may be used to improve the likelihood of eliminating certain pathogens. For example, the ‘long hot water treatment’, which involves a preliminary soak in cold water for 24 h followed by treatment for 2-3 h at 50 °C the next day is recommended for the
elimination of leaf scald pathogen *Xanthomonas albilineans* in industries where this disease is a problem (Steindl 1972).

Various designs and sizes of HWT plant are used in different industries. An important aspect of the design includes having a relatively high volume of water to seedcane (approximately 4:1) so that the water temperature does not decline substantially when each batch of seedcane is added. Also important is the need for accurate control of the water temperature, which is usually controlled by thermostats. The water in the tank must be efficiently circulated to avoid ‘hot or cold spots’ and the water must be replaced regularly; otherwise it soon becomes acidic and contaminated, with adverse effects on germination.

The HWT tank may be loaded with a single, large basket containing the seedcane to be treated. Alternatively, a design that is widely used in Africa is the ‘continuous flow’ HWT tank in which small baskets, each holding 50-70 kg of seedcane, are added successively to the tank approximately every 8-10 minutes (the interval depending on the size of the tank) and removed successively after each basket has been treated for 2 h (Fig. 8.1). The treatment temperature is accurately controlled by means of a thermostat. This system offers advantages in the ease of handling the seedcane for treatment (an overhead gantry is not necessary) and transporting it to seedcane nurseries after HWT for planting. It also minimizes handling of the treated seedcane, thus avoiding damage to the buds.

The throughput of a 4 000 L plant is approximately one tonne every two hours or 8 t/day if the plant is operated for two 8-hour shifts per day. This quantity of treated seedcane suffices to plant approximately one hectare of nursery.

![Figure 8.1. A continuous flow HWT tank; a basket containing 50-70 kg of seedcane is added and one is removed approximately every 8-10 min, after a 2 h 50 °C treatment.](image)

Increasing use is being made of tissue culture (TC) as an alternative to HWT to generate disease-free plantlets. Most TC-based systems utilize immunological and DNA-based testing of the mother plants and multiplication via meristem tip culture, which has the advantage of minimizing TC-induced variation.

HWT-treated seedcane, or disease-free plantlets obtained via a tissue culture process, is then multiplied one or more times in ‘seedcane nurseries’ to produce the planting material for commercial fields. Small-scale producers often use a one-stage nursery system, but large-scale growers often use a two-stage nursery system involving ‘A’ and ‘B’ nurseries to produce large amounts of commercial seedcane. These options are illustrated in Fig. 2.
‘A’ or ‘primary’ nurseries are often located on a permanent nursery site, where conditions for growth are good, and may be located in proximity to the HWT plant. In the A nursery a ‘nursery rotation’ might be practiced; in this the plant crop and first ratoon crop are taken for seedcane, after which the stubble of the former first ratoon block is eradicated and a ‘break crop’ planted to ensure freedom from volunteer regrowth.

In a two-stage nursery system the seedcane for planting commercial fields is produced in the ‘B’ or ‘secondary’ nurseries. Usually only the plant crop is taken from these nurseries for use as seedcane, after which they revert to commercial cane production.

Seedcane nurseries must be inspected frequently to ensure freedom from hazardous diseases and varietal purity. If necessary, ‘roguing’ operations must be conducted to eliminate infected or off-type plants. This aspect of seedcane production is often governed by sugar industry regulations, and the inspections and approval are a responsibility of specially trained and experienced industry staff members, as is the case in Swaziland (Anon 2009).
8.6 Effective crop eradication

To control systemic diseases, including RSD, smut and many others, thorough eradication of the old crop is necessary before fields are replanted. Otherwise, the pathogens that cause these diseases might persist in the form of infected ‘volunteer’ regrowth and thereby provide sources of infection in newly planted fields. If this occurs, it completely negates the benefits of planting fields with healthy seedcane.

Because RSD is readily spread during harvesting operations and because it is effectively symptomless in most varieties, and also because effective cultivar resistance or tolerance is relatively uncommon, avoidance of volunteers is a key factor in efforts to control this potentially damaging disease (Bailey and McFarlane 1992). The survival of volunteers is favored by the common practice in many industries of replanting fields as soon as possible after an old crop is ploughed out, sometimes after only a few days.

An effective break between cane plantings to ensure thorough elimination of volunteer regrowth is particularly recommended if the field to be replanted is known to have been infected with RSD (for example, by means of laboratory-based diagnostic tests). During the break between plantings the field can be left fallow or a break crop can be planted (Bailey and McFarlane 1992).

When field conditions are suitable, the use of a crop eradicant, such as glyphosate, can be an effective method of avoiding volunteer growth. In dry, sandy soils, shallow plowing to invert the cane stubble to encourage desiccation and death of the stubble can also be effective.

8.7 Roguing

The term ‘roguing’ means the inspection of the growing sugarcane crop, either seedcane or commercial cane, and removing shoots or stools that have symptoms of hazardous diseases from the field to reduce further spread.

Roguing seedcane nurseries is a common practice in many sugarcane industries and is intended to maintain an acceptable level of health in the seedcane to be used for planting. In some industries, including many in southern Africa, acceptable levels of certain diseases are specified in industry regulations (e.g. Anon 2009). For roguing to be successful or worthwhile, the disease in question must have symptoms that are readily expressed and recognized. Among the diseases that are commonly rogued from nurseries are smut (*U. scitaminea*), mosaic and green grassy shoot.

Roguing commercial cane fields is less common or worthwhile in most sugar industries as it requires affordable, trained labor; a more economically feasible option in many industries is to change to cultivars that are more resistant. However, roguing to control smut is a long established and successful practice in sugar industries in southern Africa. There, well-managed, intensive roguing of smut-infected stools or smut whips from commercial fields was found to be worthwhile to maintain the productivity of moderately susceptible cultivars, including the versatile NCo376, for many years (Pearse 1989).

8.8 Other cultural methods of disease control

In certain circumstances, manipulating the time of planting or harvest can be used to minimize the spread of a disease. An interesting example of this is the avoidance of SCMV in South Africa by not planting and harvesting susceptible varieties in the summer months. By means of this practice, the young, most susceptible stage of crop growth is not exposed to high populations of the vector aphids.
*Rhopalosiphum maidis* and *Heteroneura setarie*, which are at a peak in mid-summer (Harborne 1988).

Similarly, infection by the phytoplasmal disease white leaf can be reduced by planting in spring to avoid the peak populations of the leafhopper *Matsumuratettix hiroglyphicus* (Chen and Kusalwong 2000).

The viral disease, mosaic, is exceptional among sugarcane diseases in having a number of alternative host plants among common grass species. These can act as sources of the virus and also of the aphid vectors. Good control of grass weeds in and around cane fields can therefore contribute to the control of mosaic.

**8.9 Sugarcane industry disease control schemes**

Most sugarcane industries attempt to minimize the spread of diseases and thereby maintain productivity by implementing regulatory measures that are binding on growers.

The most common regulatory measure is a restriction on the varieties that can be grown to exclude those that are unduly susceptible to prevalent diseases and pose a risk to productivity. In industries that are climatically diverse, a variety may be permitted in those areas where conditions are not favorable for the spread of a particular disease but the same variety may be banned elsewhere. To be successful, these regulations must be based on accurate knowledge of variety reactions, best gained from controlled field trials.

Quarantine barriers may be imposed to prevent possibly infected planting material being transported from one area to another, as was applied in Australia to limit the spread of smut after it first appeared in that industry in the late 1990s. In South Africa, a quarantine barrier proscribes the movement of cane from the northern sector of the industry, where leaf scald is more common, to the southern sectors, where leaf scald is rare.

Disease control schemes in many industries include health standards for the seedcane used for planting fields. This requires the registration and inspection of intended seedcane sources by industry disease control specialists. Seedcane crops that do not meet required standards of health may be refused certification for planting, or control measures, such as roguing of the crop, might be ordered to reach the health standard.

Where commercial fields are infected by a disease at a level that is considered hazardous to other growers, a ‘plough-out’ order might be issued. Alternatively, a roguing order might be issued to force the removal of diseased plants. Both these measures are used in successful smut control schemes in southern Africa, such as in Swaziland (Anon 2009).

**8.10 Monitoring disease incidence**

Monitoring the incidence of diseases that pose a risk to productivity provides valuable data to aid in their control. Records accumulated over time provide a useful guide as to whether diseases are spreading and whether control efforts should be intensified or a change in varieties is warranted.

**8.10.1 Monitoring diseases in seedcane nurseries**

Frequent, regular inspections should be conducted in seedcane nurseries to ensure that the seedcane intended for planting has a satisfactory disease status. For diseases with readily recognized
symptoms, inspections should be on a ‘line-by-line’ basis and any plants infected by systemic diseases should be dug out and destroyed. In the case of RSD, stalks should be collected and samples of sap extracted and subjected to laboratory diagnosis (see 8.12.1).

Standards of health in seedcane nurseries should be high. For example, in southern Africa, the recommended standard for smut and mosaic is no more than 0.1% infected stools (Anon 2009).

8.10.2 Monitoring diseases in commercial fields

For commercial fields, line-by-line inspections may not be feasible. However, recording disease incidence at a number of representative sampling sites in the field can provide satisfactory estimates of incidence. A method that is widely used in southern Africa is to count the number of infected stools in a number of 50 m lengths of row; assuming that there are two ‘stools’ per meter, the average count can be expressed directly as a percentage. Whatever sampling method is used, it should be used consistently from year to year so that data are comparable over time.

For RSD, monitoring can be based on the collection of stalks from the field. Extracts of xylem sap are then subjected to diagnostic tests in the laboratory (see 8.12.1).

8.11 Chemical control

There is relatively little use of pesticides for the control of diseases in sugarcane. Most industries recommend that seedcane be dipped in fungicides before planting to improve the likelihood of germination, by inhibiting the development of sett rotting diseases. In practice, however, and particularly if conditions for germination are good, few sugarcane growers routinely use seedcane fungicides when planting commercial fields.

Fungicides are frequently used when primary seedcane nurseries are being planted with setts that have been subjected to HWT. Setts that have been subjected to HWT tend to germinate more slowly than untreated setts and hence might germinate poorly without fungicide treatment. The fungicides benomyl and triazole compounds are often recommended (Wismer and Bailey 1989).

Particularly in African industries where smut (U. scitaminea) is common, the fungicide triadimefon or a similar triazole fungicide is often applied during or after the heat treatment process to reduce infection after planting (Bailey 1983).

Because within a cane production area the proportion of land devoted to primary seedcane nurseries usually amounts to approximately only 1 % of the total area planted to cane (in areas where a 2-stage nursery scheme is practiced), the overall rate of use of fungicides within the cane production area is low. For example, where triadimefon is used during HWT of seedcane for planting in primary nurseries in Africa, approximately 1.0 kg (a.i.) of triadimefon is used to treat the seedcane for planting 1.0 ha of nursery (Bailey 1983).

Fungicides have been used experimentally to control brown rust (P. melanocephala) in susceptible varieties in order to demonstrate the effect of infection on yield. However, there is little use of fungicides to control rust in commercial practice.

The fungicides used to treat seedcane at planting are not highly toxic chemicals (compared for example with nematicides and many insecticides). Routine precautions, including the wearing of gloves, should be taken when handling and mixing the fungicides.
Because there is little use of fungicides in sugarcane agriculture and because those that are used are not highly toxic, the continued use of fungicides does not pose a significant risk to the environment.

8.12 Some common diseases of importance

Brief descriptions and a summary of control measures for some of the more important diseases of sugarcane with a worldwide distribution are given below. Space does not permit the inclusion of descriptions of the many diseases that can affect sugarcane; however, a number of guides to the identification of diseases and their control are available. A Guide to Sugarcane Diseases (Rott et al. 2000) is one of the most useful and is available in book form and as an interactive DVD. This guide includes lists of the different diseases that have been recorded in different sugarcane producing countries.

8.12.1 Ratoon stunting disease (RSD)

Cause: A bacterium, Leifsonia xyli subsp xyli

Symptoms: There are no symptoms that can be readily recognized in most cultivars. In some cultivars, when an infected stalk is sliced longitudinally, the vascular bundles at the nodes may be seen to be discolored red to dark brown (Fig. 8.3) but the absence of these markings is not a reliable indication of health.

Diagnosis: Because RSD causes no symptoms that can be readily recognized in the field, accurate diagnosis is dependent on laboratory testing based on immunological or DNA-based techniques.

Large-scale sampling of fields is invariably based on immunological tests. Diagnosis in many African sugar industries is based on immunofluorescence microscopy (IFM) conducted at the South African Sugarcane Research Institute (McFarlane et al. 1999). The evaporative binding enzyme immunoassay (EB-EIA) is used in Australia for accurate diagnosis (Croft et al. 1994).

The bacterium L. xyli subsp xyli inhabits the xylem vessels in the vascular bundles and is most readily found in mature stalks. Hence the stalks collected for diagnosis should be approximately nine months or older. Sap from the xylem vessels of undamaged pieces of mature stalk is collected via a positive pressure technique, for example using a low pressure pump, tubing and a resin adaptor to blow air through the stalk piece (Croft and Witherspoon 1982). For large-scale surveys in Africa, the samples of sap are air-dried on microscope cavity slides and can then be easily transported to the laboratory for diagnosis (McFarlane et al. 1999).

Importance: RSD probably causes greater economic loss to sugarcane industries worldwide than any other disease. Losses are greatest when the crop suffers stress but can be severe even in irrigated crops in intolerant cultivars. In individual fields, reductions in yield as high as 25 % or more are possible and, under drought conditions, infected cane may die. Reductions in production in some African industries where RSD was common have been estimated at 10 % or more (Bailey and McFarlane 1999).

Spread:
- By planting infected seedcane.
- On cutting implements during harvesting.
- Can survive in infected volunteer regrowth between plantings.
Control:
- Heat treatment of seedcane.
- Careful management of seedcane nurseries to avoid re-infection. This includes cleaning cutting implements with a disinfectant during harvesting (Davis and Bailey 2000).
- Thorough elimination of old crops, including volunteer regrowth, before fields are replanted. The use of a break from cane is recommended if the previous crops in fields to be replanted are known to have been infected.

![Figure 8.3. Red-brown discoloration of the vascular bundles at the nodes due to RSD.](image)

8.12.2 Smut

_Cause:_ A fungus, _Ustilago scitaminea_

_Symptoms:_ Infected stalks often develop long, whip-like, spore-bearing structures (called ‘smut whips’) from the apical meristems or from the lateral buds. The whips are initially covered by a silvery-white membrane; this soon deteriorates to expose the black fungal spores (Fig. 8.4). Infected plants may have a grass-like appearance due to the dense production of tillers.

_Diagnosis:_ One of the most easily recognized diseases of sugarcane from the appearance of the characteristic smut whips.

_Importance:_ Can cause severe losses in the yield of susceptible varieties and is difficult to control once firmly established.

_Spread:_
- By wind-blown spores.
- By the planting of infected seedcane.

_Control:_
- Resistant varieties.
- Healthy seedcane (HWT to control RSD also eliminates smut from seedcane).
- Roguing infected plants from nurseries.
- Roguing infected plants from fields (where economically feasible).
Figure 8.4. Whip-like fungal sori produced from the apical meristems of smut-infected shoots. The fungal membranes rupture to release the spores.

8.12.3 Mosaic

*Cause:* Sugarcane mosaic virus (SCMV) and sorghum mosaic virus (SrMV), both potyviruses. Both viruses occur in a number of distinct strains. SCMV is the more common virus.

*Symptoms:* A pattern of stripes or blotches of contrasting shades of green on the leaves. Symptoms of mosaic vary in conspicuousness among varieties and are often most conspicuous in young leaves (Fig. 8.5).

*Importance:* Can cause severe reductions in yield in susceptible varieties.

*Diagnosis:* Visual observation of the characteristic foliar symptoms is the primary means of diagnosis. Accurate diagnosis is by means of immunological and DNA-based laboratory tests.

*Spread:*  
- Primary spread occurs through the planting of infected seedcane.  
- Secondary spread occurs through various species of aphids, including *Rhopalosiphum maidis* and *Hysteroneura setariae*.

*Control:* Mosaic can be difficult to control because may be difficult to recognize and because SCMV can infect a number of common grass species in and around cane fields (Grisham 2000).

- Resistant cultivars.  
- Healthy seedcane.  
- Timing of planting and harvest to avoid peak aphid populations.
8.12.4 Rust

*Cause:* Brown rust (*Puccinia melanocephala*) and orange rust (*Puccinia kuehnii*). Brown rust is the more common pathogen and occurs worldwide. Orange rust mainly occurs in Australia and far eastern sugar industries but has recently been recorded in some African sugar industries.

*Importance:* Can cause severe reductions in yield of susceptible varieties.

*Diagnosis:* Rust can be easily recognized from the characteristic appearance of the spore-bearing pustules (sori) on the undersurfaces of the leaves (Fig. 8.6).

*Spread:* By means of wind-blown and rain-splashed spores produced in the pustules on the leaves.

*Control:* In commercial practice, rust is controlled only by the planting of resistant varieties.
8.12.5 Red rot

*Cause:* A fungus *Glomerella tucumanensis* (= *Colletotrichum falcatum*, imperfect stage).

*Symptoms:* A red colored rotting of the internal stalk tissues, sometimes with white blotches. On the leaves, infection causes elongated red blotches on the upper surface of the midribs (Figs. 8.7 and 8.8).

*Importance:* Red rot is a common disease in many sugar industries. Reductions in yield of susceptible varieties can be severe due to both the death of stalks and reduction in sucrose content and purity. Red rot is often associated with damage caused by stalk boring insects.

*Spread:*
- By the planting of infected seedcane.
- By wind-blown and rain-splashed spores produced in infected stalks and crop stubble and debris. The spores infect through the bud and nodal tissues and also through damage to the stalks, such as cracks and insect borings.

*Control:*
- The planting of resistant cultivars is the main method of control.
- Healthy seedcane.
- Minimizing insect damage.

![Figure 8.7. Red discoloration of the internal stalk tissues due to severe red rot.](image)

![Figure 8.8. Mid-rib lesions due to red rot.](image)
8.13 Diseases in selected regions

The International Society of Sugarcane Technologists (ISSCT) maintains up-to-date lists of all the diseases of sugarcane that have ever been recorded in the different countries in which the crop is grown (Rott et al. 2000). These lists are sometimes lengthy and they differ from country to country, both in sheer numbers and in the identity of the currently dominant diseases in each country. These differences are due in part to the genetic makeup of the hybrids that are interbred and grown commercially in different regions, on the duration over which sugarcane has been grown (the longer the history, the more time for diseases to occur) and on the climatic and environmental conditions under which sugarcane is grown.

Many important and potentially damaging diseases are distributed almost worldwide and should be regarded as a threat to the crop wherever it is grown. These include RSD, smut, mosaic, red rot and brown rust.

Certain other diseases are more localized in distribution, either historically or currently. Historically important diseases include sugarcane streak virus, which caused huge losses in production in South Africa in the 1920s to 1930s, because of industry reliance at the time on the susceptible variety Uba.

Currently important or potentially important diseases that occur in different countries and regions are included below.

8.13.1 Australia

Two important diseases that are unique to the Australian sugar industry are Pachymetra root rot, which is a problem in the wet tropics, and Fiji disease virus. The selection of new varieties with resistance to these diseases is the main method of control. Smut, which was historically absent from Australia, first appeared in Western Australia in 1998 after spreading probably from Indonesia. It subsequently appeared in many of the main sugarcane areas of the east coast and is now a major hazard to production.

8.13.2 Papua-New Guinea

Papua-New Guinea is generally regarded as the centre of origin of sugarcane, where ‘wild’ sugarcanes and associated pathogens co-evolved over many years. After the commercial production of sugarcane using imported hybrids commenced at Ramu Sugar Estate in the 1970s, it did not take long for a previously unknown disease to appear and cause very serious losses in yield. The new disease, termed Ramu stunt, was eventually shown to be caused by a phytoplasma, transmitted by leaf hoppers. Control was achieved through the selection of resistant varieties in field exposure trials.

8.13.3 The Far East and India

Two diseases that are common and can be destructive in the Far East are green grassy shoot and white leaf. These diseases are caused by phytoplasmas and are transmitted by a number of species of leaf hoppers as well as in seedcane. As its name implies, green grassy shoot causes infected stools to generate large numbers of grass-like tillers instead of millable stalks. Highly susceptible varieties may die.

White leaf disease is similar to green grassy shoot in causing stunting and profuse tillering. As its name implies it is characterized by the leaves of infected plants exhibiting conspicuous white streaks...
or a general chlorosis. Again infected stools of susceptible varieties may die, particularly if subjected to moisture stress.

The control of both diseases is based mainly on varietal resistance. The selection of planting dates to avoid the coincidence of young stages of growth with peaks in vector populations is reported to aid in the control of green grassy shoot.

Red rot has been a significant disease in the Indian sub-continent for many years.

8.13.4 Africa

In addition to the archetypical serious diseases in Africa of smut and RSD, mosaic (SCMV) can be a significant problem, particularly in cooler areas. Some recent outbreaks in warmer, irrigated production areas of South Africa were initiated by infection spreading in seedcane stocks.

Symptoms of yellow leaf syndrome, both SCYLV and sugarcane yellows phytoplasma (SCYP) are commonly seen but the impact of these diseases on yield is still uncertain.

Brown rust (P. melanocephala) is commonly seen and can be damaging in susceptible varieties. More recently, symptoms of orange rust (P. kuehni) have been recorded in some African sugar industries.

8.13.5 The Americas

Smut, mosaic (both SCMV and SrMV), RSD and brown rust are diseases of concern in most sugar industries in the Americas. Sugarcane yellow leaf virus (SCYLV) is reported to have the potential to cause significant reductions in yield in susceptible varieties. Leaf scald (X. albilineans) occurs in many industries and requires attention in crossing and selection programs.
8.14 The way forward towards sustainable control of diseases

The many diseases to which sugarcane is prone and the nature of the crop (see 8.1 Introduction) mean that diseases will always pose a threat to productivity wherever the crop is grown. Disease control will therefore always be an essential aspect of the management of the crop, requiring continual attention. The ideal policy is one of prevention, so that productivity is not jeopardized and the need for possibly costly control interventions is avoided.

Aspects of control that must be incorporated into every sugarcane enterprise include the following:

- Variety resistance.
- Seedcane health, achieved through a planned, well managed system of seedcane production.
- Effective destruction of the old crop before replanting. This is particularly important if the previous crop in the field to be planted was infected by a systemic disease.
- Monitoring the incidence of diseases to provide timely warning of any developing disease problem. Survey data can prompt enhanced attention to basic control measures or signal a need to change from a susceptible to a more resistant variety.

Variety resistance, together with sugar yield, cane quality and suitable agronomic characteristics, is one of the main factors affecting the choice of varieties for planting. In areas where diseases are limiting factors to production, a high level of resistance may be a prerequisite for a successful sugarcane enterprise. A system for evaluating the reactions of varieties to prevalent diseases is therefore necessary so that sound decisions on which varieties are to be extensively propagated can be made.

Given adherence to the control principles that are summarized above, the economic impact of diseases on production can be minimized.

Looking to the future, there is little doubt that the use of TC-based systems of generating pathogen-free plantlets, backed by immunological and DNA-based tests for diagnosing pathogens, will be increasingly adopted for both variety exchange between countries and for the initial stages of seedcane production as replacements for traditional practices. This will simplify variety exchange by reducing the risks of importing infected germplasm and provide a higher standard of freedom from pathogens in the initial stages of seedcane production in commercial sugarcane production.

Although achievable and the subject of ongoing research in progressive research institutes, it seems doubtful that gene transfer through molecular biological techniques to overcome disease susceptibility in otherwise valuable varieties will become of practical value. This is because, apart from the public perception of the acceptability of this technology, progress towards higher yielding and improved disease resistance of new varieties is continually being made through conventional breeding and selection programs.
8.15 Summary

Sugarcane is unusually prone to infection by damaging diseases for the following reasons, all of which favor the dissemination of pathogens and their survival from crop to crop:

- It is vegetatively propagated
- It is grown as a monoculture
- It is effectively a perennial
- The rate at which varieties can be changed by the grower is relatively slow.

**Box 8.1 Disease Control**

There are many examples where diseases have caused extremely damaging losses in productivity. The control of diseases is therefore essential for any sugarcane enterprise to be successful and this aspect of management requires constant attention and vigilance. The ideal control strategy in terms of minimizing risk and the cost of implementation is one of prevention.

The pathogens that cause diseases are either ‘non-systemic’ or ‘systemic’. Non-systemic diseases include those that are caused, for example, by foliar pathogens such as rust. Systemic diseases inhabit the cane stalk. They can therefore be spread by planting infected seedcane and they survive in the stubble from one crop to the next after harvesting and replanting.

The main method of controlling all diseases is to plant resistant varieties and this is the only method of controlling diseases caused by foliar pathogens. Control of systemic diseases is mainly achieved by means of:

- Varietal resistance
- Planting healthy seedcane
- Efficient eradication of the old crop before fields are replanted.

**Varietal resistance is the most cost-effective and most suitable method of controlling almost all sugarcane diseases in the long term.**

For this strategy to be effective and in order to optimize productivity and profitability, all sugarcane enterprises need to regularly introduce potential new varieties for agronomic and disease resistance evaluation. Only those new varieties that have adequate resistance to prevalent diseases as well as the necessary yield characteristics should be advanced for commercial utilization.

The evaluation of disease resistance requires exposure to prevalent pathogens in the field, so that they are exposed to natural infection by pathogens. Earlier stages of testing may involve inoculation, such as interplanting with ‘spreader plants’.

The risk of a serious and damaging disease outbreak occurring is lessened if production is based on at least several varieties, rather than being dependent on one or two dominant varieties.

**Ratoon stunting disease (RSD)** is arguably the most important disease of sugarcane internationally. It has the potential to cause severe reductions in productivity under all growing conditions. It also has the characteristics of having no easily recognized symptoms (and can therefore spread insidiously) and, most importantly, there is little useful varietal resistance to infection among commercial hybrids. Control of RSD must therefore be based on the production of healthy seedcane (achieved through hot water treatment and a planned system of seedcane production in well
managed nurseries) and the avoidance of volunteer regrowth from the old, possibly infected stubble of old crops before fields are replanted.

Additionally, the control of RSD aided if samples collected from the field can be submitted to laboratories from accurate diagnosis. This knowledge can be used to aid decision making on the implementation of field hygiene measures, crop eradication and the use of break crops before suspect fields are replanted.

**Monitoring the incidence of important diseases** in both seedcane nurseries and commercial fields is an important aid to control. For example, information gained from disease inspections forms the basis for estimating the effect of diseases on production, for prompting additional control measures, such as roguing, and as a guide to the need to replacing old, susceptible varieties.

The many diseases to which sugarcane is prone and the nature of the crop (see 8.1 Introduction) mean that diseases will always pose a significant threat to productivity wherever sugarcane is grown. Disease control will therefore always be an essential aspect of the management of the crop, requiring continual attention. The ideal policy is one of prevention, so that productivity is not jeopardized and possibly costly control interventions are avoided.

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- Monitoring the incidence of diseases to provide timely warning of any developing disease problem. Survey data can prompt enhanced attention to basic control measures or signal a need to change from a susceptible to a more resistant variety.

Variety resistance, together with sugar yield, cane quality and suitable agronomic characteristics, is one of the main factors affecting the choice of varieties for planting. In areas where diseases are limiting factors to production, a high level of resistance may be a prerequisite for a successful sugarcane enterprise. A system for evaluating the reactions of varieties to prevalent diseases is therefore necessary so that sound decisions on which varieties are to be extensively propagated can be made.

Given adherence to the control principles that are summarized above, the economic impact of diseases on production can be minimized.
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9. PEST CONTROL

9.1 Introduction

Commercial sugarcane is normally grown as a long-term monoculture. Crop pests thrive where a host plant is abundant in both time and space, and where controlling factors are absent or limited. Hence, cultivating sugarcane, year after year, over large, often contiguous areas can lead to widespread crop loss, and even complete crop failure where no attempt is made to contain the pests. Thus, identifying important pests, and knowing what to do about them, is vital for the sustained production of sugarcane.

Numerous insects, nematodes and a few vertebrates are pests of sugarcane. They include:

- Shoot and stalk borers;
- White grubs or canegrubs and other root or stool feeders (weevils and termites);
- Above and below ground sap feeders (scale insects, frog-, plant- and leafhoppers, whitefly, spittlebugs, soldier flies, cicadas, earth pearls, aphids and thrips);
- Leaf feeders (armyworms, trash caterpillars, loopers and locusts);
- The plant parasitic root-knot, lesion, dagger, sting, lance and stubby-root nematodes;
- Vertebrate pests (rodents, feral pigs, wallabies and some birds).

As with other plants, sugarcane can tolerate some of the damage caused by pests, without there being a loss in yield. Pests only become an economic problem when too many individuals feed on the plant. The actual number depends on various conditions, including:

- The pest species,
- Growth stage of the cane,
- Susceptibility of the cane cultivar to the pest,
- Above and below ground environment.

Practices that suppress pest population growth will reduce damage. In the past, very poisonous organochlorine pesticides were used, with good effect, to reduce pest numbers. Due to serious concerns about their effects on human health, beneficial organisms and, in particular, their persistence in the environment, these were withdrawn from use and replaced by less persistent chemicals. Some of the pesticides currently registered for use in sugarcane are very poisonous and are classed as extremely or highly hazardous (WHO 2010). As such they pose a threat to people, to non-target organisms and to the environment. However, while there is a need to reduce dependency on pesticides it is recognized that, in some situations, sustainable farming requires their judicious use to control pests (Christiansen 2000). It is worth recording that sugarcane farming does not require a lot of pesticides; in fact, the use of insecticides is below the average for comparable cash crops (Lehtonen and Goebel 2009).

9.1.1 Integrated Pest Management

Whether or not a pesticide is used, pests are best controlled by adopting an integrated pest management (IPM) approach, that is, combining appropriate strategies and practices that, directly or indirectly, prevent economically harmful pest outbreaks, increase crop yields and have minimal adverse effects on beneficial organisms, humans and the environment.
BOX 9.0 Integrated Pest Management
According to Rutherford and Conlong (2010) the most common definition of IPM is ‘a decision-making process using multiple pest management tactics to prevent economically damaging outbreaks while reducing risks to human health and the environment’. The definition by the World Bank (2010) places emphasis on reducing dependence on pesticides, describing IPM as ‘a mix of farmer-driven, ecologically based pest control practices that seek to reduce reliance on synthetic chemical pesticides. It involves (a) managing pests (keeping them below economically damaging levels) rather than seeking to eradicate them; (b) relying, to the extent possible, on non-chemical measures to keep pest populations low; and (c) selecting and applying pesticides, when they have to be used, in a way that minimizes adverse effects on beneficial organisms, humans, and the environment’.

Rutherford and Conlong (2010) list three levels of IPM used by farmers:

(1) A low level IPM where decisions regarding the use of insecticides are based on the results of scouting for pests and economic damage thresholds.

(2) A medium level IPM where additional preventative measures are adopted, such as, various cultural practices and plant tolerance or resistance, and, where possible, not using broad spectrum pesticides so that beneficial organisms are protected. These IPM strategies are targeted mainly against single pest species and do not consider all the pests in a specific agro-ecosystem.

(3) High level or bio-intensive IPM, where multiple interventions are integrated and can target multiple pests. At this level IPM is based on holistic agro-ecosystem interactions, in which knowledge about the pests, their pathogens, natural enemies, associated plants and endophytes, and the interactions between all of these, are combined to develop IPM in an area/industry-wide, environmentally friendly manner.

Practices that contribute to the integrated management of pests in sugarcane are listed in Boxes 9.1 to 9.4 (derived in part from World Bank (2010)).

Box 9.1 Pre-harvest management and cultural practices that contribute to IPM in sugarcane
- Maintain local and Industry-wide awareness of population levels of significant pests and ensure that action is taken when populations exceed thresholds. Develop procedures to prepare for the possible incursion of pests from other countries or continents.
- Manage planting or harvesting dates to avoid conditions most conducive to an increase in pest numbers at a time when the crop is most vulnerable. Manage the dates to decrease or increase the attractiveness of crops. Those with increased attractiveness can be used as trap crops.
- Use pest resistant cultivars. Ensure that susceptible cultivars are not planted in regions where the pest is prevalent. Avoid the situation where large contiguous areas are planted to pest (or disease) susceptible cultivars.
- Practise sanitation at planting. Destroy or mill infested cane from seedcane nurseries; plant fields with pest-free seedcane.
- Use organic amendments in the planting furrow to enhance early plant growth and reduce damage caused by nematodes.
- Inter-crop sugarcane with cash crops.
- Pretrash standing cane some months prior to harvest to remove potential egg-laying sites for stalk borers.
- Irrigate to reduce moisture stress – most pests flourish in moisture stressed cane.
- Manage and conserve on-farm water. Practise strip cropping, minimum tillage and trashing at harvest. Also, build conservation structures to ensure that rainfall is retained on the farm, not lost through runoff.
- Manage soil nutrients to avoid high nitrogen levels that favor some pests. Low silicon levels favor stalk borers; correct silicon deficient soils with an amendment.
- Hand-pick pests. Use trap crops and light traps.
- Manage the habitat by planting insect repellent plants in or around cane fields to repel borers.
Box 9.2 Post-harvest cultural practices that contribute to IPM in sugarcane

- Adoption of green cane harvesting and the retention of a trash blanket (mulch). The trash suppresses weed growth, conserves soil moisture, reduces soil erosion, enhances the activity of the natural pathogens and predators in the soil and is a vital resource for the production of **labile carbon**, nitrogen and other nutrients. Labile carbon is crucial for the maintenance of soil structure, water holding capacity and water infiltration and sustains soil biological activity (Kingston et al. 2007). Trashing is particularly important on shallow erodible soils and on steep slopes. This may not be advisable in some situations, e.g. wet, cold soils (valley bottoms, high rainfall areas and soils above 500 m altitude) although the trash may be collected and used as fuel.
- Field sanitation at harvest. Where borers are a problem ensure that all the stalks are removed from the field at harvest.
- Regrowth from the final ratoon crop killed with a herbicide; field replanted with minimum tillage. Ensure minimum soil disturbance in ratoon crops; minimum tillage improves soil health, including the suppression of pathogenic nematodes, and an increase in earthworm populations.
- Rotation or fallow cropping with a legume improves the nitrogen level in the soil and can reduce the numbers of pathogenic nematodes. A rotation with soybean increases the numbers of beneficial nematodes.
- Flooding fields for short periods.

Box 9.3 Biological inputs that contribute to IPM in sugarcane

- Biological control through **augmentative** or **inundative** release of pathogens, predators and egg, larval and pupal **parasitoids**.
- Adoption of practices that enhance the build-up of existing populations of natural enemies – e.g. growing flowering plants to provide nectar for parasitoids and predators. Development of buffer zones around fields.
- Use of biopesticides – e.g. formulations of *Bacillus thuringiensis* and *Metarhizium anisopliae*, and preparations based on products from the Neem tree, *Azadirachta indica*.

Box 9.4 Chemical inputs that contribute to IPM in sugarcane

- Chemicals that disrupt insect behavior - e.g. **pheromones**.
- Conventional pesticides – Those used to control pests in sugarcane include, for example (WHO (2010) recommended classification):
  
  **Ia** Extremely Hazardous - e.g. aldicarb, ethophosphos.
  **Ib** Highly Hazardous - e.g. carbofuran, endosulfan, fenamiphos, furfural, oxamyl.
  **II** Moderately Hazardous - e.g. chlorpyrifos, cypermethrin, esfenvalerate, fipronil, imidacloprid, lambda-cyhalothrin.
  **III** Slightly Hazardous - e.g. *Bacillus thuringiensis*.
  Active ingredient unlikely to present an acute hazard - e.g. tebufenozide.
- Use of geo-referenced satellite imagery to detect specific areas requiring treatment with pesticide. This can lead to a large saving in pesticide use (Anon 2010a).
9.1.2 Pesticides

Hazards associated with pesticides
Pesticides are poisonous. Across the world millions of farmers and farm workers suffer from pesticide poisoning each year. The consequences of acute pesticide poisoning range from transient symptoms, such as nausea and headaches, to death. Poisoning usually occurs as a result of ignorance of the hazards associated with pesticides, ignorance of or disregard for the procedures to be followed when using pesticides, lack of adequate protective gear and poor spraying equipment (Lehtonen and Goebel 2009; World Bank 2010). Poisoning can take place by dermal (skin) absorption, by ingestion or by inhalation. Dermal poisoning often occurs when diluting a liquid concentrate or loading knapsack sprayers, or from spillage from a leaking knapsack. Droplet size plays an important role in determining the efficacy of the treatment. Conventional knapsack sprayers are relatively inefficient, producing a range of droplet sizes; those that are too small drift away from the target, those that are too big run off the plant. In both situations the environment is at risk. Low volume and ultra low volume sprayers are more efficient and enable larger areas to be treated more quickly. Drift from these low volume sprayers can be reduced by using improved nozzle technology which reduces the number of smaller droplets (Leslie 2010). Low volume sprayers do, however, require more careful calibration and are thus more susceptible to errors (World Bank 2010). Aerial spraying or dusting enables large areas to be treated in a short time. However, wind drift is a common occurrence, resulting in environmental contamination, poisoning of non-target organisms and human exposure.

Classifying pesticide hazard
According to the hazard level classification of the World Health Organization, pesticides are placed in five groups based on their toxicity (Box 9.4). The classification represents the acute (immediate) risk to health, by poisoning, that might be encountered accidentally by any person handling the product in a competent manner (WHO 2010). Very toxic chemicals are more hazardous and carry with them a greater risk of poisoning than those that are less toxic. However, the risk of poisoning can be reduced (Box 9.5). Thus, granular formulations pose less risk to the user than liquid formulations. Application of a pesticide to the soil surface carries with it a greater risk of poisoning non-target organisms and to the environment, than applying the chemical below soil level and covering it; aerial application of a pesticide poses a greater risk to health and the environment than ground application.

Box 9.5 Hazard and Risk
When considering the danger of poisoning from pesticides, a distinction is made between hazard and risk. According to the FAO’s Code of Conduct, ‘hazard’ means the inherent property of a substance, agent or situation having the potential to cause undesirable consequences (e.g. properties that can cause adverse effects or damage to health, the environment or property). ‘Risk’ is a function of the probability of an adverse health or environmental effect, and the severity of that effect, following exposure to a pesticide (FAO 2010).

Reducing risk
The selection of pesticides as a risk reduction tool is most important. Preference should be given to pesticides that are target-specific, that degrade rapidly into innocuous metabolites after use and that are of low risk to humans and the environment. When applying a pesticide the risk of human poisoning and the risk to the environment can be reduced by adopting basic, good management practices, such as proper training of the people handling the pesticides, following the procedures stated on the product label, wearing appropriate protective clothing and ensuring that the pesticide
appliances are of a suitable design and are working correctly (FAO 2010). It is of concern that these
are not always available in some developing countries (Weinberg 2010).

Certain decision support programs can be used to assess risk levels. For example the IPM Institute of
North America has designed an online Pesticide Risk Mitigation Engine (PRiME) (IPM Institute 2010).
PRiME is designed to evaluate pesticide risk using site-specific information to assess and reduce the
potential threat to workers and terrestrial and aquatic fauna, and evaluate options for reducing the
risks. The emphasis is to assess risk rather than hazard, thus encouraging a better assessment of the
conditions required for safe, effective pesticide use. Another program called PRIMET, an acronym for
Pesticides Risks in the tropics to Man, Environment and Trade, has been developed specifically
to provide estimates of the acute and chronic risks of pesticide application to aquatic and terrestrial life
in tropical environments (Peeters et al. 2008).

9.1.3 Steps in managing a pest problem

Through Extension Networks, Farmer Field Schools or a farmer participatory training approach, all
those involved in field activities must be trained to recognize pests (and diseases) (World Bank 2010).
These include cane growers, farm workers and extension staff. Through the same networks, an
awareness must be created of all the various integrated management options that are available to
limit the damage caused by pests.

Economic threshold

Central to managing a pest problem is knowing the size of the pest population and whether or not
control is advisable. This is done by conducting surveys to assess pest numbers, either as per unit of
cane (e.g. white grubs per stool, borer larvae per stalk) or number per area or volume of soil, or as
the degree of damage caused (e.g. % internodes bored, % stalks bored). The information is used in
conjunction with the Economic Injury Level (EIL) and Economic Threshold (ET) for the pest species
(see Box 9.6).

The EIL and ET can be obtained from the local agricultural research institute or from published
information. Where an EIL is not known, growers must conduct their own crop loss studies to
determine the loss caused by the pest and the cost of control. A very basic approach is to select two
similar fields, each with, initially, similar populations of the pest. One field is then treated with a
pesticide (or other remedial practice), the other left as a control. The yield benefit (i.e. the
commercial value of the difference in yield between the treated and untreated crops) of the
pesticide treatment must be compared to the cost of purchasing and applying the pesticide. If the
cost equals the monetary benefit, the initial pest density (or damage level) in the treated field is
taken as the EIL. Although the ET can be calculated, it is typically taken to be between 50% and 90%
of the EIL, depending on the particular pest. More precise estimates of the EIL and ET are derived
from numerous such comparisons covering a range of pest levels and conditions. The ET is always
lower than the EIL to allow for sufficient time to carry out control measures. If the survey data show
that the pest population has reached the estimated ET, the grower is advised to timeously apply the
most appropriate economic control measures.

Box 9.6 Economic threshold and economic injury level

The economic threshold (ET) is defined as, ‘the population density at which control action
should be initiated to prevent an increasing pest population (injury) from reaching the
economic injury level (EIL), which is the lowest population density that will cause economic
damage’. Although usually measured in insect density, the ET is actually a time to take
action, i.e. numbers are simply an index of that time. Some workers refer to the ET as the
‘action threshold’ (Pedigo 2007).
Cane growers should routinely adopt and integrate environmentally friendly cultural practices that reduce pest numbers (see Boxes 9.1 to 9.3), and should be discouraged from using chemical control except as a last resort.

Structures must be set in place to proactively prevent new pest incursions and deal with them as soon as they occur (e.g. Sallam and Allsopp 2008). For assistance with identification of pest species, growers should contact their local agricultural research institute or CABI at http://www.cabi.org.

Everyone involved with the use of pesticides (at all levels of the supply chain and the end-user), must be properly trained in their use, handling, storage and disposal, to minimize risks to themselves, the community and the environment. Government and independent, non-government organizations play an important role in monitoring the pesticide industry and ensuring appropriate enforceable legislation with regard to labelling, transport, safe handling, storage, use and disposal of pesticides according to FAO recommendations. For more detail, see FAO (2001a and b), International Finance Corporation (2007), Lehtonen and Goebel (2009), World Bank (2010) and Chapter 12 in this manual.

The future demands that progressively less reliance is placed on poisonous chemicals to control pests. Those that are used must be incorporated with other pest management practices that are socially and environmentally appropriate – notwithstanding the need for the farming enterprise to remain profitable. This is an ongoing challenge. The World Bank (2010) provides guidelines as to when pesticide use does and does not fit in with an integrated pest management approach. This information is used by the World Bank when deciding on the merits of financing the purchase of pesticides (see Box 9.7).

**Practices that can increase a pest problem**

There are some on-farm activities that can exacerbate a pest problem. For example, ploughing out the stools of the old ratoon crop, and ploughing and disking the entire field to achieve a fine tilth prior to planting, reduces the numbers of soil dwelling predators (not to mention the negative effect on the health of the soil). Also, soil disturbance favors populations of pathogenic nematodes. Another detrimental activity is burning the trash at harvest. This has many adverse effects, (see Chapter 13), including killing off natural enemies of sugarcane pests. Also, nematode communities are more pathogenic in soils where there is no trash blanket (Stirling 2008). However, in some situations, cutting the cane without burning and retaining the trash to form a mulch, may not be a viable option, because of resistance from the cane cutters or the additional cost involved. Also, a trash blanket can have a detrimental effect on regrowth of the ratoon crop in cold and wet conditions and may exacerbate problems from armyworms (Kingston et al. 2005; see section 9.5).

Besides being used to rank the perils associated with pesticides, ‘hazard’ is used to rate the ‘inherent property of a situation having the potential to cause undesirable consequences’ (see Box 9.5). Thus, following from the previous paragraph, using a herbicide to kill off the regrowth of the last ratoon has less effect on the health of the soil (is less hazardous to the environment) than ploughing out the old stools. Also it is less hazardous to the soil dwelling predators. Similarly, burning the field before harvest is a hazard to the natural enemies of pests.

The risk associated with the hazard can be reduced by modifying the action. Thus, in some areas, an early morning ‘cold’ burn of dew-sodden cane is less of a hazard to the environment than a late afternoon ‘hot’ burn of cane when the trash is dry, but presents problems from atmospheric inversion (Kingston et al. 2005).
The following sections give an outline of some of the important pests of sugarcane, examples of practices used to control them and the potential hazard and risk to the environment when adopting these practices. Good management practices are identified as those having the least effect on people, non-target organisms and the environment whilst maintaining, or improving, the economics of sugarcane production.

9.2 Stalk borers

Moth borers, known as shoot, top and stem or stalk borers, depending on which part of the sugarcane plant is most damaged by the caterpillars, are, together, the most important insect pests...
affecting sugar industries around the world – a notable exception are the white grubs of Australia. Besides the lepidopteran larvae, a few borers are grubs of coleopterans (Leslie 2004). The life cycles of moth borers are similar. Eggs are laid on the crop. Upon hatching the neonate larvae disperse. Some initially feed on the leaves before boring into the stalk. The part of the stalk where they enter and feed differs and is generally a characteristic of the species. The larvae grow and moult several times before pupating, with or without a cocoon, within or on the stalk, or in the soil. The adults emerge to mate. The life cycle is completed in about 1 to 2 months, depending on the species and climate.

The damage is caused by the larvae feeding and tunnelling within the stalk. This reduces the mass of cane and the recoverable sucrose per unit mass of millable cane. Additional losses result from microbial infections within the borings, death of young shoots where the meristem is damaged and breaking or lodging of bored stalks.

9.2.1 Top borer, Scirpophaga excerptalis

Biology
The top borer, Scirpophaga excerptalis, is a major pest of sugarcane in many parts of India and is widely distributed in the Far East. Female S. excerptalis lay their eggs in masses on the lower surface of the leaves. The neonate larvae tunnel into the midrib of the youngest leaves. As they develop they feed on and kill the growing point of the shoot, creating dead-hearts and reducing tillering. Other symptoms include characteristic ‘shot holes’ on the leaves and red tunnels in the midrib of the leaves caused by the mining activity of the larvae. S. excerptalis passes through five generations, the most damaging being the third. Infestations are greater when high temperatures are associated with intermittently high rainfall and humidity. Also, the incidence of S. excerptalis increases as levels of soil nitrogen increase (Sallam and Allsopp 2008).

Crop loss
In India damage caused by the borer can result in a 51% reduction in cane yield and a 2.0 unit reduction in sucrose content.

Figure 9.1. Scirpophaga excerptalis larva in the growing point and female S. excerptalis (photos: NS Sallam and PG Allsopp, BSES, Australia).
Control strategies

Biological control: Populations of *S. excerptalis* are naturally held in check by egg parasitoids (*Telenomus* species), late instar parasitoids (species of *Rhaconotus* and *Isotima*) and pupal parasitoids (species of *Stenobracon* and *Xanthopimpla*). The failure of neonate larvae to gain access into the plant is also an important mortality factor (Sallam and Allsopp 2008). Large-scale control of *S. excerptalis*, and other borers, was achieved in Pakistan following inundative releases of *Trichogramma chilonis* over several thousands of hectares (Ashraf and Fatima 1996).

Cultural practices: In India, intercropping plant cane with various cash crops, including black cumin, coriander, fenugreek, fennel, garlic, methi, onions, radishes, sunflower and turnips, reduced the incidence of *S. excerptalis*. Damage was much lower in crops planted in late spring than when planted in autumn. Early maturing cultivars were more susceptible to borer infestation than late-maturing cultivars. The collection and destruction of borer egg masses and adults of the first and second generations is a common and effective method of control in India; combined with the removal of infested shoots, numbers of the third generation were reduced by 50%. This method is also cheaper than using an insecticide. Integrating the hand collection and destruction of egg-masses of the first and second generations with treatment with carbofuran and the subsequent release of *Trichogramma chilonis* and *T. japonicum* at 50,000 adults/ha per week during the third generation, increased cane yield by 18% (Sallam and Allsopp 2008).

Pesticides: The incidence of the borer was reduced following treatment with endosulfan (WHO hazard class II) and cane yield increased following treatment with phosphamidon (WHO hazard class Ia). Treatment with neem based products in India and Bangladesh reduced top borer incidence. ‘Neem’ is the common name of *Azadirachta indica*, a tree with insecticidal and insect repellent properties, widely grown in eastern tropical regions. Table 9.1 includes the practices used to control *S. excerptalis* and the impact they have on the environment.

9.2.2 Sugarcane stem borers, *Diatraea* species

Biology

Several species of *Diatraea* are important pests in the sugar industries in southern USA, the Caribbean, Central America, and the warmer portions of South America south to northern Argentina. The most widespread and common is *D. saccharalis*. Female *D. saccharalis* lay their eggs on the underside of the leaves in the upper part of the canopy. After hatching the neonate larvae feed on the young unfurled leaves and later bore into the young internodes near the meristem. This can lead to the death of the shoot, visible as dead-hearts (Hall et al. 2007). Damage by *D. saccharalis* is greater in vigorously growing cane (White et al. 2010). As with other borers most crop damage results from the older larvae tunnelling within the stalk. Besides reducing stalk mass and sucrose content, bored stalks may break or lodge.}

![Figure 9.2. Larva of *Diatraea saccharalis* parasitized by *Cotesia flavipes* (photo: HN de Oliveira, Brazil) and adult *D. saccharalis* (photo: W White, USDA).](image-url)
Crop loss

*D. saccharalis* is the most destructive insect attacking sugarcane in Louisiana. Annual losses in sugar yields average 20% in fields where season-long infestations are not kept below the economic threshold level (Legendre 2001).

**Control strategies**

**Biological control**: *South America*: Biological control is widely used to control stalk borers. In Brazil, *D. saccharalis* populations are contained by the braconid larval parasitoid, *Cotesia flavipes* and damage levels are kept below 2% (Sampaio 2009; Meyer et al. 2011). The effectiveness of this parasitoid is such that it is regarded as one of the best examples of classical biological control in Brazil. The combined releases of *C. flavipes* with the egg parasitoid, *Trichogramma galloi*, provides additional control of *D. saccharalis* (Botelho et al. 1999). Two tachinid fly parasitoids, *Lydella (=Metagonistylum) minense* and *Paratheresia claripalpis*, also contribute to the control of the borer in Brazil and Colombia (Rossi and Fowler 2003; Leslie 2004). *P. claripalpis* is the main parasitoid of *D. saccharalis* in Argentina (Willink et al. 1991).

*North America*: *D. saccharalis* is one of the most important insect pests in Florida. Variable control is achieved with *C. flavipes* and another wasp parasitoid, *Alabagrus stigmatera*. Augmentative releases of *C. flavipes*, reared in the laboratory, have been very effective in controlling the borer (Hall et al. 2007). Regular scouting is advised to assess borer levels as well as levels of parasitism by the parasitoids. If borer levels are near the economic injury threshold of two to three larvae per 100 sampled stalks, but more than 50% of the larvae are parasitized, then insecticides are not recommended (Hall et al. 2007). However, where the levels of parasitism are lower, the application of an insecticide is recommended. In Louisiana attempts to use *C. flavipes* to control *D. saccharalis* have failed, seemingly due the absence of suitable cues for the parasitoids in the young tillering cane (White et al. 2004).

**Cultural practices**: Growers are advised to plant borer-free seedcane of cultivars with resistance to *D. saccharalis*. This can be almost as effective as using an insecticide, except when borer populations are high (Bessin et al. 1990). Large areas planted to borer susceptible cultivars increases the risk of a pest outbreak (Legendre 2001). As maize is a good host of *D. saccharalis*, it should be planted far away from cane fields to reduce mid-summer infestations of moths migrating from senescing maize fields.

In both Louisiana and Florida, fire ants, spiders, ground beetles and earwigs are valuable natural control agents. To reduce the risk of poisoning them, insecticides should not be used to control the first generation borer infestations which occur in spring; crop injury from this generation is of no economic importance. Many of the overwintering larvae in the stubble, remaining from the last ratoon, can be killed by ploughing out the stools as quickly as possible after the final harvest (Legendre 2001). However, excessive tillage has adverse effects on soil organic matter, soil structure and the soil fauna, and should be avoided (Kingston et al. 2007).

**Pesticides**: The chemicals registered for use against *D. saccharalis* in Florida range from those that are highly hazardous (cyfluthrin and carbofuran), to moderately hazardous (esfenvalerate and lambda-cyhalothrin) and to one that is unlikely to present an acute hazard to humans, tebufenozide. This is an insect growth regulator that mimics the action of the insect moulting hormone, ecdysome. Lepidopteran larvae exposed to the chemical cease to feed and undergo a lethal, unsuccessful moult (WHO 2010). Also registered is a formulation containing *Bacillus thuringiensis* subsp. *kurstaki*, classified as group III Slightly Hazardous (WHO 2010). The chemicals labelled for borer control in Louisiana are cyfluthrin (WHO hazard class Ib), esfenvalerate (WHO hazard class II), and tebufenozide.
9.2.3 African sugarcane borer, *Eldana saccharina*

**Biology**

The African sugarcane stalk borer, *Eldana saccharina*, is indigenous to areas of sub-Saharan Africa. In South Africa, it was first reported in 1939 and is now the most serious insect pest of sugarcane in the country, affecting mostly cane quality. Extensive damage by this borer can result in consignments being rejected when they arrive at the mill. Where particularly heavy infestations occur the entire crop can be lost. Mated females lay about 400 eggs, in batches, in cryptic positions on or near the base of the sugarcane stalks. After hatching the neonate larvae disperse and bore into the stalk. Most of the damage is caused by the later instar larvae as they feed on the internal tissues of the lower part of the stalk. The larvae are able to bore through the nodal plate and hence can damage several internodes. The damage is exacerbated by the red rot fungus, *Glomerella tucumanensis*, that infects bored tissues and reduces cane quality. Pupation occurs with or without a cocoon, usually in or on the bored stalk. The life cycle is completed in about 8 weeks and overlapping generations occur.

**Crop loss**

The loss caused by *E. saccharina* is estimated to be about R150 000 000 per year (Goebel and Way 2007). Additional losses are incurred as a result of growers having to harvest cane before it is fully mature to avoid the large increase in infestation rates that occurs in older cane (Atkinson and Carnegie 1989; Ramburan et al. 2009).

**Control strategies**

**Biological control:** Whereas biological control with parasitoids provides effective control of many of the world’s sugarcane borers, this is not so with *E. saccharina*. Despite considerable research to find suitable parasitoids, none has been successful (Conlong 1997, 2001; Conlong and Rutherford 2009).

**Cultural practices:** Damage from *E. saccharina* can be reduced by avoiding high levels of soil nitrogen and low levels of silicon, both of which favor the borer (Anon 2005; Keeping and Meyer 2006). The risk of an *E. saccharina* outbreak in South Africa is reduced as populations are monitored by the survey teams of local pest, disease and variety control committees (LPD&VCCs). These committees are legally constituted bodies with the authority and power to enforce regulations concerning pests, diseases and varieties in each region or mill area (Anon 2005). LPD&VCCs have the right to (1), enter a grower’s land to perform their function; (2) issue orders for remedial action to reduce the threat of a pest or disease outbreak, e.g. destruction of infested or diseased cane that might affect adjacent growers’ production, including out of season cane with excessive levels of *E. saccharina*; (3) ensure that only approved cultivars are grown in their particular region and (4) monitor and approve all grower seedcane nurseries (McFarlane and Maher 2008). The monitoring by the LPD&VCCs is integrated with several practices to reduce numbers of *E. saccharina* (Anon 2005). These are included in Table 9.1 and rated according to their relative hazard and risk to the environment. Note that the relative hazard and risk levels are compared within the table and are not necessarily directly comparable with the levels in other tables.

The female moths of *E. saccharina* preferentially lay their eggs on maize plants. Research indicates that planting genetically modified maize producing *Bacillus thuringiensis* toxin (*Bt*-maize) as a trap crop adjacent to cane fields is an effective way of reducing borer numbers in cane (Keeping et al. 2007). In addition, planting *Melanis minutiflora* around the field perimeter to repel *E. saccharina* is also effective in suppressing numbers. *M. minutiflora* also suppresses *Cynodon dactylon*, which is a...
serious invasive creeping grass (Conlong and Rutherford 2009). Although these methods of controlling *E. saccharina* are still in the experimental phase and thus have limited adoption, they appear promising management options with no adverse effects on the environment.

**Pesticides:** In South Africa the sugar mills are closed between December and April. This means that crops that are 10 months old in December can only be harvested when they are 14 or 15 months old. Such ‘carry-over’ cane is particularly susceptible to *E. saccharina* (Atkinson and Carnegie 1989). Chemical control with alpha-cypermethrin (WHO hazard class II insecticide) is used in sugarcane fields that will be ‘carried over’ the summer period. The chemical is applied to the cane by mistblower, or by air, on several occasions in spring, when moths are most active, and prevents the build-up of the borer in carry-over cane. Cane with damage levels above a minimum threshold may not be carried over and must be harvested before the end of the milling season. Use of the insecticide enables a greater area of cane to be carried over than would otherwise be possible. Cane to be carried-over need not necessarily be treated with insecticide: (1) where damage levels are low; (2) if it is a resistant variety; and (3) if the crop is unlikely to experience moisture stress (Leslie 2003; Leslie *et al.* 2006).

### 9.2.4 Other stalk borers

Several species of *Chilo* are important pests of cane in the Far East, Australasia, Madagascar, Mauritius, Reunion and Africa. Whereas species of *Diatraea* are confined to the New World, *Chilo* occurs only in the Old World. On Reunion Island, *C. sacchariphagus* is controlled through inundative releases of the egg parasitoid, *Trichogramma chilonis* (Goebel *et al.* 2010). Outbreaks of *C. tumidicostalis* in Thailand were contained by augmentative releases of *Cotesia flavipes* (White *et al.* 2007). *C. sacchariphagus* was recently found on sugar estates in central Mozambique and poses a serious threat to the neighboring South African sugar industry. Indigenous parasitoids were common in the eggs of the borer, but not in larvae or pupae. The pupal parasitoid, *Xanthopimpla stemmator*, was released in the sugar estates in 2001 and is now established (Way and Turner 1999; White *et al.* 2007).

*C. auricilius, C. infuscattellus* and *C. tumidicostalis* are important pests of cane on the Indian subcontinent. Recommended control measures for *C. infuscattellus* include trash mulching, removing and destroying the dead hearts, release of a **tachinid** parasitoid, *Sturmiopsis inferens*, and the use of soil applied granular insecticides, carbofuran or chlorpyriphos, and leaf applied liquid insecticides, gamma HCH, endosulfan or chlorpyriphos (Anon 2008). In Pakistan, control of the borers *C. infuscattellus* and *Emmalocera depressella* was achieved by inundative releases of *T. chilonis* (Ashraf and Fatima 1996).

The **lesser sugarcane borer**, *Chilo agamemnon*, is a significant pest of sugarcane in Egypt, causing an estimated loss in yield of sucrose of between 15 and 20%. It is controlled by the inundative release of large numbers of laboratory reared *Trichogramma evanescens*, a **hymenopteran** egg parasitoid. Effective control is achieved by releasing 100 000 individuals/ha, on three to five occasions at 10 day intervals (Tohamy 2008).

The **Mexican rice borer**, *Eoreuma loftini*, is a serious problem in the sugar industries of Mexico and Texas, and now poses a serious threat to cane production in Louisiana. At present the only way to reduce crop damage caused by *E. loftini* is by growing resistant cultivars (Showler and Castro 2010). In collaboration with BSES in Australia, an integrated contingency plan has been developed detailing the steps to be taken following an incursion of the borer in Louisiana (White *et al.* 2007).
The lesser cornstalk borer, *Elastomopalus lignosellus*, is a sporadic but destructive pest of sugarcane in several countries including Cuba, Argentina, Brazil, Venezuela, Mexico and the USA. It is associated with poor, sandy soils, dry conditions and high temperatures. In Argentina considerable damage from the borer can occur during the tillering stage of sugarcane. Irrigated crops and those following a green-cane harvest, may suffer almost no attack, while as many as half of the shoots may be attacked under conventional practices. Sugar yields may be reduced by 55 % (Salvatore et al. 2007).

The noctuid moth borer, *Sesamia grisescens*, is one of the major constraints to sugar production in Papua New Guinea. When borer levels are high the cane is sprayed with the WHO hazard class II insecticide, lambda-cyhalothrin. At lower borer levels control is achieved with the release of the parasitoids *Pediobius furvus* and *Cotesia flavipes*, and roguing of infested cane (Kuniata et al. 2001).

The sugarcane longhorn stem borer, *Dorysthenes buqueti*, is a major pest attacking sugarcane in Thailand. A closely related species causes damage to cane in Indonesia. In Thailand severe damage, caused by the beetle grubs feeding on the cane setts and stool, results in widespread crop loss, with sucrose yields reduced by as much as 46% in the plant crop and 57% in the following ratoon (Pliansinchai et al. 2007). The eggs are laid in the soil near the cane plant. The hatched larvae bore into the base of the stalks and into the lower internodes, causing extensive damage. There are 8-9 instars, the most destructive being the last. The mature larvae are large, reaching a size of about 70 mm in length and 12 mm in width. After about a year the larvae pupate inside a mud chamber and one to two months later the adults emerge. Control is by means of endosulfan and fenobucarb, both moderately hazardous WHO class II pesticides, and the use of resistant or tolerant cultivars. Grub populations are naturally controlled by entomopathogenic fungi, *Metarhizium anisopliae* in Thailand and *M. flavoviride* in Indonesia (Sallam 2009).

The sugarcane weevil borer (*Rhabdoscelus obscurus*) is common in Australia and Papua New Guinea. The larvae bore into the lower part of the stalk, particularly where previous damage has occurred. Affected stalks are lighter and the associated fungal infection that occurs reduces sugar content and quality. Infestations can be reduced through good field hygiene, including the removal of cane residue from fields and cutting cane close to the ground. Resistant cultivars should be used where the weevil borer is prevalent. The insecticide, fipronil, rated moderately hazardous, is recommended when borer numbers are high or to protect susceptible cultivars (Allsopp et al. 2000).
Table 9.1. Environmental hazard and risk levels associated with management practices used to control sugarcane stalk borers.

| Management practices with the greatest environmental hazard and risk | • Aerial or ground application of pesticides rated as extremely hazardous (cyfluthrin and phosphamidon); highly hazardous (alpha-cypermethrin, carbofuran and endosulfan); or moderately hazardous (chlorpyrifos, esfenvalerate, fenobucarb, fipronil, gamma BHC and lambda-cyhalothrin).  
• Ploughing out the stubble and regrowth from the last ratoon to kill off overwintering larvae of D. saccharalis.  
• Burning the trash on the cane at harvest (although this may be justified where E. saccharina infestation levels are very high).  
• Spray application based on schedules and/or not cognizant of climatic conditions. Spray applications close to rivers, dams or habitation. |
| Management practices that present a hazard, but the risk to the environment is lower | • Ground application of pesticides. This carries less risk of environmental pollution than aerial application.  
• When spraying insecticides the risk of drift onto non-target areas is decreased if wind speeds are low. Also, risk is reduced if the chemicals are not applied when conditions favor runoff, during rain, or during temperature inversions.  
• Aerial or ground application of insecticides that are rated by the WHO as unlikely to present an acute hazard (e.g. tebufenozide).  
• Application of the biopesticide, Bacillus thuringiensis subsp. kurstaki and insecticidal products derived from the neem tree (Azadirachta indica). |
| Management practices likely to be both sustainable and have the least effect on the environment | • Scout cane fields to assess borer infestation levels. Ensure that stalk borer populations do not exceed designated thresholds.  
• Augment natural biological control with inundative releases of egg, larval and pupal parasitoids.  
• Manually remove eggs from leaves and remove infested shoots.  
• Plant cultivars resistant to borers; avoid large contiguous areas planted to borer-susceptible cultivars, especially in soils where moisture stress is common.  
• Plant with borer-free seedcane. Use hot water treated seedcane if necessary.  
• Intercrop with food crops.  
• Adopt practices that conserve soil moisture.  
• Avoid high levels of nitrogen in high risk situations.  
• Treat silicon deficient fields with a Si amendment. Avoid high N:Si ratios.  
• Pretrash standing cane to reduce borer numbers.  
• Harvest cane without burning and retain the trash as a mulch.  
• Remove all stalk material from the harvested field.  
• Kill regrowth from last ratoon with glyphosate herbicide and replant the field using minimum tillage.  
• Plant insect repellent plants around field perimeter to repel invading moths.  
• Use trap crops, e.g. Bt-maize adjacent to cane fields for E. saccharina, but avoid planting conventional maize close to cane fields. |

9.3 White grubs

White grubs occur in all sugarcane industries. The grubs are the larvae of numerous beetle species from several families; they feed on the roots of the cane and can cause extensive damage. As they are underground, the damage often goes unnoticed until marked symptoms appear in the crop – typically, patchy development of stools. The management options for white grub control and the impact that these procedures have on the environment is illustrated by those used for the control of white grubs in Australia.
9.3.1 Canegrubs in Australia

**Biology**
In the Australian Sugar Industry, white grubs, known locally as canegrubs, are the most important insect pests. They are the larvae of a number of endemic scarab species; the most damaging being the greyback canegrub, *Dermolepida albohirtum*. Other important species are *Lepidiota consobrina*, *L. negatoria*, *L. frenchi*, *Antitrogus consanguineus* and *A. parvulus* (Allsopp 2010). The life cycle is completed in one or two years, depending on the species. The larvae pupate in the soil. After emerging from the pupae, the adults leave the soil to mate. Female beetles return to the soil to lay their eggs. There are three larval stages, the most damaging being the third instar (Hunt *et al.* 2001; Allsopp *et al.* 2002). Their feeding destroys the roots, which results in reduced uptake of water and nutrients, leading to wilting and yellowing of the leaves, poor growth and, without proper anchorage, lodging of tall cane. Severe root damage can also result in the removal of whole stools by the mechanical harvesters (Allsopp *et al.* 2000).

**Crop loss**
The annual cost of canegrubs is estimated to be between A$15 and 22.5 million, though in a bad year losses can be double this amount. The values exclude the additional expense of having to prematurely replant fields as a direct result of grub damage (Garside *et al.* 2000; Hunt *et al.* 2003).

![Figure 9.4. Left to right: Adult greyback canegrub, *Dermolepida albohirtum*, White grub, Bundaberg, Australia and Canegrub infested with *Metarhizium anisopliae* the ‘active ingredient’ of the bioinsecticide ‘Biocane’ (photo: BSES, Australia).](image)

![Figure 9.5. Extensive damage caused by cane grubs (photo: BSES, Australia).](image)
Control strategies

Biocontrol: The bioinsecticide, Biocane, a formulation of the fungal pathogen *Metarhizium anisopliae*, is used in low to medium risk plant cane fields (e.g. late planted fields and areas where grub problems have not occurred). Control may persist through to the second ratoon (Allsopp 2010).

Cultural practices: Grub tolerant cultivars should be used when replanting fields previously affected by cane grubs. Grub numbers decline in undisturbed soil, so soil disturbance should be kept to a minimum in the transition from destroying the last ratoon crop and replanting the field. A herbicide should be used to kill the old crop and the seedcane planted with minimum soil disturbance. Notwithstanding the foregoing, intensive preplant tillage can reduce grub numbers, but this does not persist through to the ratoon crops. Since Childers beetles (*A. parvulus*) do not disperse widely from where they emerge, tillage can be effective against this species (Allsopp *et al.* 2000). Grub numbers decline after a weed free or legume fallow between cane cropping cycles.

Greyback canegrub beetles prefer to lay their eggs in the soil in fields of taller cane rather than short cane. Crops planted early or harvested early become taller than crops planted or harvested late. Thus early planted or ratooned fields subsequently host greater numbers of grubs and suffer the most damage. Fields or strips of tall cane can be used as traps to divert the egg-laying beetles from more valuable, younger crops. Damage to trap crops can be alleviated by the subsoil application of imidacloprid. Also, harvesting crops according to ratoon number, older ratoons first, will push grub damage into the older and less valuable ratoons that are due to be ploughed out (Hunt *et al.* 2001). Area-wide management of canegrubs requires that the ‘trapped’ grubs are killed, either with an insecticide or by ploughing out the last ratoon. The former may not be economical in an old ratoon, and the latter may be counter-productive as tillage has an adverse effect on the natural predators and pathogens of the canegrubs. Light traps can be used to attract and kill egg-laying females (Allsopp *et al.* 2000; Robertson 2001).

Pesticides: The chemicals used to control canegrubs in Australia are granular formulations of ethoprophos and cadusafos, (rated Ia, extremely hazardous, and Ib, highly hazardous, respectively), and controlled release granular formulations of chlorpyrifos and imidacloprid and a liquid formulation of imidacloprid (both rated II, moderately hazardous (WHO 2010)). Ethoprophos and cadusafos are used as knockdown insecticides when existing grub numbers indicate a high risk of damage (Allsopp 2010). Chlorpyrifos and imidacloprid are applied at planting in fields with a moderate to high risk of grub damage. The pH sensitive formulation of chlorpyrifos should not be used in alkaline soils. Correct placement of chlorpyrifos granules is vital to ensure contact with the canegrubs. Imidacloprid is systemic, so its placement is less critical and it can be applied in a narrow band. This means that imidacloprid can be more easily integrated with minimum tillage practices associated with newer planting systems (Allsopp 2010).

By scouting for grubs and identifying the species present, together with historical records of the risk of grub damage in the field, an assessment can be made as to whether an insecticide is needed, and if so, which one should be used (Allsopp *et al.* 2002; Allsopp 2010). The impact on the environment of practices used to control canegrubs is summarized in Table 9.2. The relative hazard and risk levels should be compared within the table and are not necessarily directly comparable with the levels in other tables.
### Table 9.2. Environmental hazard and risk levels associated with management practices used to control canegrubs in Australia.

<table>
<thead>
<tr>
<th>Environmental hazard and risk level</th>
<th>Conditions</th>
<th>Canegrub management practices</th>
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</table>
| Management practices with the greatest environmental hazard and risk | All soils - fields with high risk of canegrub damage and/or if greyback canegrub is the dominant species | • Subsoil application of pesticides rated as extremely hazardous (ethoprophos); and highly hazardous (cadusafos), in plant and ratoon cane.  
• Deep tillage to kill the regrowth from last ratoon and destroy grubs. |
| Hazard level high, but risk is lower | Soils with pH <6.0 | • The need to use insecticides is minimized by scouting and only resorting to their use if warranted by the grub species, numbers present and historical risk of damage.  
• Application of chlorpyrifos (rated moderately hazardous) buried with cane setts at planting.  
• Subsoil application of insecticide imidacloprid (moderately hazardous) in plant and ratoon cane. |
| Management practices likely to be both sustainable and have the least effect on the environment. | All fields | • Cane harvested without burning. Trash retained as a mulch.  
• Regrowth from last ratoon killed with glyphosate herbicide to avoid soil disturbance.  
• Fields replanted using minimum tillage to enhance populations of natural pathogens of canegrubs.  
• Use of *Metarhizium* bioinsecticide in plant cane fields with moderate to low risk of grub damage.  
• Use of grub tolerant cultivars.  
• Inclusion of a legume crop between cane crop cycles.  
• Light traps used to catch the beetles and thus reduce numbers of egg-laying adults. |

Each of the management practices is not enough on its own to adequately suppress grub numbers. To be effective they must be integrated with other control measures. Successful area-wide control depends on cane growers being aware of these practices and adopting them where appropriate. In turn, this process depends on the spread of information through extension activity. It is estimated that losses from greyback canegrubs were some 80% lower in 2002 following a series of BSES grub control training courses given the year before to cane growers in northern and central Queensland (Hunt *et al.* 2003).

### 9.3.2 Other white grubs and soil insect pests

In Florida the most important white grub is *Ligyrus subtropicus*. It feeds on the roots and stool causing chlorosis of the leaves, stunted growth, lodging and stool death where heavy infestations occur. Control is achieved by: (a) disking infested fields which kills many grubs and exposes others to insectivorous birds; (b) replanting at more frequent intervals (damage is most severe in ratoon crops, but this is costly); (c) in the muck soils, flooding infested fields for several days when water temperature is at or above 25°C (Cherry and Nuessly 2008).

The white grub, *Hoplochelus marginalis* is a major pest of sugarcane on Reunion Island. Control is by the entomopathogenic fungus, *Beauveria brongniarti* (Jeuffrault *et al.* 2004). Another white grub species, *Dasylepida ishigakiensis*, is an important pest in Japan. Rotary tillage reduces the number of larvae in the soil (*Kijima and Tarora* 2010). Seven species of grubs have been reported from South Africa: *Hypopholis sommeri*, *Schizonycha affinis*, *Adoretus fusculus*, *Astinopholis sp*, *Anomola sp*, *Heteronychus licas* and *Maladera sp*. No one species is common to all parts of the industry and some
have a restricted distribution. Deep ploughing of fields to be replanted is recommended where high grub numbers are evident.

Grubs of the longhorn beetle, *Migdolus fryanus*, are a serious pest of sugarcane in São Paulo State in Brazil (Dinardo-Miranda *et al.* 2010). They feed on both the roots and the stool, causing extensive damage. The cane plants become stunted and, without proper anchorage, are easily pulled out of the ground. As a result the crop stand, yield and longevity are drastically reduced. Losses vary from a few tonnes of cane per hectare to, in most cases, the complete destruction of the crop and the corresponding need to replant the field. However, certain attributes of *M. fryanus* reduce its potential to cause even greater losses, viz, the females have a low reproductive capacity (about 30 eggs per individual), which restricts population growth; the larvae are sensitive to physical disturbance, making them vulnerable to ploughing and disking, and females are without functional wings, so spread of the infestations is limited (Anon 2010b). The control of *M. fryanus* is based on three integrated procedures: (1) physical control, by removing the crop and destroying the vulnerable larvae with a mouldboard plow or cane stool-remover, during the cold, dry months when numbers are greatest in the surface layers of the soil; (2) chemical control using endosulfan plus fipronil (both WHO class II insecticides); and (3) cultural control, by using synthetic pheromone traps to attract and kill the male beetles. The traps can also be used to monitor populations and predict outbreaks of the pest (Anon 2010b). Trials show that treatment with fipronil plus imidacloprid may also provide protection against the grubs (Dinardo-Miranda *et al.* 2010).

The sugarcane weevil, *Sphenophorus levis*, is a pest of sugarcane in the Central-South region of Brazil. Damage is caused by the larvae that bore into the stool and, sometimes, the first basal internode. Large cavities are created, leading to stunted growth of the shoots and resulting in annual losses of up to 30% (Anon 2010a; Dinardo-Miranda and Fracasso 2010). Also the longevity of the crop is drastically reduced. Management of the weevil includes mechanical destruction of infested ratoons and the use of the insecticides, carbofuran (hazard class 1b), bifenthrin, fipronil and imidacloprid (all hazard class II) (Dinardo-Miranda *et al.* 2006; Dinardo-Miranda and Fracasso 2010). Soil application of the entomopathogenic fungus, *Beauveria bassiana*, is also effective against *S. levis* (Badilla and Alves 1991).

**Termites** are common pests of sugarcane in many countries. They occur in colonies as different castes: workers, soldiers and reproductives, including a very large, wingless, egg-laying queen. The nests are below ground and may be some distance from cane fields. Damage is caused by the workers feeding on newly planted setts, the base of the stalks and tissues inside the stalks. Dry conditions exacerbate the problem. Chemical control of termites includes imidacloprid (hazard class II) used in a bait and as a treatment at planting. Damage may be lessened by using irrigation to avoid moisture stress (Leslie 2004).

### 9.4 Sap Feeders

The insects of this group fall within the insect Order, Hemiptera. They have piercing and sucking mouthparts. Most feed on the leaves of the sugarcane but some attack the stems, buds or roots. The life cycle is simple and is without a pupal stage. The eggs hatch into nymphs, which resemble the adults, and after several moults they develop wings and become sexually mature; some adults are wingless. The nymphs of most species are relatively immobile, but some have an active crawler stage. By means of their long mouthparts they are able to access and remove large quantities of sap from the plant. The symptoms of damage include wilting and yellowing of leaves. Some species are associated with a black sooty mould produced by a fungus that grows on the honey-dew, the sugar-rich excreta of the nymphs. Several species in this group are regarded as pests primarily because they transmit sugarcane diseases.
9.4.1 Above ground sap feeders

The sugarcane planthopper, *Perkinsiella saccharicida*, is a pest of some importance on sugarcane in a number of countries, in part because it is a vector of the virus that causes Fiji disease. Control has included the use of the insecticides, parathion (WHO hazard class Ia, extremely hazardous), dicrotophos (WHO hazard class 1b, highly hazardous), and HCH and dimethoate (both hazard class II, moderately hazardous). A serious outbreak in Hawaii was controlled by an introduced egg predator, *Tytthus mundulus*, and by local natural enemies (Hill 2008). *P. saccharicida* in Florida is controlled by another egg predator, *T. parviceps*, and by the egg parasitoid, *Anagarus* sp. Numbers of *P. saccharicida* are also kept in check culturally as the occurrence of peak populations coincides with the time the cane is harvested (Leslie 2004).

Sap feeding pest species in Africa and surrounding islands include the coccids, *Saccharipulvinaria iceryi* and *S. elongata*, the armored scale, *Aulacaspis tegalensis*, the tropiduchid, *Numicia viridis* and the aphid species, *Rhopalosiphum pad, R. maidis* and *Hysterneura setariae*. The aphids are important vectors of the sugarcane mosaic virus. In North, South and Central America there are a number of species of sap-feeders that attack sugarcane. The yellow sugarcane aphid, *Sipha flava*, can be a serious pest of sugarcane in Colombia, Ecuador and Florida. In Colombia it is controlled by pirimicarb (hazard class II) and Malathion (hazard class III) and the use of tolerant cultivars. In Florida control is by means of the pyrethroids, lambda-cyhalothrin and gamma-cyhalothrin (hazard class II) (Leslie 2004). The sugarcane aphid, *Melanaphis sacchari*, is of concern in Louisiana as it is spreading and is the main vector of sugarcane yellow leaf virus and sugarcane mosaic virus (White et al. 2007).

The sugarcane scale insect, *Melanaspis glomerata*, the Indian sugarcane leafhopper, *Pyrrillia perpusilla*, the whitefly, *Aleurolobus barodensis*, and the white wooly aphid, *Ceratovacuna lanigera* are among the most important sap feeders of sugarcane on the Indian subcontinent. Each can have a considerable effect on yield. The sugarcane scale, *M. glomerata* is controlled by: (1) the insecticides, malathion (hazard class III) and dimethoate (hazard class II) used as a seedcane dip; (2) using clean seed cane; (3) detrashing the standing cane; and (4) destroying infested crop residues by burning the trash at harvest (Leslie 2004). Originally reliant on insecticides, the control of *P. perpusilla* is now provided by *Epiricania melanoleuca*, a lepidopteran parasitoid of the nymphs of the leafhopper, and by an egg parasitoid, *Parachrysocharis javensis* (Leslie 2004). Other recommendations include avoiding high levels of nitrogen, detrashing the cane, and treatment with monocrotophos (hazard class Ib), endosulfan (hazard class II) or malathion (hazard class II) (Anon 2008). The white fly, *A. Barodensis*, is especially a problem in ratoon crops. Recommended control options include burning the trash from infested fields, avoiding excessive use of nitrogenous fertilizers and treating the cane with fenitrothion (hazard class II) or monocrotophos (Anon 2008). Control options for the white wooly aphid *C. lanigera*, include the release of predaceous biocontrol agents, *Dipha aphidivora*, *Micromus* species and coccinellids, using clean seedcane and spraying affected areas with monocrotophos or with the moderately hazardous acephate, chlorpyrifos or endosulfan (Anon 2008). In Papua New Guinea, the white wooly aphid is controlled by the predatory larvae of a phycitid moth, *Conobathra aphidivora* (Kuniata et al. 2001).

Other above ground sap feeding pests include: the sugarcane lace bug, *Leptodictya tabida*, which is a problem in Florida; the planthopper, *Eumetopina flavipes*, which is a widespread sugarcane pest in South East Asia, and a vector of the Ramu stunt virus, an important sugarcane pathogen; and the sugarcane thrips, *Fulmekiola serrata*, which has recently become a problem in South Africa (Leslie 2005; White et al. 2007).
9.4.2 Below ground sap feeders

**Earth pearls** or margarodes scale insects are pests in Australia, Mauritius and Zimbabwe. In Australia, the damage caused by the pink ground pearl, *Eumargarodes laingi*, can result in a 75% loss in yield. Nymphs form cysts in the soil and feed on the roots, causing stunting of the stalks, yellowing of the leaves and eventually the death of the stalk. Control is achieved by: (1) fallowing infested fields; (2) soil tillage with a plough or rotary hoe; (3) ensuring that grass crops and weeds are excluded; (4) using tolerant or resistant cultivars; and (5) fumigating with metam-sodium (hazard class II) prior to planting. The fumigant reduces earth pearl numbers in the plant crop but unless a resistant cultivar is grown, numbers will increase in the ratoons (Allsopp et al. 2000).

The **spittlebug**, *Mahanarva fimbriolata*, is a serious pest in the state of São Paulo in Brazil. In the past, populations were kept down by the practice of burning the cane at harvest and the absence of a trash blanket. When a change in the law restricted burning, numbers proliferated, leading to the current problem. Eggs are laid in the soil. After hatching, the nymphs feed on sap from the roots, damaging the vascular system and causing root death. The nymphs are enveloped in a ball of spittle produced from anal secretions derived from plant sap. They undergo a number of moults before leaving the soil as adults. The adults also cause damage by injecting toxins into the leaves which affects photosynthesis. Crop injury by the spittlebug adversely affects cane yields and sucrose production, as well as the production of ethanol (Mutton et al. 2007, 2010). Control is by means of insecticides, thiamethoxam and imidacloprid, sprayed around the base of the stalks (Dinardo-Miranda et al. 2008), and the fungus *Metarhizium anisopliae*. In 2008 an estimated 750 000 hectares were treated with *M. anisopliae* for the control of spittlebug species in Brazil (ZengZhi et al. 2010). Treatment with aldicarb and carbofuran both gave efficient control of *M. fimbriolata* (Dinardo-Miranda et al. 2002).

In Argentina the **spittlebugs**, *Tomaspis nonozulia*, *T. australis* and *Tapajosa rubromarginata* have become more of a problem since the adoption of green cane harvesting and drip irrigation (White et al. 2010). In Mexico and Guatemala the **froghopper**, *Aeneolamia postica*, is an important pest. Other species of *Aeneolamia* are serious pests in Belize, Guyana and Trinidad. Control of *A. postica* in Guatemala is achieved with post-harvest tillage, to reduce the number of diapausing eggs in the soil, adhesive traps and the application of strains of the entomopathogenic fungus, *Metarhizium anisopliae* (Leslie 2004; Márquez 2005).

The **sugarcane soldier fly**, *Inopus rubriceps*, and the yellow soldier fly, *I. flavus*, are pests of sugarcane in Australia. The larvae feed on the roots and reduce the yield per crop and the number of economic ratoons. Insecticides are not registered for their control; instead a number of cultural practices are used to reduce their numbers. These include ploughing out infested crops early in the harvest season; planting new crops late in the season to avoid cane being present during the flight period of the adults; minimizing soil disturbance to protect natural predators; and ensuring quick, vigorous ratooning through cultivar choice and the selection of good ratooning conditions when the field is harvested. In addition, since the larvae depend on grasses for food, numbers are reduced by ensuring grass free fallows between crop cycles and, for example, planting a non-graminaceous rotation crop, such as soybean, and ensuring a lengthy fallow period during which no food is available for the larvae in the soil (Allsopp et al. 2000; Samson 2007).

Species of **cicadas** are important pests in Argentina, Australia, Madagascar and Papua New Guinea. In Australia and Papua New Guinea control is achieved by ploughing out infested crops, followed by a bare fallow. The plough-out kills almost the entire cicada population in the soil (Allsopp et al. 2000). In Papua New Guinea it was found that by not using an insecticide aimed at the control of a
stalk borer, the natural enemies increased and reduced cicada populations below damaging levels (Kuniata et al. 2001).

A summary of the environmental impact of management practices to control sap feeders is given in Table 9.3.

Table 9.3. Environmental hazard and risk levels associated with management practices used to control above and below ground sap feeders.

<table>
<thead>
<tr>
<th>Environmental hazard and risk level</th>
<th>Management practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management practices with the greatest environmental hazard and risk</td>
<td>Above ground sap feeders</td>
</tr>
<tr>
<td></td>
<td>Application of extremely, highly, moderately and slightly hazardous insecticides to the cane foliage.</td>
</tr>
<tr>
<td></td>
<td>Above ground application of moderately hazardous insecticides.</td>
</tr>
<tr>
<td></td>
<td>Ploughing out badly infested crops.</td>
</tr>
<tr>
<td></td>
<td>Post-harvest tillage to kill diapausing eggs in the soil.</td>
</tr>
<tr>
<td>Hazard level high but risk is lower</td>
<td>Below ground sap feeders</td>
</tr>
<tr>
<td></td>
<td>Burning infested crop residues at harvest.</td>
</tr>
<tr>
<td></td>
<td>Below ground application of granular formulations of extremely and moderately hazardous insecticides.</td>
</tr>
<tr>
<td>Management practices likely to be both sustainable and have the least effect on the environment</td>
<td>Above ground sap feeders</td>
</tr>
<tr>
<td></td>
<td>Use of predators and parasitoids.</td>
</tr>
<tr>
<td></td>
<td>Use of clean seedcane.</td>
</tr>
<tr>
<td></td>
<td>Avoiding high levels of soil nitrogen.</td>
</tr>
<tr>
<td></td>
<td>Detrashing standing cane.</td>
</tr>
<tr>
<td></td>
<td>Minimal soil disturbance.</td>
</tr>
<tr>
<td></td>
<td>Use of <em>Metarhizium</em> based biopesticide.</td>
</tr>
<tr>
<td></td>
<td>Use of tolerant and resistant cultivars.</td>
</tr>
<tr>
<td></td>
<td>Grass-free fallows between crop cycles.</td>
</tr>
<tr>
<td></td>
<td>Adhesive traps.</td>
</tr>
</tbody>
</table>

9.5 Leaf feeders

**Armyworms and trash caterpillars**

Leaf feeding insects are found on sugarcane throughout the world. The most important pests in this group are the caterpillars of various moths (lepidopterans) and the hoppers and adults of locusts and grasshoppers (orthopterans). The caterpillars of species of *Spodoptera* and *Mythimna* are associated with crop damage in Africa, Asia, Australasia, Malaysia and South America. Species of *Leucania* also occur in Australia. Infestations tend to be more common in fields with a trash blanket. An increase in numbers of *Mythimna* populations occurred in Mauritius following the introduction of mechanized harvesting and the retention of a green cane trash blanket (Ganeshan 2007). The larvae hatch from eggs laid on the host, or in surrounding grassed areas, and move to young cane crops where they feed on the leaves. Complete defoliation can occur but the crop may recover where growing conditions are favorable. Repeated defoliation can lead to a serious loss in yield. Various natural enemies, including parasitoids and pathogens, provide natural control. For example, in Papua New Guinea, *S. exempta* and *M. loreyi* are usually kept in check by tachinid parasitoids (Kuniata et al. 2001). Chemical control is normally not advised as, most often, the damage has occurred before the problem has been recognized. Repeated defoliation plus the presence of young larvae under the trash, positively identified as a defoliating species, may warrant the use of an insecticide. Chlorpyrifos, permethrin and trichlorfon, all WHO hazard class II chemicals, are registered for armyworm in Australia (Allsopp et al. 2000).

Caterpillars of *Mocis* species are also important leaf feeding pests. In Argentina, extensive damage caused by the grassworm looper, *Mocis latipes*, can result in a reduction in the height and weight of the cane plants and a 50% loss in sucrose yield (White et al. 2010). Control methods include removal of alternate hosts by weed control and the use of chlorpyrifos (Salvatore and Willink 2004).
Locusts and grasshoppers
Locusts and grasshoppers are sporadic pests of sugarcane. They feed on the green leaves, and in heavily infested cane the entire blade is consumed, leaving only the midribs. Eggs are laid in pods in the soil. After hatching, the flightless nymphs, known as hoppers, disperse as scattered groups. Where they become crowded and conditions are suitable, they become gregarious and form larger bands, consuming all the vegetation in their path. They moult several times before becoming winged adults which swarm, sometimes in vast numbers. The swarms cause considerable damage to crops. Control of the adults with insecticides is difficult and often not worthwhile. Rather the bands of hoppers should be targeted as they are grouped together and are much less mobile (Allsopp et al. 2000). Insecticides registered for locust control in Australia are chlorpyrifos and diazinon, both WHO hazard class II chemicals. The entomopathogenic fungus, *Metarhizium acridum*, is effective against locusts, though more costly than the standard insecticide treatment.

9.6 Nematodes
Plant feeding nematodes are ubiquitous in farmland and yet most farmers are unaware of their presence. Most are very small, worm-like animals (less than 2 mm in length), and not visible to the naked eye. Life stages include an egg and normally four juvenile stages and the adult stage. The plant feeding nematodes associated with sugarcane are represented by more than 300 species worldwide – the most important being the root-knot nematodes, *Meloidogyne javanica* and *M. incognita*, and the lesion nematode, *Pratylenchus zeae*. Other species are important, such as the dagger nematode, *Xiphinema elongatum*, in Australia and South Africa, *X. mampara*, in South Africa, the sting nematode, *Belonolaimus longicaudata*, in Florida, lance nematodes, *Hoplolaimus* spp, in Burkina Faso and India and stubby-root nematodes, *Paratrichodorus* spp, in several countries. Spiral nematodes, *Helicotylenchus* spp, and stunt nematodes, *Tylenchorhynchus* spp, are commonly found associated with sugarcane in most countries (Cadet and Spaull 2005).

Symptoms of damage
The nematodes feed on the contents of the cells of the roots and, where large populations occur, cause extensive damage and limit the functioning of the root system. Symptoms include reddish-purple or purplish-black lesions on the roots; they become stubby, coarse and brittle; the tips may be enlarged, as discreet galls, or as elongated swellings; the root system is sparse and appears dark (Stirling and Blair 2000; Cadet and Spaull 2005). The above ground symptoms associated with nematode damage include a reduction in the number and length of stalks, the leaf canopy is slow to develop over the inter-row, giving the field a more open appearance, and the young green leaves curl longitudinally and appear spiky. These are also symptoms of drought-stressed cane and are therefore not diagnostic.

Figure 9.6. Soil nematodes and sugarcane roots damaged by nematodes (photos: SASRI).

Crop loss
It has long been known that nematodes are a serious constraint to sugarcane production on sandy soils. However, it is now recognized that they also suppress cane growth on fine textured soils and
have a significant effect on yield (Blair and Stirling 2007; Berry et al. 2008). Estimates of the annual yield losses from nematode damage amount to A$82 million in Australia (Blair and Stirling 2007), R250 million in South Africa (Spaull and Cadet 2003) and up to US $44 million in the USA (Koenning et al. 1999). In South Africa, annual losses over a 4-year period caused by the root knot nematode, *M. javanica*, amounted to a 30% reduction in yield.

These amounts exclude the loss in income incurred from fewer economic ratoon crops, where nematodes are not controlled, and the need to replant more frequently (Cadet and Spaull 2003). On sandy soils additional costs are incurred, as crops affected by nematodes are slow to develop a full leaf canopy, resulting in the need for at least one extra herbicide application (assuming the previous crop was burnt at harvest and there was no trash blanket).

**Control strategies**

**Cultural practices:** Using cultivars that are resistant to or tolerant of nematodes is an effective and cost efficient means of sustaining yields (Spaull and Cadet 2003). Manipulating the dates of planting and ratooning can be used to avoid coinciding the early, vulnerable period of root development with the period of high soil temperatures and peak nematode activity. This may not be suitable when cane grubs are a problem and probably only appropriate in the more temperate regions, where soil temperatures fall below 25°C for a period (Spaull et al. 2005).

Research in Australia showed that (a) changing from the practice of burning the cane prior to harvest, to harvesting the cane green and retaining the trash as a mulch, reduced the numbers of *P. zeae* and *M. javanica*; (b) destroying the regrowth from the last ratoon with a herbicide and replanting using minimum tillage, minimized soil disturbance which in turn suppressed multiplication of *P. zeae*, and other plant feeding nematodes; and (c) rotating sugarcane with a soybean fallow increased the yield of the following sugarcane crop and reduced populations of plant feeding nematodes (Stirling 2008). Other legumes can be used as nematode suppressive rotation crops. Numbers of beneficial nematodes increase following a soybean fallow and under a trash blanket (Cadet 1985; Berry et al. 2007; Stirling et al. 2010).

Damage to young plant cane can be avoided by planting the cane setts in the furrow lined with filtercake, at about 50 kg/ha (Moberly and Meyer 1978), and, where water is available, by irrigating the cane to avoid moisture stress.

**Pesticides:** The most effective control option for reducing the impact of nematodes on sugarcane, but one that poses the greatest hazard to the environment, is the use of a nematicide. Before resorting to chemical control, the cane grower needs to know whether or not nematodes are likely to be a significant constraint to production in a particular field. If appropriate laboratory facilities are available, the risk of yield loss can be assessed from the number of *M. javanica* and/or *P. zeae* in soil samples collected from the field before planting. Significant root damage can be expected, and control options considered, when numbers of one or both species exceed 100 per 200 g of soil (Stirling and Blair 2000). Without laboratory facilities, growers must base their decision on the growth response of young cane treated with a nematicide in test plots within the field (Donaldson 1987).

On sandy soils with large populations of plant feeding nematodes, it may not be possible to grow cane productively without treatment with a nematicide. The chemicals used to control nematodes include aldicarb, carbofuran, ethoprophos, fenamiphos, furfural and oxamyl; all rated as extremely or highly hazardous (WHO 2010). The chemicals are applied in the furrow at planting or, in Australia, at the three to five leaf stage. For chemicals registered for ratoon cane, application is made over the row, or in a furrow drawn alongside the row (Cadet and Spaull 2005).
The impact on the environment of practices used to control nematodes is summarized in Table 9.4. The relative environmental hazard and risk levels should be compared within the table and are not necessarily directly comparable with the levels in other tables.

Table 9.4. Summary of the environmental hazard and risk levels associated with management practices used to control nematodes.

<table>
<thead>
<tr>
<th>Environmental hazard and risk level</th>
<th>Conditions</th>
<th>Nematode management practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practices with the greatest environmental hazard and risk</td>
<td>Sandy soils infested with root knot, lesion, dagger or sting nematodes</td>
<td>On very sandy soils, surface application of aldicarb granules (rated as extremely hazardous) as a band over-the-row of ratoon cane whether originating from a crop that was burnt or cut green at harvest.</td>
</tr>
</tbody>
</table>
| Practices where hazard level is high but risk is lower | As above | • In plant cane: Application of extremely and highly hazardous nematicides, aldicarb, carbofuran, ethoprophos, fenamiphos, oxamyl, or furfural, in the furrow over the setts at planting and covered with soil.  
• In ratoon cane: Application of nematicide in a shallow furrow drawn alongside the cane row and covered with soil.  
• In ratoon cane (irrigated cane only): Application of furfural over the cane row followed by 10 mm irrigation water.  
• Cane rows adjacent to waterways or dams are not treated.  
• Risk is reduced if the chemicals are buried, or irrigated into the soil. |
| Management practices likely to be both sustainable and have the least effect on the environment | All soils with less than 90% sand particles and infested with root knot, lesion, dagger or sting nematodes | • Adoption of green cane harvesting and retention of a trash blanket.  
• Regrowth from the last ratoon destroyed with a herbicide.  
• Use of minimum tillage when replanting fields and avoidance of soil disturbance in ratoon crops.  
• Use of nematode resistant or tolerant cultivars – applies to all soils.  
• Planting with filtercake.  
• On sandy soils scheduling time of planting and ratooning to the period just before or at the onset of cooler conditions.  
• Planting a legume crop (preferably soybean) between cane cycles. |
9.7 Vertebrates

Several species of mammals and a few birds feed on sugarcane. **Rodents** are the most common and can cause considerable damage. They include *Holochilus sciureus* in Central America; *Sigmodon hispidus* in Mexico and Guatemala; *Rattus norvegicus, R. rattus* and particularly *R. exulans* in Hawaii; *S. hispidus, R. rattus* and *Neofiber alleni* in Florida; *Melomys burtoni, M. cervinipes* and especially *R. sordidus* in Australia; *Millardia meltada, Bandicota bengalensis, B. indica and Nesokia indica* in India and *Mus formosanus and Apodemus agrarius* in Taiwan (Leslie 2004). The rodents chew the stalks exposing the internal tissues to infection by bacteria and fungi, which reduces sucrose content, and the stalks may break. Some species, such as *N. indica*, feed below ground causing stool death. Damage may be extensive, with up to 60% crop loss having been recorded in Mexico (Leslie 2004). In Australia, the cost of yield losses resulting from the damage caused by rodents can be as much as A$25 million in a season (Ward 2008).

**Control strategies**

Control of rodents mostly relies on the use of rodenticides applied as baits. The chemicals include zinc phosphide and coumatetralyl (both highly hazardous), and diphacinone and strychnine sulphate (both extremely hazardous) (Leslie 2004). In Australia, zinc phosphide and coumatetralyl are used as baits for *R. sordidus*. They are used in conjunction with cultural practices designed to restrict the protein intake of the females, which limits their reproductive potential. Access to protein-rich seeds is reduced by keeping the fields and their margins weed-free during the breeding season, mowing adjacent grasslands to ensure seed-heads do not develop and encouraging canopy formation in nearby woodland to suppress grasses (Allsopp et al. 2000). Deciding whether poison baits should be used is determined by regular scouting. In Guatemala, the use of poisons is minimized and emphasis placed on eliminating places of shelter, controlling weeds and promoting and protecting raptor activity (Márquez 2005).

A study in Queensland, Australia, showed that the risk of secondary poisoning of raptors feeding on poisoned rats was minimal because (1) the avian predators search open, low canopy areas whereas the rats prefer high canopy cover; (2) baiting protocols require that the baits are not placed in open canopy crops; (3) low levels of rodenticide are used in the sugar industry; and (4) the raptors have a high toxic threshold to the chemicals (Ward 2008).

Other vertebrate pests include: **Vervet monkeys** (* Chlorocebus pygerythrus*), **bushpigs** (*Potamochoerus porcus*) and **hippopotamus** (*Hippopotamus amphibius*) in southern Africa; **feral pigs** (*Sus scrofa*) in Australia (nocturnal and difficult to control); the **wallabies**, *Macropus agilis, M. rufogriseus* and *M. parryi* in Australia (damage only occurs during dry periods); **Asian elephants** (*Elephas maximus*) in West Bengal (an intermittent problem – besides causing damage to cane fields, they can be very dangerous to people); **porcupines** (occasionally a pest of sugarcane in India); the **eastern swamphen** (*Porphyrio porphyrio*) and **sulphur-crested cockatoos** (*Cacatua galerita*) (minor pests in Australia) (Allsopp et al. 2000; Srivastava 2000; Leslie 2004; Kingston et al. 2007; Santra et al. 2008). These pests are mostly sporadic and of localized importance, though affected cane growers can experience serious losses. Control in some instances is achieved by hunting and the use of conventional or electric fences.
9.8 Social, financial and environmental costs of pest control

9.8.1 Social cost of practices used to control pests

An inevitable consequence of humans using poisonous chemicals to control pests is that some individuals will be accidentally poisoned. A recent (2008) World Bank report estimates that 355,000 people worldwide die each year from unintentional pesticide poisoning. An earlier but authoritative study suggests that this figure is a gross underestimate (Weinberg 2010).

In an effort to protect farm workers, communities and the environment from the undeniable and widespread harm caused by hazardous pesticides, especially in developing countries, calls are being made by a number of non-government organizations for a global program of action. Called the Strategic Approach to International Chemicals Management (SAICM), it was adopted in 2006 by a consensus of environment ministers, health ministers and other delegates from more than one hundred governments. It was also approved by representatives of relevant intergovernmental organizations including the World Health Organization, the UN Food and Agriculture Organization and the UN Environment Program. Its goal is to create a world where chemical exposure is no longer a significant source of adverse effects on human health and the environment (Weinberg 2010). To achieve this, it is necessary to restrict the use of highly hazardous pesticides (HHPs) and to identify less dangerous pesticides to do specific tasks within an integrated pest management system.

The HHPs include WHO hazard classes Ia, Ib and II, plus additional pesticides identified by the Pesticide Action Network (PAN) as being the cause of serious health concerns (Weinberg 2010). PAN has compiled a list of more than 390 pesticides that are considered to be HHPs that should be withdrawn (PAN 2009). Of the 36 pesticides referred to in this chapter on the pests of sugarcane, 33 are included in the list. The Environmental Protection Agency in America has recently announced that, due to new concerns about residue levels, production of aldicarb, one of PAN’s HHPs used in sugarcane agriculture, will cease at the end of 2014 (EPA 2010). Another sugarcane HHP, endosulfan, is to be banned from use in Brazil in 2013. It is already banned in 45 other countries due to its association with medical disorders, plus its persistence in the environment (Hirata 2010).

9.8.2 Financial cost of pests

Estimated annual yield losses due to insect, nematode and rodent pests are given Table 9.5. Losses from canegrubs in Australia (the predominant insect pests in that country) vary according to how well they are controlled and environmental conditions. Based on data from Garside et al. (2000) and Hunt et al. (2003) they range from 497 000 to 746 000 t cane per annum; in a bad year losses may be twice these amounts. Losses attributed to the greyback cane grub, the most damaging of the canegrubs in Australia, range between 232 000 and 331 000 t cane per year (Hunt et al. 2003). The crop loss due to nematodes in Australia, 2 718 000 t cane per year, is 4.4 times greater than an assumed average loss of 621 000 t cane from canegrubs. In South Africa the estimated annual crop loss from the stalk borer, E. saccharina, the main insect pest, is 981 000 t cane. The estimated crop loss due to nematodes in South Africa, 1 603 000 t cane, is 1.6 times greater than that from E. saccharina (Table 9.5). The crop loss estimate for E. saccharina is likely to be an over-estimate as it is derived from field trials with cultivar NCo376, which is susceptible to E. saccharina and is no longer widely grown in South Africa.

Relative annual crop loss in sugarcane production due to nematodes ranges from 14.6% in Burkina Faso, 11% in Cote d’Ivoire, 9% in Australia, 7.6% in South Africa, 4% in USA to 3% in Peru (Cadet and Spaull 2005). Whereas ongoing crop losses are greater with nematodes, insect pests pose a greater risk as most are much more mobile and widespread outbreaks are more common.
The high crop loss figure for rodents in Australia in Table 9.5 is for the 1999/2000 growing season, when unfavorable weather conditions affected the normal constraints to population growth (Ward 2008).

Besides the losses incurred as a result of lower yields, the cane grower also carries the cost of the various management practices required to reduce the numbers of the pests sufficiently to ensure an economic yield. Root feeding pests such as nematodes, white grubs, sugarcane weevils and soldier flies not only reduce the yield of each crop but also the number of economic ratoons that can be harvested from a single planting. This means additional costs associated with more frequent replanting (Cadet and Spaull 2003).

Table 9.5. Estimated losses from pests (expressed as actual tonnes cane per annum or the tonnes cane per annum equivalent of losses originally expressed in dollars or rands).

<table>
<thead>
<tr>
<th>Sugarcane industry</th>
<th>Insects</th>
<th>Nematodes</th>
<th>Rodents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>285 000</td>
<td>–</td>
<td>142 000</td>
</tr>
<tr>
<td>Australia</td>
<td>497 000 to 746 000</td>
<td>2 718 000</td>
<td>829 000</td>
</tr>
<tr>
<td>South Africa</td>
<td>981 000</td>
<td>1 603 000</td>
<td>–</td>
</tr>
<tr>
<td>USA</td>
<td>630 000</td>
<td>1 093 000</td>
<td>–</td>
</tr>
</tbody>
</table>

1Froghopper plus white grubs and 2Sigmodon hispidus (Márquez 2005); 3Soil insects (Garside et al. 2000) and white grubs (Hunt et al. 2003); 4Blair and Stirling 2007; 5(Ward 2008); tonnes cane conversion from Australian dollar derived from Hunt et al. (2003); 6E. saccharina in South Africa, derived from Goebel and Way (2007); tonnes cane conversion for South African Rand derived from Anon (2009); 7(Spaull and Cadet 2003); 8Eoreuma loftini and Diatraea saccharalis in Texas only (Legaspi et al. 1999); 9(Koenning et al. 1999); tonnes cane conversion from US dollar derived from Roka et al. (2010).

9.8.3 Environmental cost of practices used to control pests

Whereas some biocontrol interventions have been very successful, as with the braconid larval parasitoid, C. flavipes used to control the stalk borer, D saccharalis, in Brazil, others have been disastrous. For example, the cane toad, Bufo marinus, originally introduced to Queensland from Hawaii in 1935 to control canegrubs, is an ongoing serious threat to the native fauna in Queensland and is described as an ecological disaster (Allsopp et al. 2000). Similarly, the domestic cat, Felis catus, originally released to control rodents destroying sugarcane in the plantations of northern Queensland, now poses a threat to the native fauna (Abbott 2008). An even greater problem has been created by the Indian mongoose, Herpestes auropunctatus, introduced to control rats in Caribbean sugar plantations; it has been responsible for reducing the numbers of many of the native vertebrate species and the extinction of several others (DiFiore 2001).
9.9 Summary

Sugarcane is host to a wide array of insect, nematode and vertebrate pests. While some damage can be tolerated by the cane plant there comes a point when, if left uncontrolled, some pests cause significant losses, even to the extent of total crop failure. In sugar industries around the world stalk borers and, in Australia, canegrubs, are perceived to be the most important pests of sugarcane. However, according to yield loss estimates, plant feeding nematodes have a greater effect on cane production.

Control of the pests has mostly relied on highly hazardous pesticides. Of all the actions associated with growing sugarcane, the greatest risk to the well being of farmers, farm workers and rural communities, comes from the use of pesticides. They also present a risk to non-target organisms and to the environment.

Currently there are a number of management practices that can be used to control sugarcane pests and which present little or no risk to the well-being of people or the environment.

These include:

- **Use of biological control agents** – predators and parasitoids. Also habitat management using insect repellent plants.

- **Use of benign chemicals and biopesticides** – e.g. tebufenozide, neem based products and formulations of *Metarhizium* spp.

- **Adoption of various agronomic practices** – e.g. planting pest free seedcane; using resistant and tolerant cultivars; management of planting or harvesting dates to the detriment of certain pest species; adopting green cane harvesting with a trash blanket and replanting using minimum tillage; use of organic amendments in the planting furrow to enhance early plant growth and reduce damage caused by nematodes; avoiding moisture stress through irrigation; intercropping and rotation cropping with cash crops (including rotation with soybean that favors beneficial nematodes); flooding fields for short periods; avoidance of high levels of N and low levels of Si.

- **Capture of pests** – hand picking and the use of trap crops, light traps and pheromone traps.

Calls are being made to ban the highly hazardous pesticides used in agriculture. Most of the chemicals registered for pest control in sugarcane fall into this group. However, in many situations, economic production of sugarcane is dependent on them.

To reduce the risk of poisoning and environmental contamination, and until safer control options are available, greater emphasis has to be placed on (a) training farm workers, (b) the provision of appropriate safety clothing and (c) improved application technology. Highly hazardous pesticides should be withdrawn from countries where it cannot be guaranteed that they can be handled within margins of acceptable risk to the user (FAO 2010).
9.10 References


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# Chapter 10: Chemical Ripening

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10. CHEMICAL RIPENING, FLOWER SUPPRESSION and GROWTH

10.1 Introduction

A range of chemical ripeners are available for use on specific cultivars, mainly on irrigated well grown and managed immature upright cane in the early or late season. Chemical ripeners are used to improve cane quality, milling efficiency, reduce transport costs and facilitate management.

There can be a negative impact on cane yield and this is extenuated by any delay in the harvesting program. Flowering can be suppressed by the use of chemicals, and this is also discussed.

Good management practice (GMP) is based primarily on the selection of the crop and the ability to uniformly spray the crop prior to harvest at the correct time. It is important that, once sprayed, the crop continues to grow well and is then harvesting at the optimum time. Lodged cane is not suited to ripener application.

It is essential that there is no drift onto neighbouring fields and crops as the chemicals used tend to be growth regulants or low dosages of herbicide. Conditions at spraying and the spray operation need very careful monitoring and control, and this is a critical aspect of GMP.

Agronomic practices must ensure favourable biomass production from high levels of incident solar radiation and temperature. Stresses, both biotic and abiotic, that impact negatively on biomass production, reduce the efficacy of a chemical ripener. Crops that have responded to the flowering stimulus are also unlikely to respond favourably to chemical ripening.

The use of chemicals to suppress flowering is restricted to areas with very profuse flowering such as in the Sudan, Hawaii, Brazil and Malawi.

The financial, milling, transport and management benefits to chemical ripening and flower suppression have been substantial when applied according to recommended GMP.

Chemical ripeners offer one of the best and quickest returns on investment when used on the appropriate cultivar under the correct growing conditions, and when harvesting and milling programs are strictly adhered to.

In the longer term, the objective must be to breed and select cultivars that mature in time without chemical ripening and to use cultivars which are low in flowering.

10.2 Background

Initially, when payment was based on cane yield and not sugar, the emphasis was on increasing growth. Consequently the first growth regulant to be commercially applied to cane was gibberellic acid in Hawaii. Once payment was based on sucrose the emphasis was on using growth regulants to increase sucrose and cane quality. Hawaii and South Africa in the 1960s were the main pioneers of the commercial application of chemical ripeners. Ethephon (e.g. Ethrel), Embark and the glyphosate Polaris were introduced first. These were followed by registration of the glyphosate herbicide Roundup and later Fusilade. Moddus is currently used in Brazil and Australia, and is being re-evaluated in South Africa. The herbicide groups of chemical ripeners are used at much lower dosage rates than those used for herbicide application.
There are concerns regarding chemical application when there is the risk of not being able to harvest sprayed crops on time. Another concern is the possible impact on personnel and the environment, particularly from poor adherence to GMP.

10.3 Natural ripening

Ripening increases both fresh and dry mass of sucrose, expressed as stalk fresh and dry matter content respectively (Glover 1971). The impact on crop dry matter from responses to low temperature, drying off and chemical ripening is difficult to interpret when based on fresh weight measures of productivity (Muchow et al. 1996). During ripening additional sucrose is stored in internodes or as monosaccharides, converted to sucrose. The reduction of monosaccharides in the stalk is of particular economic benefit if sucrose is required, since glucose and fructose detract from full recovery of sucrose in the milling process (Culverwell 1996). However, monosaccharides are usually less than 5% of the total sugars in the stalks of 12-month old crops (Robertson et al. 1997). Although ripening can be forced to develop in sugarcane when it is relatively young, e.g. by lack of soil water (Inman-Bamber 2004) ripening is usually associated with a short period leading up to harvesting. The roles of temperature, age and water stress in the ripening process are discussed below.

10.3.1 Temperature

Sucrose production is highest when fully canopied crops are intercepting high levels of solar radiation (Glaziou et al. 1964 cited in Yates 1986) when temperature variations through the year are low on crops grown close to the equator (Yates 1986). However, the amount of sucrose produced relative to the total biomass is low when growth is vigorous. Many fully developed young internodes are produced with the capacity to store greater amounts of sucrose. There is good economic sense in producing crops that have a high ratio of sucrose to cane mass and, for this reason, much effort is expended in breeding cultivars with this characteristic. It has been shown that 12-month old crops ratooned in winter and spring allocate lower fractions of biomass to foliage and more to sucrose than crops ratooned in autumn and summer (Donaldson 2009). This leads to higher sucrose content in the sugarcane stalks during winter and spring due to the natural ripening process.

Photosynthetic and respiration rates are sensitive to variations in temperature (Sinclair and Muchow 1999; Greulach and Adams 1967) and temperature has a direct effect on radiation use efficiency (RUE) (Donaldson 2009). Photosynthetic efficiency increases with temperature from 2.7 g (CH$_2$O)/MJ of PAR at 10 °C to 8.2 g/MJ at 20 °C, according to Liu and Bull (2001) using data from Hartt and Burr (1965).

Low temperatures reduce respiration rates to a greater extent than photosynthesis (Glaziou 1964 cited in Yates 1986; Glover 1973) implying that a greater portion of photosynthate is available for storage when temperatures are low (Glover 1973).

Photosynthetic efficiency falls and stalk growth rate slows at low temperatures (<17 °C) and results in sucrose content increasing. After a period of exposure to low temperature there is a slow partial recovery in photosynthetic efficiency (Waldron et al. 1967). Leaves produced during cooler months are smaller and the portion of green foliage in biomass decreases during the cooler winter months (Donaldson 2009). This reduction in leaf reduces the loss of photosynthate from respiration of green foliage, which may be six times higher in leaves than stalks (on dry mass basis) at temperatures of 16 °C (Glover 1973).
Ebrahim et al. (1998) reported that the optimum temperature for sugarcane growth was 27 °C, whilst 15 °C and 45 °C were regarded respectively as well below and above the optimum. However, the optimum temperature for C₄ plants (such as sugarcane) is more likely to be in the range of 30-35 °C (Bonhomme 2000). The growth of 7-month old plants subjected to temperature regimes of 23-33 °C and 25-38 °C for two months in a controlled environment facility were compared (Bonnett et al. 2006). Plants subjected to the higher temperatures produced more internodes that were shorter and had higher water content than plants subjected to lower temperatures. The sucrose fresh mass and dry mass content of internodes grown at higher temperatures were also lower, and had higher fiber and lower hexose levels than in internodes grown at the lower temperatures. This was evidence that less sucrose is stored at temperatures higher than the optimum in sugarcane (Bonnett et al. 2006).

Photosynthetic ‘stress’ was presumed to develop in sugarcane crops at temperatures below 5 °C and above 50 °C (Park et al. 2005), whereas base temperatures (at which growth starts or stops) of various growth processes could range from 7.6 °C (Campbell et al. 1998) to 19 °C (Bacchi and Sousa 1977). Minimum threshold temperatures for sugarcane growth therefore are substantially higher than those for photosynthesis which were suggested by Park et al. (2005). This implies that photosynthates could be produced at temperatures too low for extension growth and that storage of sucrose could be enhanced under such conditions.

The eventual sucrose concentrations in cane (which is the integration of the whole sequence of effects of temperature from the level of enzyme activity to growth and storage of sucrose in sugarcane), during a mill season have been used to illustrate the effects of temperature on 12-month old well irrigated crops at Pongola, South Africa (Glover 1971). The cultivar NCo310 made up more than 90 % of the crop that had not been ripened with chemicals, but may have been dried-off for 2-3 months. By inverting minimum temperatures and displacing those by three months the correlation between mean monthly minimum temperatures of the preceding three months and sucrose % cane (fresh mass) was demonstrated (Fig. 10.1).

![Figure 10.1](image)

**Figure 10.1.** A: Sucrose content in relation to minimum temperatures during a milling season. B: The association between inverted minimum temperature (left Y-axis) displaced by three months and sucrose content. Modified after Glover (1971).

Plants grown in a controlled environment facility by Glaszio et al. (1964) required 90 days to reach a maximum sucrose % cane when grown at a constant temperature of 17 °C. When these plants were then subjected to a constant 30 °C, it took 35 days for the sucrose % cane to fall to 6.5 %. It is significant that the effects of temperature were related to changes in sucrose content in fresh mass...
by both Glover (1971) and Glaszio et al. (1964); a clearer interpretation of the effects of temperature would have been possible had the authors related the effects on sucrose mass or sucrose content of stalk dry mass.

Low temperatures delay canopy development and stalk emergence of well grown crops ratooned annually in autumn and winter. The growth period of stalks (from stalk emergence to harvesting at 12 months), although relatively shorter in winter ratoons than in summer ratooned crops, occurs during periods of high solar radiation at close to optimum temperatures. The autumn and early winter ratoons are characterized by high cane yields with relatively low sucrose content and are therefore good candidates for ripening by either chemicals or controlled water stress (drying-off). Late summer ratooned crops experience cool winter temperatures at an advanced age (6-8 months) and are ripened by the cool winter temperatures. The recovery during the second summer (6-4 months before harvesting) from the ripened state is often slow and the condition of the crops is such that they would be expected to respond poorly to chemical ripening (Donaldson 2009).

10.3.2 Age

Approximately 60 % of the final stalk dry mass of a two year crop is attained by the end of the first year. Glover (1973) calculated that during the second year of the crop, respiration losses ranged from 30-50 % of photosynthate but were never higher than 30 % of that during the first year. The increased loss of photosynthate during the second year is attributed to the increasing size of the stalk with a relatively constant leaf area.

Gosnell (1968) observed that there was a decrease in the rate of leaf emergence and a drop in tissue moisture content in ageing crops. Although cane quality was not affected by age up to 15 months, sucrose yield increments declined and recovery of sucrose was adversely affected by substantially higher levels of fiber.

Lonsdale and Gosnell (1975) showed that the rates of cane and sucrose production fell rapidly after the age of 12 months in crops ratooned in July and September (winter/spring in Zimbabwe) and after 10 and 14 months of age in May and November ratoons. Generally, crop growth in the second year was only 20 % of that during the first year. In contrast, cane and sucrose yields of well irrigated crops were more than doubled between the ages of 12 and 22 months in New South Wales, Australia, even though RUE decreased from 1.23 to 0.90 g/MJ intercepted solar radiation (Hughes and Muchow 1998). It is significant that in this study the results apply to a plant crop (September planted) that intercepted only about 58 % of incident solar radiation during the first 12 months of growth and about 90 % during the ensuing 10 months. Crops ratooned annually in summer can intercept 77-87 % of solar radiation (Donaldson 2009).

Photosynthesis in the leaves is purportedly controlled by factors in the stalk and it has been suggested that, regardless of leaf age and environment, photosynthesis declines as the stalk matures in sugarcane crops (Amaya et al. 1995 cited in McCormick et al. 2006).

While the sucrose content in young crops varies greatly with the season in which they are harvested, Rostron (1971) concluded that there was little difference in sucrose % dm in crops older than 13 months (Fig. 10.2).
Figure 10.2. Sucrose content of ageing crops started during eight different months.

Factors other than the season effect (e.g. lodging) may then cause variations in sucrose content. Recently it has been shown that the growth and therefore sucrose content during the second summer of annual ratoons harvested in late summer are affected by their inability to respond to good conditions after winter (Donaldson 2009; van Heerden et al. 2010). The feedback of high sugar levels produced in the stalk during winter is thought to reduce photosynthesis (McCormick et al. 2006) during spring and early summer, and this may then cause summer harvested crops to yield poorly (Donaldson 2009).

10.3.3 Water stress

In crops that rely on rainfall only, it is accepted that the crop will be subjected to periods of stress. The amount and distribution of rainfall, soil characteristics, crop stage and atmospheric demand, determine the severity and duration of stress.

Drying-off is a common practice based on suspending or reducing irrigation water of well irrigated crops for a period before harvesting to increase the sucrose content of stalks (Clements 1980). The interactions between soils of different characteristics, particularly in regards to water holding characteristics, and atmospheric demand, which result in evaporation from the soil and transpiration by the sugarcane plant, are complex. When atmospheric demand is not met by normal evapotranspiration, various responses are elicited by the plant to protect and maintain itself. Inman-Bamber (1986) described ripening as occurring when leaf water potential was between -0.2 and -1.2 MPa; this mild stress reduced plant extension but was insufficient to substantially increase stomatal resistance. The relatively mild degree of stress that is required for ripening has often been overlooked and this may have resulted in vague or inappropriate drying-off practices being recommended (Robertson and Donaldson 1998).

Robertson and Donaldson (1998) suggested that increases in sucrose yields through drying-off were more likely to be realised where cane yield is not affected by imposed water stress. When stalk dry mass yield is reduced by more than 10 % (relative to a well watered crop) sucrose yields are reduced linearly with fall in stalk dry mass yield. Their analysis (Robertson and Donaldson 1998) provided the framework for developing drying-off recommendations and risk analyses in Australia (Robertson et al. 1999) and South Africa (Donaldson and Bezuidenhout 2000). Singels et al. (2000) determined that partitioning to the sucrose fraction of biomass was favored when the mean relative plant available soil water content (RSCW) dropped below 55 %. The partitioning to sucrose therefore occurred well
before biomass accumulation was reduced, which was first evident when RSWC dropped below 35% (Fig. 10.3).

Figure 10.3. Plant extension (growth) of sugarcane and declining soil moisture content. Circles are measured soil water content and the broken line is the simulated soil water content.

From the above observations it is clear that at optimum temperatures sugarcane growth is most rapid and sucrose accumulation is high. Once past a given age, internodes attain a genetically determined maximum sucrose concentration. Younger internodes of a stalk can be forced to attain higher levels of sucrose concentrations by subjection to mild stress (e.g. water stress) that over an extended period causes less hydrolysis of sucrose and greater diversion to the stalk. While drying-off is highly recommended as a practice to avoid soil and crop damage during harvesting operations, it may often not always produce the desired ripening effects. Thus the alternative practice of ripening sugarcane crops by spraying them with chemicals at various intervals before harvesting has been developed to ripen crops when solar radiation, temperatures and soil water favour vigorous growth leading up to the time of harvesting.

**Box 10.1 Factors that promote good responses to chemical ripening**

- Cane grown within the optimum temperature range (>20 °C to <38 °C) promotes vigorous growth and low sucrose: cane ratios. Temperatures outside the optimum range alter growth patterns and negate good responses to chemical ripening.
- Good soil moisture status and nutritional levels promote crop vigor. Even mild levels of moisture or nutritional stress at the time of application may totally negate good responses to applied ripeners.
- Young annually harvested crops that are still growing vigorously respond best to ripening with chemicals. In older cane photosynthesis declines and respiration increases, so that crops tend to store more sucrose and use less for growth.

**10.4 Chemical Ripening**

**10.4.1 Milling periods and crop characteristics**

The growth rate, particularly during the final six months, of crops harvested annually will largely determine their maturity and sucrose content of stalks at harvest. In low altitude tropical regions, temperature variations generally tend to be small throughout the season and rainfall distribution determines when crops can be harvested. Harvesting is usually programmed for the dry season to avoid wet infield conditions during harvesting. However, during the start of the milling period late
rains in summer/autumn and/or the residual soil water in deep profiles may encourage vigorous
growth and cause low sucrose content for the first few months into the milling period. Vigorously
growing crops with relatively low sucrose content are good candidates for chemical ripening
provided soil water remains above 50% of total available water (TAW). When TAW drops below 50 %
natural ripening is induced and the stress that develops in the plant could also interfere with action
of chemicals applied as ripeners.

In semi-arid subtropical regions low temperatures (winter) and low rainfall coincide and harvesting is
programmed around the period when sucrose content peaks, which is in late winter/early spring.
The length of the milling season is largely determined by the milling capacity and the size of the crop.
In regions where crops are harvested close to the age of 12 months and milling capacity is limited, it
is inevitable that harvesting programs will include some months on either side of the ‘peak sucrose’
period. Autumn harvested crops have not been subjected to the ripening effects of low
temperatures and vigorous growth will be encouraged by good late summer rainfall. After the ‘peak
sucrose’ period more rapid growth could resume once the effects of winter are reversed. Recent
research has shown that the decline in sucrose content in the months after winter is not solely a
function of increasing temperatures and increased growth rates, but also due to growth having been
arrested during winter when the crops are relatively immature (Donaldson 2009). Mid-summer is
also the period when stalks of crops that have flowered start to deteriorate. Smaller leaves are
produced once flowers are initiated and older leaves senesce rapidly during summer without being
replaced by new leaves. The green canopy is therefore destroyed after flowering and may no longer
be able to sustain the crop. Measures to prevent flower initiation and deterioration of stalks are
discussed in section 10.5.

10.4.2 Identifying crops that are suitable for chemical ripening

Chemical ripeners must only be applied to relatively immature crops that are growing vigorously at
the time of application. High temperatures and an abundance of soil water favour high rates of
photosynthesis (and therefore growth) and these should persist after the application of the
chemical. The presence of long upper internodes and more than eight well grown green leaves per
stalk is a useful indicator of vigorous growth. These are easily monitored in the field; however, the
true maturity of the crop cannot easily be assessed without analysing the stalk juices. Handheld
refractometers give an indication of brix levels in juice, but will only be effective if protocols are
followed rigorously. For various reasons, the practice of determining the suitability of crops for
chemical ripening using handheld refractometers has not been recommended and is not widely used
by commercial sugarcane farmers in southern Africa. More comprehensive juice analysis offered by
specialist laboratories found at mills or research institutes is likely to be the most feasible alternative
of determining crop maturity.

The stress which neutralises the benefits from chemical ripeners occurs well before leaf rolling is
detected and can best be anticipated by monitoring the soil water available to the crop using simple
profit and loss (TAW + rainfall – Et) schedules or models used to schedule irrigation, e.g. Canesim
(Singels and Donaldson 2000). The period when low soil water starts limiting growth (drops below 50
% TAM) before harvesting must be as short as possible. If conflict exists between maintaining high
soil water to ensure good ripener responses and drying the soil profile in preparation for harvesting,
the latter should take priority. Wet soil conditions during harvesting operations should be avoided
even if this means that chemical ripening becomes ineffective. The feasibility of chemical ripening
should then be reassessed and possibly be avoided. It also means that drying-off periods of
chemically ripened crops should be short and, if a drying-off program can replace a chemical
treatment program, it should be strongly advised where the drying-off process is unlikely to be
interrupted by rainfall and a risk analysis (Roberston et al. 1999) indicates a potentially high success rate from a drying-off program.

<table>
<thead>
<tr>
<th>Box 10.2 Features indicating vigorous growth in well grown crops</th>
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<tbody>
<tr>
<td>• More than eight large green leaves per stalk.</td>
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<tr>
<td>• Leaves are green and disease-free.</td>
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<tr>
<td>• Long internodes, particularly in upper half of the stalk.</td>
</tr>
<tr>
<td>• Uniform growth throughout the target field.</td>
</tr>
<tr>
<td>• However the crop should be mainly upright and not lodged.</td>
</tr>
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**10.4.3 Chemicals used for ripening**

Only products that have been registered by the local authorities and accepted by the market should be used as ripeners. These products will have been proven by stringent scientific criteria to enhance sucrose yields. Any negative effects of the chemical on growth of sugarcane such as causing damage or reduced growth rates in the following crop will disqualify the chemical from being registered and promoted for commercial use. The toxicity data of chemicals and some possible impacts on the environment are indicated on the label and these should be carefully interpreted for each specific set of conditions that exist for each area (field) to be treated. Directives on the label are aimed at maximizing the benefits and reducing all risks and liabilities associated with the practice of applying chemicals to a crop. The data on the label of a product are mere guidelines and it is highly recommended that further information on the product and how it should be applied be gathered from all available sources to complement the label data.

The following four chemicals are currently used commercially alone or in combination on sugarcane as ripeners.

- **Glyphosate** containing isopropylamine salts (some common names: Roundup and Polado), is a herbicide used widely to eradicate sugarcane in preparation for replanting fields and is a very effective broad spectrum herbicide. At very much lower concentrations it is a highly effective chemical ripener. The active compound suppresses the formation of new apical stalk tissue (Hilton et al. 1980; Eastwood and Davis 1997) because of interference in the synthesis of aromatic amino acids, which are drawn into the production of lignin (Herrman 1995). Prolific auxiliary bud development (side-shooting) often occurs after application because of reduced apical dominance (Rostron 1985; Eastwood and Davis 1997).

- **Ethephon** containing 2-chloroethyl phosphonic acid (some common names: Ethrel and Ethephon), is a highly effective chemical ripener in South Africa and Swaziland when applied to immature sugarcane in autumn (March-May) to crops with juice purities of less than 75 % (Rostron 1977b). After uptake by the leaves, the active compound releases the plant growth regulating hormone ethylene (Jaramillo et al. 1977), which results in a reduction (up to 50 %) in lamina size (area) and mass of leaves produced after application (Rostron 1974; 1977b; Eastwood and Davis 1997). The shortening of the newly formed leaves often gives a fan-like appearance to the leaf canopy. Stalk growth is at most only transiently affected as indicated by the shortening of only one or two internodes (Rostron 1985) and the product is not effective on all cultivars.

- **Fusilade** containing fluazifop-p-butyl (some common names: Fusilade Super or Fusilade Forte), is a herbicide that is also used to eradicate sugarcane and as a grass killer. At very low
concentrations it is a highly effective chemical ripener. The active compound interferes with long-chain fatty acid synthesis required for the formation of waxes, suberin and cutin in cell walls (Gronwald 1991). At low concentrations two typical symptoms are: (1) death of one or more of the youngest spindle leaves occurs, usually without affecting any of the older leaves (Rostron 1985) and (2) characteristic black necrotic rings form on the young elongating internodes (Rostron 1985; Eastwood and Davis 1997). Auxiliary bud development (side-shooting) after application is also a common symptom when apical dominance is destroyed (Rostron 1985; 1989).

- **Moddus** containing trinexapac-ethyl (common name: Moddus), is a cyclohexanedione plant growth regulator used as an anti-lodging agent in cereals and to suppress growth of turf grasses. At lower concentrations it can be used as a chemical ripener in sugarcane. The active compound transiently inhibits the conversion of an inactive precursor (GA$_{20}$) of the plant hormone gibberellic acid (GA) into one of its main bioactive forms (GA$_1$). In the process GA$_{20}$ accumulates, while the suppression of GA$_1$ levels leads to an inhibition of internode elongation (Resende et al. 2000; Rixon et al. 2007). This product is used as a ripener in Brazil and Australia and is currently being re-investigated in South Africa.

- **Combination treatments.** The synergistic action of ethephon followed by a later application of Fusilade Super (FS) has been proven to be economically beneficial in some cultivars grown in South Africa, Swaziland and Malawi. The treatment entails the sequential application of ethephon and FS, separated by about five to six weeks, the ethephon treatment being applied 12 weeks before harvest date. The combined treatment (which may also be ethephon followed by glyphosate) has proven to be more effective than when the two ripeners are applied as single treatments (Rostron 1985; Sweet et al. 1987; Donaldson 1994; 1999; 2001). The potential benefits of this combined treatment for the Australian sugar industry were also recently demonstrated (Morgan et al. 2007). The additional benefit maybe too small to offset the extra cost of the chemical and its application (Donaldson 1999) in some cultivars. Thus local cultivars need to be screened for their responsiveness towards the combination treatment in each country.

### Box 10.3 Characteristics of a good ripener formulation

- Not toxic to humans and animals, both terrestrial and aquatic.
- No adverse residual activity on the growth of the following ratoons.
- Enhances sucrose yield, not only sucrose content.
- Enhances sucrose yields over a reasonable period to fit into a harvesting program and is not easily disrupted by stress.
- Rapidly absorbed by foliage and not easily washed off by rain.
- Does not promote development of pests or diseases.
- Is effective on a broad spectrum of cultivars.
- Has been studied extensively and is registered and promoted by reputable organizations.

### 10.4.4 Cultivar responses to chemical ripening

The practice of using only one or two cultivars on large commercial farms or in a district of many smaller farms has in the past generally favored the use of chemicals to ripen crops. This is particularly so where popular cultivars that are very responsive to chemical ripening (e.g. NCo376) are harvested at a relatively young age (about 12 months old), as has been the practice for many years in countries such as Swaziland. Breeding programs have produced a range of cultivars that...
have enabled the farmer to develop better cultivar x season (x soil type) planting strategies that are aimed at minimizing the risk of yield losses from pests and diseases, but also maintaining sucrose yields at a more even level throughout the season, regardless of seasonal fluctuations. It is imperative that the farmer also gains information on the potential responses of each cultivar to each of the available ripener treatments. This is necessary because not all cultivars respond equally well to chemical ripeners (Rostron 1989; Kingston and Rixon 2007). A good example was the succession of NCO376 by N14 in South Africa. NCO376 is known to respond particularly well to ethephon, glyphosate and Fusilade Forte as well as to the combination treatment, whereas N14 does not respond to ethephon and also requires a higher rate of Fusilade Forte. The combination treatment is also not recommended for N14 (Rostron 1974; Sweet et al. 1987; Leibbrandt 1989; Donaldson 1989; 1999; 2001). Therefore maximum benefits can only be achieved from a well-structured chemical ripening program that includes cultivar differences and strict adherence to the harvesting and milling program.

Several other studies have produced examples of South African cultivars that do not respond equally well to chemical ripeners (Rostron 1989; Donaldson 2001). Chemical ripener evaluations on different cultivars (Hilton et al. 1980; McCatty 1980; Dusky et al. 1986; Eastwood and Davis 1997; Resende et al. 2000; Kingston and Rixon 2007; Morgan et al. 2007; Rixon et al. 2007) in different sugar industries have confirmed that each cultivar should be tested for its responses to different ripener treatments. At present, there is no good predictor of cultivar potential responses other than levels of juice purity <75 % for ethephon and <85 % for Fusilade Forte and glyphosate. The criterion of juice purity levels is a generalisation and certain cultivars that may comply with the requirement of <75 % juice purity may for other reasons (which remain elusive) may not respond to ethephon, e.g. N14 in South Africa (Donaldson 1989; Leibbrandt 1989). Cultivars also respond differently to Moddus.

Different cultivars appear to have different levels of the four main biologically active gibberellins (GA$_1$, GA$_3$, GA$_4$ and GA$_7$) (Resende et al. 2000; Rixon et al. 2007), but Moddus inhibits only GA$_1$ synthesis (Rixon et al. 2007) and therefore the role of the other gibberellins when GA$_1$ is inhibited, is unclear. Information on the best ripener treatment may not be available when a cultivar is released for commercial use because it may take several years to produce these data in controlled experiments. The best treatment to use until this information is released is Fusilade Forte at the lowest rate recommended for other cultivars in the district. The very low probability of the residual effects from Fusilade formulations makes it a better choice than glyphosate. When better data become available from scientific studies, which usually incorporate concepts that arise from observations in commercial practises, a ripener program should be adjusted to accommodate the new information.

**Box 10.4 Matching cultivars with best ripener treatment**

- The design of a ripener program should also match a cultivar with its best ripener treatment because cultivars may require different chemicals, different rates and different spray to harvest intervals.
- Cultivar information should be sought from research institutions, purveyors of the chemical or local farmer/agronomist associations. Use only recommended rates.
- Alternatively, when information is not available, well-designed field experiments taking particular note of factors that promote vigorous growth indicated in Boxes 10.1.1 and 10.1.2, could be conducted to produce the required information.
10.4.5 Methods of applying chemical ripeners

Besides identifying crops best suited for chemical ripening and matching them with the most appropriate treatment (chemical and spray to harvest interval) another operation that will determine the success or failure of the ripening program is the even application of the spray mixture over the crop. It is essential that the method of application and the apparatus, together with weather conditions, ensure that the spray mixture is evenly distributed over the target crop. The choice of method used to apply ripeners is often dictated by the terrain on which the crop is grown. Even though maldistribution and off-target drift are potentially greater hazards from application by aircraft than from handheld rigs, there are very few commercial instances where ripeners are not applied by aircraft.

Aerial applications
The most commonly used method of applying ripeners to sugarcane crops is by fixed wing aircraft or rotary wing aircraft (Figure 4). Micro-light aircraft have been used on a limited scale and should be cautioned against. Only ethephon has the appropriate formulations that have label registration for application at the low volumes (high concentration) used in micro-light apparatus. Stringent regulations need to be followed to ensure safety to the pilot and the environment when ripeners are applied by aircraft. Some of these are discussed in Chapter 12. Where the requirements for safe use of aircraft cannot be met, alternative methods using knapsacks and tractor mounted booms can be very effective.

Figure 4. Demonstration of the distribution patterns of a ripener applied by a rotary winged aircraft.

Ground applications by knapsack
Farmers may choose to apply ripeners by handheld booms connected to knapsacks. Such operations are very successful and this method is highly recommended, because many of the risks that are associated with aerial applications are either eliminated or minimised by handheld rig applications. However, the possible exposure of the operators to the chemical is a major concern when handheld rigs are used. Employing techniques and following set procedures that minimise exposure to the chemicals and training a disciplined team in the use of handheld rigs, may be the best option for small and medium sized farms. The area sprayed can be better linked to harvesting schedules, so that a field is harvested when peak responses are anticipated. When aircraft are used large areas are sprayed so that fields are often harvested before and/or after the anticipated peak response. Crops should be carefully inspected for lodging before the spraying operation begins. Lodged areas should
be avoided because they could lead to over application and stalk breakage when operators step on fallen stalks. Also, lodged cane responds poorly to ripeners.

Tractor mounted rigs
Tractor mounted spray booms that are elevated above the crop canopy may be used in conjunction with or as an alternative to handheld rigs to apply ripeners. The use of tractor mounted rigs which rely on the PTO to drive a pump that pressurises the spray mixture is possibly a ‘safer’ alternative to handheld rigs, with respect to exposure to the spray mixture. An elevated boom extending up to 9 m carries a number of spray nozzles connected via delivery tubing to a 20 L container housed on a platform attached to the three-point linkage system on the back of the tractor. The spray mixture in a 20 L container is pressurised by a PTO driven pump. The platform that links to the three-point linkage system on the rear of the tractor can be elevated to the required height so that the boom and spray nozzles are about 50 cm above the crop canopy. This method is most successful when fields are laid out in rectangular ‘blocks’ that are separated by a space that allows access for a tractor, as is typical in overhead irrigated fields. The use of mistblowers to apply ripeners is not a recommended practice. Their use should also be discouraged because of the poor distribution of the chemical over the crop canopy.

**Box 10.5 Considerations related to method of application**

- Achieving an even distribution of chemical over the crop.
- Minimizing loss of chemical from target to air, soil or into soil water.
- Achieving the most economic, most environmentally benign and greatest efficacy from the ripener.
- Safety of operators should be a priority.

10.4.6 Factors influencing crop response to chemical ripeners

Spray to harvest intervals and rates of chemical ripeners
A harvesting schedule for the farm/estate has to be finalized in good time before a spraying program can be drawn up. This spray program and field identity and marking systems to be used need to be communicated to the spray operator in good time. This can help coordinate spraying operations for the district, and ensure that spraying can be done to schedule. The operator should consider having contingency plans to cope with unforeseen weather conditions. The spraying dates should be set according to the appropriate spray to harvest dates for a particular chemical treatment and to the weather conditions over the period the ripening response develops. Generally, all four chemical ripeners will raise sucrose content within 4-8 weeks after application (Rostron 1974; 1977a; 1977b; Donaldson 1989; Soopaya and Nayamuth 2001; Morgan *et al.* 2007). The persistence of cane quality improvement above that of an unsprayed crop can vary from 12 weeks to more than 20 weeks (but weaken in the later stages) after application depending on the type of ripener (Rostron 1977b; Clowes 1980; Eastwood and Davis 1997; Resende *et al.* 2000). However, there is usually an optimal spray to harvest period during which time the sucrose yield (t sucrose/ha) benefit associated with using a particular chemical ripener is maximised. Both the rates at which chemicals should be applied and the spray to harvest interval may need to be established from local data to optimise the benefits from a ripening program. Information included on the product label is generally applicable. More specific data might be available from the institute doing research on sugarcane. When used as indicated, chemical ripeners improve stalk sucrose content (% cane), but their mode of action, namely to suppress stalk and/or leaf growth, could potentially have negative effects on millable cane yield (t cane/ha) at harvest if the spray to harvest period is too long. It is therefore essential that the spray to harvest interval is determined on maximum sucrose yield gains when compared with

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unsprayed controls in well designed experiments. A spray to harvest interval that is too long will result in a loss of millable cane yield (t cane/ha), which could potentially reduce the economic benefit of chemical ripeners in terms of sucrose yields (t sucrose/ha). Farmers should be prepared to conduct well controlled chemical ripener evaluation trials in production areas where these chemicals are used, to gain the appropriate information for their specific conditions.

Box 10.6 Setting up a spray program
- Design a spray program based on harvest date and optimum spray to harvest intervals.
- Match area to be sprayed with harvesting capabilities.
- Communicate spray program to neighbors.
- Strictly adhere to the harvesting program after spraying.

Agronomic factors
When crop vigor in the latter stages of growth is such that long immature internodes are being formed, growth can be modified by chemical ripeners to enhance sucrose yields.

- **General crop management.** High yielding crops that have been optimally fertilised and carefully managed from crop start to harvest will respond best to chemical ripeners. Chemical ripening should never be considered as the panacea to malnourished, mismanaged crops that yield poorly at harvest. Highest yielding crops should receive the highest priority for chemical ripening. Therefore the use of chemical ripeners places a higher demand on sound crop management practices and detailed planning of harvesting schedules (Eastwood and Davis 1997; Rixon et al. 2007).

- **Drought stress and ripeners.** Drought stress in a sugarcane crop lowers growth potential but also may have severe negative consequences on the benefits realised from chemical ripening. A good example is the application of glyphosate (e.g. Roundup and Polado) to drought stressed cane, which has led to adverse residual effects (e.g. prolonged stunting of the next ratoon crop) in several countries (Donaldson and Inman-Bamber 1982; Sweet et al. 1987; Eastwood and Davis 1997). Thus it appears that the metabolism and translocation of glyphosate in stressed crops is different and causes reduced growth in the following crop. This was the reason for glyphosate losing favor with South African sugarcane producers soon after being registered (Donaldson 1999). Drought stress is also known to reduce the efficacy of the active compounds of Fusilade once absorbed by the leaves. For example, esterase enzymes within the plant convert fluazifop-p-butyl (Fusilade Super or Fusilade Forte) to a more active form (Gronwald 1991; Eastwood and Davis 1997). However, during drought stress plants produce less of these esterase enzymes, thus lowering conversion of fluazifop-p-butyl to its more active form (Donaldson and van Staden 1992; Donaldson 1999; Eastwood and Davis 1997). Similarly, bioactive GA₃ is not produced in large amounts in slow growing drought stressed cane, thus lowering the efficacy of trinexapac-ethyl (Moddus) as a chemical ripener (Rixon et al. 2007).

Experiences with glyphosate are an illustration of the possible residual effects that may develop from applying growth regulating chemicals to drought stressed sugarcane crops. In addition to reducing the efficacy of the ripener, drought stress may also have negative effects on the yields of the next ratoon (Clowes 1980; McCatty 1980; Donaldson and Inman-Bamber 1981; Rostron 1985; Donaldson and van Staden 1992; Donaldson 1986; 1999; Eastwood and Davis 1997; Rixon et al. 2007). The positive effects of mild drought stress and chemical ripeners on cane quality are not additive (Morgan et al. 2007). In typical dryland agriculture
under more marginal conditions chemical ripening is usually only recommended in areas with soils of high water holding capacity.

It is normally advocated that a chemically ripened crop should be irrigated for as long as possible, excluding the period immediately before harvest. This is simply to allow the soil to dry out sufficiently so that soil compaction and crop damage are avoided during infield operations (Donaldson 1986; 1999). Every effort should be made to avoid soil compaction and mechanical damage to the crop. This may mean that ripener programs are suspended until good drainage systems are in place and infield traffic is directed to minimize crop and soil damage.

- **Topping height adjustment.** Vigorously growing crops develop long green ‘tops’ that would most often not contribute towards substantial sucrose storage because of the immaturity of those tissues. Much of the green top is removed (topped) during harvesting. However, chemical ripening effectively increases the sucrose content of the young upper internodes, and therefore topping height should be higher than for unripened stalks (Soopramanien *et al.* 1990). The upward adjustment of the topping height of ripened cane cancels much of the negative effects that the chemical may have on the growth of stalks, so that yield losses from the correct use of ripeners may be less than 2% (Donaldson 1989). Millable cane yield loss in chemically ripened crops can often be wrongly perceived because of the visual appearance of ripened cane, which is often shorter than unripened cane (Di Bella *et al.* 2008). It should be noted that although the largest improvement in sucrose content can be expected to develop in the upper, more immature sections of the stalk where internode elongation is taking place (Rostron 1977b; Soopramanien *et al.* 1990; Eastwood and Davis 1997), internodes lower down the stalk that are already fully elongated at the time of ripener application, often also respond favourably (Rostron 1977b; Clowes 1980), especially in the case of glyphosate (Tianco and Gonzales 1980).

- **Lodging.** Lodging per se often causes breakage and smothering of cane stalks causing some stalks to die and, as a consequence, reduces biomass accumulation leading up to harvest. Ripener application to severely lodged sugarcane can lead to poor and variable quality improvement responses (Kingston *et al.* 1991; Kingston and Rixon 2007). This is primarily due to the variable nature of lodging but, immediately following severe lodging, changes in the orientation of the green leaf canopy could cause poor interception of the chemical ripener. The green canopy is reformed when the recumbent stalks have again assumed an erect growth habit, making these crops again more suitable to intercept the ripener being applied. Responses to ripeners tend to be much reduced when applied to lodged crops and could be less than 50 % of the response from an erect crop (author’s unpublished data). The application of certain ripeners to erect crops could lower the incidence of lodging during the time between ripener applications and harvesting when compared to unsprayed crops (Selleck *et al.* 1974). However, the opposite may also be true if the growth regulator creates a ‘top-heavy’ crop. Crop growth regulators such as trinexapac-ethyl (Moddus) may stimulate root growth in the following crop (Resende *et al.* 2000) and the more extensive roots might then enhance resistance to lodging (Rixon *et al.* 2007). Practical aspects of this technology are presently being investigated by scientists at the South African Sugarcane Research Institute.

- **Management implications.** The application of chemical ripeners can have other desirable impacts on management. The reduction in foliage (leaf area and tops) can sometimes reduce lodging and trash, and facilitate topping and produce a better burn. There can also be positive impacts such as cane delivered to the mill being cleaner, with less trash, improved bundle
weights and lower transport costs per tonne of sugar. This last consideration is particularly important for cane that has to be delivered some distance to the mill.

Pest and disease infected crops
Pest or disease infestations reduce crop growth vigor and as a consequence responses to ripener application will be affected. The negative impact may either be through poor responses in terms of cane quality or by reducing cane yields, or both these factors. Studies that have included pest infested or diseased crops are rare, because crop vigor is reduced by pest and disease and crops are then unsuitable for good responses to develop (Martin et al. 1980; Eastwood and Davis 1997). Some evidence suggests that chemical ripening of cane infected with ratoon stunting disease (RSD) may even lead to additional yield losses (Martin et al. 1980). Because most diseases interfere either with the photosynthetic capacity or general metabolism of the crop, they are likely to restrict the uptake of foliar applied chemicals and disrupt the processing of the chemical by the plant which is required to produce the ripening responses (Soopramanien et al. 1984; Rixon et al. 2007). In southern African sugar industries, the application of ripeners to crops infested by the African sugarcane borer (Eldana saccharina) is avoided because of the reduced responses associated with such crops, and to avoid the risk of increased infestation following the use of ripeners on infested crops (Sweet et al. 1987).

Box 10.7 Fine-tuning to maximize benefits from ripeners
- Target high yielding, immature crops.
- Maintain standard fertilizer programs.
- Avoid stressed, flowered and diseased crops.
- Keep drying-off period short.
- Top stalks higher up the stalk.
- Lodged crops should be relegated to lower priority and topped with greater care.
- Consider phasing out the use of chemicals to ripen crops by using appropriate cultivars, careful drying-off, adjusting topping height and/or ageing crops.

10.5 Flowering

10.5.1 The occurrence of flowering

Flowering in sugarcane is induced when day length shortens from 12 h 30 min in autumn provided the shoots are old enough to respond to the flowering stimulus (Ethirajan 1987). Moore (1987) has observed that some clones will respond to the increasing day length changes in spring. It is not clear whether flowers are initiated in autumn but then only emerge in the spring. Night temperatures between 18 °C and 27 °C during the inductive photoperiod, which lasts for about 30 days, produce the strongest stimulus for flowering. Day temperatures are not critical up to 48 °C (Coleman 1968). When minimum (night) temperatures decline below a critical level of about 18 °C for more than 10 days during the initiation period, flowering is inhibited in Hawaii (18-21 °N) while in Louisiana (30 °N) six nights of these non-inductive temperatures will prevent flowering (Coleman 1968).

Flowering may also be reduced when crops are subjected to moisture stress during the photo inductive period (Gosnell 1973). In some countries, flowering is localised to low altitude areas where suitable temperatures are experienced. For example, in the South African sugar industry, flowering is most profuse along the foothills of the Lebombo Mountains of Mpumalanga and less so in the Pongola flood plains. Large areas of the Swaziland sugar industry are also affected by flowering. Flowering may be an annual event in some areas, although it is seldom that more than 60 % of the stalks produce flowers along the coastal areas of KwaZulu-Natal. In other areas flowering is sporadic.
and often not profuse. In contrast, other sugar industries are affected more by flowering, e.g. flowering is profuse and is an annual event that affects the entire estate of Kenana in Sudan. When the flower inflorescence develops in the stalk apex, it terminates the formation of new nodes and internodes (Fig. 10.5). After flower initiation, newly formed sheaths develop more rapidly and are elongated. This additional development of the sheaths is at the expense of blade development, which become progressively smaller. Sheaths envelop the flower pedicle. The photosynthetic leaf area of plants is reduced and consequently the ability of the stalk to accumulate biomass is compromised when older leaves senesce and are replaced by smaller blades. In some instances, axillary buds on nodes below the pedicle develop into side-shoots, which become the source of photosynthate that prevents rapid deterioration of stalks (Julien and Soopramanien 1976; Julien et al. 1980). Non-flowered stalks, which may have been smaller at the time of flower formation, maintain their vigor and in time become superior to flowered stalks.

Figure 10.5. Flowers terminate vegetative growth and limit the yield potentials of crops.

10.5.2 Suppression of the flowering process

In the Sudan (13° 05’ N, 410 m asl) sugarcane flowers annually and it is common that 80 to 100 % of the stalks produce flowers. Under the conditions in the Sudan, large benefits from suppressing flower initiation with ethephon have been achieved (Hardy et al. 1986). Other instances of benefits from suppressed flowering using ethephon have been reported by Moore and Osgood (1986) and Fadayomi et al. (1995). Ethephon has been used on a commercial scale in countries such as Hawaii, Brazil and Malawi (Hardy et al. 1986). Recent field observations on the KwaZulu-Natal south coast confirm that ethephon will reduce the adverse effects of flowering on yields of crops that are harvested after September or in the following season (Humm 2001). This is because under such conditions the period between flower emergence and harvesting would be long (more than 10 months) and it is likely that stalks with flowers would deteriorate during this time. In contrast to the observations by Humm (2001), Hardy et al. (1986) and Moore and Osgood (1986), no benefit could be demonstrated from ethephon applied to cultivar N23 (48 % flowered stalks) harvested at the age of 14 months. Furthermore, yields of N17 treated with ethephon were lower than both untreated cane (37 % flowered stalks) and of cane which had not flowered after being exposed to lights at dawn (Donaldson 1996). Flowering affects cultivars differently (Nuss and Maharaj 1992; Julien and Soopramanien 1976; Donaldson 1996). It is therefore important to quantify the effects of ethephon on yields when flowering does and does not occur, because flowering is generally neither profuse nor an annual event in all sugar industries (Donaldson and Singels 2004).
Ethrel may, however, cause suckering (bull shoots/water shoots) and the bull shoots are known to lower cane quality if they form part of the harvested crop during mechanical harvesting. With manual harvesting it should be easy to train cutters to exclude the bull shoots. The trade-off between using Ethrel to avoid the effects of flowering (and suffering the ill effects of bull shoots) should be weighed up against the losses from deterioration of flowered stalks. It may be prudent then not to use Ethrel in mechanically harvested fields that flower profusely, but then to harvest the crop as a priority to avoid the effects of flowering which advance with age and increasing temperatures. The other alternative is to avoid planting cultivars that have a high propensity to flower in fields that will be harvested by machines.

**Box 10.8 Flower Suppression**

Flowering can have a negative effect on sugarcane yield and quality (Berding and Hurney 2005) because internode and green leaf production ceases and this then leads to arrested growth. The benefits from applying chemicals to prevent flower initiation should be tested at field level because of the many factors which impact negatively on efficacy. Crops exhibiting profuse flowering should not be sprayed because the ripener is likely to be intercepted by flowers and the ripener will be competing with the natural slowing down process in growth that occurs in flowered stalks (Kingston et al. 1991). Many cultivars do not produce flowers (shy-flowering cultivars) and these should be tested as they offer the best option in the long term for end of season harvesting.

### 10.6.1 Effects of some ripening chemicals on soil organisms

The misconception that these chemicals are environmentally ‘safe’ is based on either the low dosages used (herbicide-types) or that the products only affect plant growth. When compared with herbicide usage they therefore appear to be a low risk to the environment. While glyphosate is commonly incorrectly purported to be rapidly degraded by soil organisms it is considered to be ‘extremely persistent’ by the EPA of the USA where it has been calculated to have a half life of 100 days in field conditions, and in laboratory studies was shown to reduce plant resistance to disease and reduce the growth of nitrogen-fixing bacteria (Cox 1998). Soil microbial activity is arrested by ethylene oxide (Negre et al. 1988), a product which could possibly be formed when ethylene levels are raised by deposits of ethephon from chemical ripening. Fluazifop-butyl has been calculated to have been hydrolysed to 40 % of its original concentration after 21 days in a dry soil, and this was more rapid in wetter soils (Negre et al. 1988). It has been found to bind strongly to homoionc clays but, despite its strong adsorption to soils, Kulshrestha et al. (1995) found that fluazifop-p-butyl leached to at least 15 cm deep in soybean fields in India. Fluazifop-p-butyl is reported to be of low mobility in soils and does not present an appreciable risk to groundwater contamination.

Several case studies have reported that Fusilade may be toxic to fungi and this is summarised in the following statements: “Fluazifop-p-butyl has been shown to inhibit fungal growth” (Abdel-Mallek et
Abdel-Mallek et al. (1996) found that "fungal populations were temporarily (one to two weeks) decreased at rates above 3.0 µg/g and for longer periods of time (more than eight weeks) at rates above 6.0 µg/g." The concluding statement following these revelations is that "Fluazifop does not have a significant effect on fungal populations when applied at recommended field rates." However, no cognizance appears to have been taken of potential accumulation points created by field structures and waterways.

**10.6.2 Chemical release into the environment**

Fusilade is not readily degraded by photolysis and is not prone to volatilization at lower temperatures. However, the potential to volatilize may increase with increasing temperature (Helling et al. 1971). In many countries midday temperatures above 25 °C are common, and volatilization then becomes a strong possibility. Consequently spraying may need to be restricted to the early morning, which brings with it the danger of spraying during periods when temperature inversions are common. Ethephon was applied at 0.55 kg/ha in a water carrier volume of 93.5 L/ha and delivered at a height of 7.6 m and an average speed of 145 km/h to assess drift from the target. Enough ethephon was detected in the range of 7.6 to 61 m from the point of release of the spray to cause tomato flower and fruit drop. In addition, droplets were detected at a distance of 122 m from the application point. Indications were that aerial spraying of ethephon at rates required for control of flower initiation in sugarcane will not adversely affect tomatoes further than 244 m from the spray edge (De Frank 1988). In South Africa buffer zones greater than 200 m are not common in mixed crop farming areas and incidents of crops being affected by spray drift, even though they occur annually, are seldom reported.

It is anticipated that the sugarcane canopy will intercept most of the chemical being applied. However, there is some risk that drift beyond the target field, which is common, will cause the chemical to collect in drainage lines and waterways. Water flowing from these watercourses will carry the contaminant into collection points such as rivers, pools, dams and swamps. An aircraft swath is relatively narrow (20 to 25 m) and therefore one field will have several passes, each of which could deliver chemical into the waterway. It is therefore easy to envisage how pools and/or dams fed by such waterways could be contaminated by ripeners delivered by aircraft. The toxicity of glyphosate to frogs and of Fusilade to fish species is common knowledge, but is often overlooked by users of these products. Several other aquatic invertebrates are also known to be killed by these compounds. The purveyors of ethephon formulations also caution against the product reaching water conduits during spraying operations. The reason may be related to the phytotoxicity of very low levels of ethylene when taken up by plant roots and its toxicity to aquatic organisms (Anon 2009). The half life of Fusilade in an aquatic environment may range from 79 days to 2.2 years (Anon 1998). Increased temperatures can increase the rate of hydrolysis (Balinova and Lalova 1992).

All the chemicals used as sugarcane ripeners could affect plant growth. Although only graminaceous species are affected by Fusilade, all vegetation bordering sugarcane fields is at high risk especially when an aircraft is used to deliver any of the ripeners. Incidents of chemical drift over long distances from aerial spaying are annual occurrences in sugarcane industries. These only come to light when neighbouring farmers complain of poor crop growth, unfamiliar symptoms and/or fruit drop. Cases that have been investigated have included crops of young sugarcane, vegetables and several fruit types. Such incidents are seldom recorded, are rarely challenged in a court of law and are poorly publicised. It is therefore imperative to take precautions to minimise the risk of spray drift when applying chemicals by aircraft to sugarcane. This currently includes the addition of adjuvants to spray mixture to reduce drift. The paucity of toxicological information of these adjuvants is, however, a concern and users should be cautioned against the use of products that have little toxicological data. Generally toxicological data are based purely on the active ingredient (technical product) or the
killing agent’. However, commercial formulations may contain several stabilising compounds, surfactants and/or oil concentrates (Buhler and Burnside 1984), which may enhance the efficacy and toxicity of the product significantly. These added chemicals are often not listed on data sheets and could include chemicals such as naphthalene, petroleum or paraffin distillates and other petroleum solvents each of which has its own toxicological profile. Data sheets often refer to these as ‘inert’ and they are also often referred to by a code that gives no information and cannot be easily identified even by diligent independent researchers. The user is therefore mostly unaware of the composition of the product and the potential impact of its content on the environment.

Exposure to sub-lethal doses that are used in ripening sugarcane may potentially initiate mechanisms that build up resistance to the chemical by both target and non-target organisms. The possibility that the practice of ripening sugarcane with low dosages of herbicides may induce tolerance to higher dosages of the chemical in weeds should be considered (Lee and Ngim 2000).

10.7 Potential impacts of growth regulators on economics and possible collateral damage

10.7.1 Economic impacts

Since the technology of regulating sugarcane growth through applied chemicals to either enhance sucrose content or suppress flower initiation became commercial practice in the 1960s it has been proven to be of great benefit to many sugarcane growers worldwide. Rostron (1996) estimated a cost benefit ratio range of 1:6 to 1:15 for chemical ripeners used in Swaziland. These benefits increased the net returns during 1994 by 9.7 million Elangeni per annum (about 1.3 million US$) in Swaziland. The correct use of ripeners has been estimated to increase sucrose yields on average by 0.8 t/ha in dryland sugarcane and by 1.2 t/ha in irrigated fields in South Africa.

The benefits from using ethephon to suppress flowering may be negligible where flowering is not profuse or in areas where flowering is not an annual occurrence, as in South Africa (Donaldson and Singles 2004). Hardy et al. (1986) demonstrated that annually harvested crops treated with ethephon yielded 36 % more sucrose than untreated crops when flowering was profuse (80-100 % flowering stalks) in Sudan.

When chemical ripeners are used correctly cane yields of treated crops are usually >98 % of that of untreated controls and there may be a reduction in molasses yields associated with increase in sucrose yields. Total biomass yields are therefore not adversely affected by chemical ripening. However cane, sucrose and biomass yield losses exceeding 10 % can easily develop when incorrect rates are applied and/or the appropriate spray to harvested interval is exceeded.

10.7.2 Potential social health impacts

Exposure of humans to these chemicals may commonly cause reactions ranging from skin and eye irritations to severe digestive tract burns and diarrhoea, destruction of mucous membranes and chemical pneumonitis (Cox 1998). Exposure to these chemicals in the undiluted formulation is possible at any point from factory to field. After spraying, the chemicals may contaminate soil, air and water that could be consumed by animals and humans. A fact sheet (Cox 1998) lists increased risk of non-Hodgkins’ lymphoma, miscarriages and premature births amongst people (mainly farmers) exposed to glyphosate. Although the risk was considered low, some genotoxic damage (binucleated cells with micronuclei, BNMM) was associated with exposure to glyphosate applied as a ripener in Valle del Cauca, Colombia (Bolognesi 2009). While fluazifop-p-butyl was regarded as “not likely to be carcinogenic to humans” (Anon 2005), its risk as an endocrine disrupter, and effects on embryo and reproductive organ development, were of concern and needed to be reassessed (Locke
et al. undated). New formulations of glyphosate and Fusilade may have excluded offending additives but this has been after many years of commercial use of the products containing environmentally destructive components. Ethephon is listed as a dangerous cholinesterase inhibitor by the Pesticide Action Network North America (PANNA), which notes that many ‘inert’ substances in formulations are known to have adverse effects on humans and the environment (Kegsley et al. 2010).

10.8 Mitigating factors impacting on the effective use of ripeners and ethephon to control flowering

After the patent expiry date, many generic products become available throughout the world. Each new formulation may have different ‘additives’ and may also not have the same concentration of the active ingredient. Dosage rates that are then recommended are usually based on little new efficacy data. Consequently, dosage rates may be adjusted according to anecdotal evidence, e.g. when commercial applications indicate poor results in field data.

The most widely used ripeners in the past have been ethephon and glyphosate. Ethephon has been shown to be effective only on relatively immature sugarcane and not effective on some commercially grown cultivars. Establishing specific cultivar responses to ripeners needs carefully conducted testing procedures and the maturity of the crop to be sprayed needs to be accurately determined. For both these reasons it is very likely that ethephon is often not being used as effectively as it could be.

In many countries Fusilade formulations are preferred to glyphosate, because Fusilade is less damaging to the regrowth and yields of stressed crops. Slow adoption of new technology results in some industries still using glyphosate (e.g. a large estate in Sudan in 2008). The efficacy of Fusilade is now known to be lower on stressed crops. Before the action of stress on the mode of action of Fusilade was known, some incorrectly suggested that higher dosage rates would correct poor responses to the ripener. Often the higher rates have been retained in the recommendations despite the new knowledge, because of the very favorable cost: return ratios. It is possible that some cultivars require higher rates than the standard recommended rates. Despite the formal recommendation of different rates for different cultivars, it is very likely that in a commercial situation the highest rate is adopted for the entire group of cultivars. The reason is merely to avoid the effort required to apply specific rates to different cultivars. It is very clear that vigorous growth of the crop is a fundamental requirement for the most effective use of chemical ripeners. Despite this it appears to be common practice to suspend irrigation at about the time that the ripener is applied, and this could nullify the response on soils with low soil water holding capacity. When drying-off is practised in relation to soil water characteristics, predicted atmospheric demands (evapotranspiration) and plant stress physiology (e.g. Donaldson and Bezuidenhout 2000) the crop ripens very efficiently and cannot be improved by ripening chemicals. The severe adverse effects that commercial applications of glyphosate had on the ratooning ability of sugarcane when used on stressed crops in the South African industry during 1982 is an example of incorrectly following clear label specifications. Experiments during the same period showed that, when applied correctly to well irrigated crops of NCo376, sucrose yields were increased on average by 3 t/ha over a period of four years. No residual activity was evident from glyphosate under these good growing conditions (Donaldson and Inman-Bamber 1982).

The consequences of mistiming ethephon applications in relation to flower initiation dates were evident in the results of experiments conducted by Hardy et al. (1986) in Sudan. When applied correctly ethephon increased yields by up to 4.1 t sugar/ha but was less effective when the application was made too late (i.e. too close to the date of initiation).
It is clear that the choice of ripener and the rates used may be dictated by the conditions prevailing at field level. Cultivar-specific responses, for example, may determine whether ethephon can be used and/or the rate at which Fusilade should be applied. Cultivar type could also determine whether the combination of ethephon and Fusilade is the best ripening option.

Milling periods should be centered on the time of peak sucrose yields when crops have high naturally induced sucrose content. Recent research has shown that sucrose yields may be depressed after spring in South Africa (Reduced Spring Growth Phenomenon, RSGP) (Donaldson 2009; van Heerden et al. 2010). New cultivars may need to be introduced or milling periods may need to be adjusted to avoid harvesting crops most severely affected by RSGP. This may then also reduce the potential effects of flowering on yields and therefore reduce the need to apply chemicals to suppress flowering.

Choice of new cultivars is mainly based on yields and mitigating possible reductions from pests and diseases. Cultivars are also matched to soil characteristics and season effects to ensure that sustainable yields are attained. This may include choosing shy-flowering cultivars and cultivars with naturally high sucrose content that could eliminate or reduce the need for chemical ripening and flower suppression practices.

Drainage structures are often required to avoid stagnant water causing anaerobic conditions around sugarcane stools. These drainage structures could be the conduits of water contaminated with chemicals applied to sugarcane that lead into larger waterways and wetlands, marshes, pools, rivers and dams.

Irrigation is often suspended in preparation for harvesting. If the practice is used to dry the soil profile and thereby avoid soil compaction and damage to stools during harvesting operations, then an assessment of the need to simultaneously ripen the crop with a chemical should be made. Damage to stools due to wet conditions at harvest should be avoided, and the dry conditions may eliminate the need for chemical ripening. However, care should be taken to use the appropriate length of the drying-off period to ripen the crop. Irrigation after the ripener application is usually required to maintain vigorous growth in soils with low water content. The drying off period should, however, ensure that soil water levels are appropriate to avoid damage during harvesting operations. Irrigating a field within 12 hours of application is discouraged – this is to avoid chemicals from being washed off the foliage before they are absorbed by the leaves.

The fact that ripeners are applied mainly by aircraft significantly increases the chances that non-target organisms will be affected by spray drift. Often the terrain on which sugarcane is cultivated makes it difficult for fixed wing aircraft to safely reach areas and achieve an even distribution. Rotary winged or micro-light aircraft may then be employed. Applications from micro-light aircraft raise the risk of contaminating the pilot and of chemical drift onto non-target organisms. The use of mistblowers to deliver ripeners has had poor results because of poor distribution patterns. This, together with the high risk of drift onto non-target areas should discourage any grower who is concerned with safety for the community and the environment. Aerially applied chemicals are more prone to volatilisation because of the smaller droplet sizes in the spray cloud. It is well known that most chemicals are significantly more toxic when they are inhaled or absorbed through mucous membranes than when they are absorbed through dry skin (dermal toxicity). Ground rigs distribute chemicals more evenly than when applied by aircraft and this means that lower rates (≤ 10 % less) are generally recommended, particularly when larger spray volumes are used. The risk of drift and collateral damage can be greatly reduced by applications from ground rigs. Exposure of personnel to the product during application can be minimised by rigorous training, controlled handling of the product and the use of protective clothing and masks.
10.9 Conclusion

It is clear that under specific conditions chemicals can be used to ripen crops and reduce the adverse effects of flowering.

The benefits can be economically attractive; the potential collateral damage can be obvious, but is often latent or ill-defined.

Adhering to GMP will increase the probability of good returns and reduce the impact on the environment of these chemicals (see 10.10 below).

In the long term, breeding and the selection of suitable cultivars is the best option.

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<th>Box 10.9 Summary of GMPs when using chemical ripeners and flower suppressants</th>
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<td>• All practices should place high priority on the safety of personnel, protection of the environment and achieving the best economic returns.</td>
</tr>
<tr>
<td>• Select high yielding fields with responsive cultivars which are immature, with well grown internodes at the top and which have at least eight green healthy leaves. The crop must not be under stress and must have low sucrose content. Stalks should be tested for juice purity.</td>
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<tr>
<td>• Select fields that are accessible and where there is least likelihood of drift hazard to neighboring crops.</td>
</tr>
<tr>
<td>• Infield structures must be erected to prevent contaminated surface water from exiting a treated field immediately after spraying.</td>
</tr>
<tr>
<td>• Apply only registered ripeners and select ripener to suit the specific cultivar and conditions.</td>
</tr>
<tr>
<td>• Irrigate after spraying to maintain crop vigor, but avoid over irrigation as soils should be dry at harvest to avoid damage to stools.</td>
</tr>
<tr>
<td>• Draw up the spray program based on the harvesting schedule and time of season. This will help to avoid exceeding the stipulated spray to harvest interval.</td>
</tr>
<tr>
<td>• Take all precautions to minimize exposure of personnel to chemicals.</td>
</tr>
<tr>
<td>• Apply the ripener at the recommended dosage using the appropriate method of application.</td>
</tr>
<tr>
<td>• The spraying method used should minimize exposure of personnel to chemicals and cause the least damage to the environment.</td>
</tr>
<tr>
<td>• Use experienced, licensed and registered crop spray operators.</td>
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</tbody>
</table>
- Train and monitor personnel on the safe use of chemicals to develop a ‘safety first’ mindset.

- Provide personnel with safety clothing and other equipment.

- Keep detailed records of each spraying event. Ensure that the pilot signs off after each operation.

- Alert neighbors and relevant authorities before each spraying operation.

- Spray under good weather conditions to minimize the risk of the chemical moving off the target, and establish appropriate buffer zones.

- Harvest fields according to the planned schedule.

- Top stalks higher than normal and close to the stalk apex.

- In the long term the emphasis must be to breed and select cultivars to fulfill the role that chemical ripeners have. This would save on costs, reduce risk and be more acceptable to personnel and to the environment.
10.11 References


**Acknowledgement**

Part of this chapter was written in parallel with and adapted from Chapter 4 Ripening and postharvest deterioration, by van Heerden PDR, Eggleston G and Donaldson RA (2011) In: *Physiology of Sugarcane*, Moore PH and Botha F (eds) Shelby Allen, Wiley-Blackwell, 2121 State Avenue, Ames, IA 50014, T: 515-292-0140 ext. 647 E: shallen@wiley.com
CHAPTER 11 HARVESTING AND HAULAGE - PETER BRAITHWAITE

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11. HARVESTING AND HAULAGE

This chapter introduces the most important (and expensive) aspects of sugarcane production; the harvest of the crop and its transport to the mill.

11.1 Harvesting

The importance of a harvesting program for the season is stressed. Hand cutting is still practiced in many parts of the world, particularly when cane is burnt before harvesting. The move to green harvesting has brought with it a move to chopper harvesting, which is widely practiced in many countries. Whole-stick harvesters are still used in some areas, but have been largely phased out. Factors affecting harvesting and loading are described, as well as the social and environmental considerations.

11.1.1 Pre-harvest

The planning of the harvesting season starts with the development of a harvesting program to sequence the cutting of fields in order to maximize the profitability of the farm by taking advantage of the high sucrose yield period matched to the crushing capacity of the mill. Factors to be considered include:

- Plough-out considerations
- Replant program
- Historical performance
- Yield estimates
- Crop age, cultivar, lodging
- Ripening by drying off, climate or chemicals
- Mill crush rate and season length
- Frost
- Pests and diseases
- Drainage, soil conditions
- Fire protection
- Burn vs. trash
- Farm balance for following seasons.

A basic plan can be developed manually; however, detailed planning requires sophisticated programming based on an agricultural management information system, such as offered by SQR software in Pietermaritzburg, South Africa (McGlinchey and Dell 2010).

11.1.2 Manual system

Manual harvesting of sugarcane can be broken down into the following components:

- Burning or trashing
- Base cutting
- Topping
- Stacking or windrowing (Figure 11.1)
- Loading
In many parts of Africa the majority of hand cut cane is currently burnt before cutting commences. The main reason for burning is to maximize production from each cutter. Depending on conditions burning can increase a cutter’s performance by up to 30% (Meyer and Fenwick 2003). When yields are above 90 t/ha, cutting green cane become difficult as the trash interferes with stacking and acceptable base cutting.

However, in many countries the Government or the environmental lobby is putting pressure on industries to ban or regulate burning. The economics of trashing vs. burning has been the subject of debate for many years (Meyer et al. 2005, van Antwerpen et al. 2006, Richard 2007, Gomaz et al. 2007, McElligott 2007, Purchase et al. 2008, Muir et al. 2009, Wiedenfeld 2009, Lecler et al. 2009). This has been backed up by many decades of research outcomes that have highlighted the pros and cons of retaining a trash blanket in the field instead of burning cane prior to harvest (see Chapter 2.9.7 and Chapter 13.3.3). For example Thompson (1965, 1966) found that the potential conservation of rainfall from trashing was equivalent to 90 mm/an, which would have a significant impact on crop yield, especially in dry years along the east coast of South Africa. The value of this additional water in terms of yield was established by Thompson (1976) to average 9 tons cane per 100 mm water lost through transpiration. This average response to trashing was further corroborated by van Antwerpen et al (2006), when reviewing the results of sixty years of cropping from the long term burning and trashing trial located at Mt Edgecombe (BT1 trial). The best yield responses to trashing were associated with dry years while in wet years the responses were smaller and often negative when compared with burning.

Trashed cane can generally be supplied to the mill quicker than burnt cane, reducing deterioration and improving cane quality. Other reported benefits of trashing, include:

- weeds suppression, thereby reducing weed control costs (Lorenzi et. al., 1982);
- protection of the soil surface from erosion (Prove et. al., 1986);
- a valuable potential source of labile carbon (Bell et al., 2001) and other nutrients (Mitchell and Larsen, 2000). Labile carbon is an important fraction of the organic carbon pool in soil and assists in the maintenance of soil structure, water holding capacity, water infiltration (Bell et. al., 2001) as well as an energy source for soil micro-flora.
Further benefits are discussed in Chapter 13.3.3. Potential disadvantages include poor ratooning leading to yield reductions in high lying areas or under wet conditions due in part to lower ground temperatures. With greencane harvesting, the increase in trash results in higher costs in terms of reduced payloads, mill capacity and factory performance. In addition, the sugar quality in terms of the VHP standards for pol and color may also be a problem.

Given the large number of variables that can impact on the economics of trashing, Wynne and van Antwerpen (2004) developed a Decision Support System (DSS) that can assist managers in evaluating different ‘what if’ scenarios concerning the economic consequences affecting the harvesting process, whether to trash or burn. The variables include the weather conditions, size of the farm, sugarcane price, cane age at harvest, yield in tons cane per hectare per month, the number of seasons that trashing was practiced, value of the trash, the cost of fertilizers and herbicides, harvesting and transport costs and labor requirements. Purchase et al. (2008) used this program to assess costs and benefits of trash removal in the South Africa sugar industry (see 14.5.2).

**Base cutting and topping**

There is more sucrose at the base of the stalk compared with the middle or top (Mann 1980) and it is therefore critical that the cutter cuts at ground level to maximize yields, and also to facilitate the ratooning of the following crop. Poor base cutting provides increased entry points for pests and diseases.

With respect to topping, the natural breaking point is used to indicate the topping height of cane. The height of topping is important, as topping too high increases transport costs and at the same time reduces the efficiency of mill extraction and sugar recovery. Topping too low results in a loss of sucrose.

The performance of a cane cutter is largely dependent on the type of knife used and the training that has been given. The traditional cane knife for cutting *green cane* is a straight bladed, short handled knife, which requires the operator to get his wrist within 20 cm of the ground in order to get an acceptable base cut. A modified knife, the short handled curved bladed knife, is more ergonomically acceptable to the cutters and results in increased productivity of approximately 7% (Brookes 1983). It is also common practice to pretrash the green cane before cutting, with a number of different tools being used in different countries.

The preferred knife when cutting *burnt cane* is the long handled Australian knife. When compared to the short handled knife the daily output is conservatively estimated to improve by 10-15%.

**Stacking or windrowing**

Cutters are remunerated for the tonnes of cane cut in a day. They prefer to have the cane weighed in the field to ensure that they are receiving fair compensation. This is possible when cutters produce their own stacks and there are cranes with scales or portable weighbridges on the zones.

In cases where it is not possible to weigh the cane, usually when the cane is windrowed for mechanical loading, an estimate of cane cut has to be agreed with the cutter, based on estimated yield and length of row cut. This can become an emotive issue, and accurate estimating and cross-checks with the weight of cane across the weighbridge at the mill is critical.

Whether stacking or windrowing, cutters are paid a basic rate for an agreed minimum daily task plus a bonus rate for additional tonnage. Basic tasks vary between countries and farms. The average for burnt cut and stacked cane is 5 t/cutter and 9 t/cutter for burnt and windrowed. A study carried out in South Africa (Meyer and Fenwick 2003) showed that cane cutter performance is largely
dependent on the harvesting systems adopted and the motivational and hygiene factors in place in the work place.

**Loading**

Loading of cane in the field is dependent on a number of factors. In steep terrain the preferred method is to extract the cane using agricultural tractors with self-loading and self-offloading trailers and move the cane from the field to a transloading zone. Where the trailer cannot self-offload a crane will be required on the transloading zone. In the field the cutters build stacks strategically placed so as to allow reasonable access for the tractor trailer combination, and presented in such a way that the trailer cables or chains can be threaded around the bundles to facilitate winching onto the trailers.

Alternative systems used in Zimbabwe and Malawi rely on separate winch tractors to load the haulage trailers (Mascane system). This has the advantage of being able to use multiple trailers and haul more tonnage with the prime mover. Single trailers are only efficient when the haulage distance from field to zone does not exceed approximately 1 km.

There are basically two types of mechanical loaders, slewing or non-slewing (Meyer 1997). Slewing loaders (Figure 11.2) usually pick up the cane and load into infield transport travelling alongside. Non-slewing loaders usually pick cane up from windrows or hand made bundles and have to maneuver in order to load into infield transport or to make stacks. Continuous loaders have been used extensively in the past but are no longer favored.

![Figure 11.2. Typical self-propelled slewing grab loader in operation.](image)

Loaders range in capacity and cost, from simple non-slewing attachments for tractors loading 10 t/h, to self-propelled machines loading 60 t/h. Annual output and utilization will determine loading cost per tonne.

Loaders that push-pile are responsible for increased extraneous matter, mostly soil, being delivered to the mill.

In certain places, pallet systems are used. Pallets are dropped in the field to be loaded mechanically or by hand. A simple trailer chassis is used to pick up the pallets. The time required to drop an empty
pallet and pick up a loaded pallet is fairly short, and a single tractor can handle more cane than would have been possible with a self-loading trailer.

11.1.3 Mechanical whole stick

The cutting operation can be mechanized by simple cutting arrangements attached to tractors, small hand held self-propelled walk behind cutters, or fully mechanized whole stick or chopped cane harvesters (Meyer 1999, 2001; Meyer et al. 2002).

Recently two small hand held self-propelled walk behind cutters have been tried and operated commercially on the Sezela Sugar Estate in South Africa.

Also in South Africa, a brush cutter with redesigned blade configuration was shown to offer a viable alternative to the conventional method of hand cutting (Lyne et al. 2007). A more viable option tested and now being used commercially is the use of a modified hand held sickle mower named the ‘Cane Thumper’ (Langton et al. 2008) (Figure 11.3). The cane thumper can be used in both burnt and green cane, with the cane being windrowed or stacked by hand, as in the manual cutting system.

![Figure 11.3. Self-propelled ‘Cane Thumper’ cane cutter.](image)

With whole stick harvesters (Figure 11.4) the cane is base cut and topped in one or two rows of green cane per pass. The piling arms place six rows of cane in a single row. After windrowing the cane is burnt and mechanically loaded into road transport vehicles, using high capacity push-pile loaders. Although whole stick harvesters are still used, where conditions permit, in countries such as Argentina, Brazil, Mauritius, Mexico, Paraguay, Reunion and South Africa, the chopper harvester method is now the preferred method.
In Hawaii, on one estate, the crop is burnt and then harvested using crawler mounted Vee cutters, after which the cane is pushed into large piles. The cane is then mechanically loaded into road transport using mobile cranes with 4 t grab capacities.

Other types of whole stalk harvesters which bundle (Figure 11.5) or windrow the cane have been developed in numerous countries such as Australia, Barbados, Brazil, India, Mauritius, Mexico, Reunion and South Africa. These machines have generally not been very successful and in most instances have been limited to harvesting burnt, erect cane.

**11.1.4 Chopper harvesters**

Chopper harvesters (Figure 11.6) cut and top one or two rows of cane per pass, and chop the cane stalks into billets approximately 200-400 mm in length. Cane tops missed by the external topper, and trash and other extraneous matter are removed by primary and secondary extractor fans. The billets
are delivered into basket type trailers travelling alongside the harvester. For a detailed description of the various operations which include topping, gathering, feeding, base cutting, chopping, cleaning, instrumentation and performance, see the Australian Bureau of Sugar Experiment Stations (BSES) manual of cane growing.

![Figure 11.6. Chopper harvester operating in green cane.](image)

The advantage of the chopper harvester over all the other harvesting systems is that it can harvest both burnt and green cane, erect or lodged, with yields in excess of 150 t/ha. Chopper harvesters are being used successfully in over 20 countries and, for example, in Australia and Florida harvest the total crop. The vast majority of Brazil’s enormous expansion is being cut by chopper harvesters. The disadvantages of chopper harvesters vs. hand cut cane include more extraneous matter and higher cane losses. Experiments in Swaziland (de Beer and Boevey 1979) showed that, when comparing chopper harvesting against hand harvesting under a burnt regime, of the estimated 118.9 t cane/ha standing in the field, 116.4 t/ha were recovered when hand harvesting and 110.8 t/ha when using a chopper harvester. The extraneous matter when hand cut measured 3.1 vs. 6.1 % for the chopper harvester. This level of loss has been confirmed by many other researchers.

Recent work using chopper harvesters to harvest trash for biomass have shown that cane losses can be significantly reduced by slowing down the extractors fans.

11.1.5 Factors affecting harvesting and loading

**Agronomic and irrigation issues**

The perception is that the effect of machinery going infield will reduce the crop yield over time. Concerns include:

- The mismatch between row spacing and the machinery track width is a concern which results in soil compaction and crop damage.
- Choppers travel every row as opposed to existing grab loading systems, which only travel approximately 40 % of the rows.
- Poor layouts result in machinery crossing rows with resultant damage to the crop.
- Pressure to supply the mill results in machinery operating during wet conditions resulting in compaction and stool damage.
- Poor row profiles result in poor cutting and damage to the stools.
• Chopper harvesters tend to uproot stools in plant cane.
• Ideally, cultivars should be selected with traits that include free trashing, thick non-brittle stalks of even length, and resistance to lodging, stool tipping, suckering, flowering and spread of disease (smut, RSD and rust).

Considerations with regard to the haulage system
A critical factor affecting chopper harvester performance is the number and capacity of infield haulage units and the distance they have to travel to transfer their load. Factors to consider include:

• Cost of total chain.
• Distance from the mill dictates whether one needs to transship or direct haul from machine to mill.
• Potential compaction and damage to the crop which will dictate gross mass, axle loads, tire and track specifications, track widths, speed, wet weather operation and prime mover kW and drive.
• Trailers must match the mill receiving facilities. Ideally, the cut to crush delay should not exceed three hours.
• The payload to GVM ratio should be maximized to prevent hauling tons of dead weight around.
• The smaller the billet size, the better the payload; therefore contractors will be tempted to reduce lengths where possible. However, very small billet sizes are detrimental to quality and, from the farmer’s point of view, billet size should be maximized.
• Bin trailers are prone to tipping over; therefore careful consideration should be given to their design.
• It is important that the loading is done quickly and effectively, while ensuring that spillage is limited and that the legal payload is achieved (Peter Lyne).

What are the implications in the mill?
Not all mills are geared to accept billeted cane and modifications may be necessary to ensure acceptance. Examples include:

• Increased capacity of tipplers to cope with higher payloads as a result of the increased density of billeted cane.
• Depending on the angle and design of the feed table, modifications may be necessary to move the cane, such as on slates or bars between chains.
• Rock removal systems treat billeted cane as rocks, and therefore have to be modified to cope.
• Due to the higher density of billeted cane, the feed rate needs to be controlled to prevent choking.
• The advantages of billeted cane to the mill are ease of handling, rock free, very little sand and trash, and reduced energy to drive the preparation knives.
• A disadvantage is that billeted cane cannot be stored.
• Green cane affects the recovery of sugar, the effective capacity of the mill and the milling costs (Rein 2005).

Chopper harvester performance and costs
The main factors affecting harvester output and cost include:

• Crop conditions (yield, cultivar, erect or lodged, green or burnt, dry or wet).
• Harvester (type, operator efficiency, forward speed, adjustments, hours per day, season length).
• Field conditions (terrain, row length, row spacing, row profile, headland width, field layout, irrigation system, soil type, drains, stores, roads and waterways).
• Infield loading.
- Transport system; it is critical that the harvester does not have to wait for the haulage vehicles.
- Tonnage cut per machine.

It follows therefore that chopper harvesting calls for more sophistication than the manual operation, and implementation must be preceded by detailed planning starting with the correct layout and planting of the fields to professional management of the harvesting and haulage operation.

**Effect on quality**
The main factors that affect quality of cane related to field and harvest conditions include:

- Ambient temperature
- Ambient humidity
- Rainfall and wind
- Degree of burn of cane
- Damage to billets
- Billet length
- Delay between burn and cut
- Delay between cut and crush
- Cultivar
- Topping height and base cutting height.

Billeted cane deteriorates very quickly, especially in hot conditions, and will have an advantage over whole stick only if there are no delays from cut to mill. Larger billets deteriorate more slowly than small billets (Wood, 1976).

Delays in getting the cane onto the mill tables is a concern in all areas, therefore the introduction of billeted cane increases the need for better scheduling to reduce delays and stock piles.

It is important that the cane payment system incentivizes the supplier to deliver clean, fresh cane.

**Acceptable criteria**
It is recommended that criteria be set for chopper harvester operations. The following criteria are used by a large estate in Swaziland:

- Cane delay
- Burn to cut – 12 h
- Cut to crush – 3 h
- Fields must be laid out according to agreed standards
- Fields must be free of rocks where possible
- Fields should be rolled after planting
- Purity
- better than mill average
- Pol, sucrose %
- better than mill average
- Stools uprooted
- less than 1 %
- Stubble height
- less than 5 %
- Stumps split
- less than 2 %
- Rows run over
- less than 5 %
- Cane left in field
- less than 0.2 t/ha
- Extraneous matter
- less than 5 %.
The setting of and strict adherence to agreed criteria is critical to ensuring a satisfactory operation and is particularly important when using outside contractors, as chopper harvesters are expensive, complicated machines that require a high level of skill and expertise to operate.

Assuming there is sufficient interest from contractors to ensure a healthy level of competitiveness, the contractor route is generally preferred to private ownership.

11.1.6 Summary of social, financial and environmental risks and benefits of each practice

The objective of the harvesting and haulage operation is to cut and deliver fresh cane to the mill which has been cut close to the ground and is free of trash, tops, sheaths, soil, rocks or other extraneous matter. However, across the globe, sugarcane is cultivated under a wide range of topographical and climatic conditions that have resulted in diverse harvesting methods and different results (see Table 11.2).

Historically cane has been burnt before cutting in order to optimize cutting productivity, maximize haulage payloads and ensure clean cane for the mill.

Current trends are to move away from burning to satisfy environmental concerns, conserve moisture, reduce soil erosion, control weeds and to take advantage of the value of tops and trash. The tops are left in the field for agronomic benefits such as provided by a mulch for soil, and water conservation and nutrient value. The trash can be removed and used by the mill to fuel the boilers which in turn produce a value in electricity which can be used to drive an irrigation system or can be sold to the national grid. In a recent study conducted in South Africa the economic benefits of changing from burnt to green cane harvesting are quantified in a multi stepped Decision Support System described by van Antwerpen et al. (2001) as detailed in Chapters 13.3, 13.4 and 14.5.

In many countries, it is still favored to cut cane manually, due to advantages such as cheap labor, steep conditions, better quality, less damage to stools and lower soil compaction. The major disadvantage of manually cut cane is that it is preferable to burn the cane before harvest in order to improve cutter productivity, and the long delays between burn and crush negatively affect the mill. In addition, there are serious potential threats to the safety and health of cutters which include eye damage from sharp objects, knife inflicted wounds to the body (mainly to the feet, legs, arms and hands), and fatigue from heat exhaustion and poor diet. Attention is being paid to all these factors, and protective clothing which includes safety goggles, gloves, leg shin guards, steel capped boots and smocks are freely available. Unfortunately cutters often find the protective clothing restrictive and prefer not to use it. Where cutters are employed on large estates it is common to supply housing, scientifically designed menus, safe transport and adequate drinking water at the work place. Risk associated with hand cutting and the huge labor requirement includes the use of child labor, not paying minimum wages, and unsafe working environment. The prevalence of HIV/AIDS in some countries is a serious threat in that it is having an effect on the availability of healthy cane cutters.

While there will always be a place for hand cut cane under certain conditions, such as steep terrain or small plots, the trend to satisfy the move to green cane harvesting is towards mechanization.

Based on the assumption that green cane harvesting is the preferred method to follow in order to satisfy environmental demands and take advantage of the surface residue and energy in trash, chopper harvesters emerge as the viable option, as these are the only machines that can cut green, lodged, high yielding fields. However, chopper harvesters cannot operate on steep slopes and when compared to manual operations can result in more damage to the crop, more cane losses, spread of
smut disease, increased extraneous matter, and severe soil compaction. When using chopper harvesters the preferred practice is to use controlled traffic with vehicle guidance on all field traffic.

The move to chopper harvesters calls for more sophistication in the harvesting operation and must be preceded by detailed planning, starting with the correct layout and planting of the fields to professional management of the harvesting and haulage operation. Soil levels in cane delivered to the mill in dry conditions are in the region of 1%, but can rise to as high as 10% in wet conditions. From a capital cost point of view mills then have to invest in larger clarifiers and filters and other mud handling equipment to deal with additional soil. The cane payment system must be designed to incentivize the farmer to supply clean, fresh cane.

Soil levels in cane can also be increased by mechanical loaders, and in Brazil and South Africa (Gordon 1978) levels are being reduced by placing cane in small bundles, forming bigger windrows and using improved push-piling attachments on slewing loaders. Other ways of reducing soil in cane include improved field preparation, effective maintenance of equipment, operator training and incentive schemes for operators. When using chopper harvesters consideration should be given to using yield mapping equipment. Yield maps facilitate the move to precision agriculture which is in the process of being tested on several large sugarcane estates in Brazil, and which has already proved very successful in other annual cropping systems.

Soil compaction and cane stool damage remain major concerns under mechanization, and the challenges are to find a crop row configuration that satisfies the needs of mechanization, irrigation and agronomy.
Box 11.1 Summary of good management practices for harvesting

Planning
- Farm layout, including headlands, roads, drainage and slopes.
- Row width, length and profile.

Pre-harvest
- Sequence cutting of fields to maximize sucrose potential
- Dry off naturally, or apply chemicals to artificially mature cane.

Burn vs. trash
- Cut cane green to take advantage of environmental factors
- Burn cane only where necessary and permitted.

Cutting
- Use appropriate method which includes manual, hand held cutters, tractor mounted cutters, whole stick harvesters or chopper harvesters.
- Cane to be correctly cut at the base and top and delivered free of trash.
- Cane to be delivered to the mill as soon after cutting as possible (cut to crush delay).

Cane presentation after cutting
- Windrow for mechanical loaders.
- Stacking for self loading trailers.

Loading in field
- Manual
- Self loading trailers
- Grab loaders
- Slew loaders
- Direct from harvesters.
11.2 Haulage

The main types of cane transport trailers and various factors affecting haulage are described. Because harvesting and transport operations are usually the most expensive elements of cane production, every effort should be made to optimize this system and keep costs to a minimum. It is also critical that the system feeding the mill should ensure that there is a consistent supply of clean, fresh cane. This is one of the most important metrics in the whole supply chain.

11.2.1 Haulage systems

A wide range of infield and direct rail and road transport equipment and vehicles are used to transport green and burnt whole stick and billeted cane in the world’s cane producing industries. Infield, small tractor and trailer rigs are generally used to move the cane from the field to transloading centers (Chatterton and Braithwaite 1985).

Manually harvested cane infield can be presented either in bundles or in windrows (Figure 11.8). Bundled cane is usually self-loaded onto small trailers. There are rear loading, side loading and side loading self-tipping trailers in operation.

Figure 11.8. Manually cut burnt sugarcane being placed in windrows.

Bundles are generally in the region of 3-4 t and are presented in such a way that the trailer cables or chains can be threaded around the bundles to facilitate winching onto trailers.

Alternate systems, for example in Zimbabwe and Malawi (Anon 2000), rely on separate winch tractors to load the haulage trailers, known locally as the Mascane system. This has the advantage of being able to use multiple trailers and haul more tonnage with the prime mover. Single trailers are efficient only when the haulage distance from field to zone does not exceed 1 km (Figure 11.9).
A good road network (Figure 11.10) is fundamental to an efficient haulage system. In addition the roads need to be designed and built to prevent soil and water erosion. In steep areas roads are built on the contour and are shaped to control water flow. Bezuidenhout and Meyer (2005) show that significant reductions in transport costs can be achieved by implementing an optimal cane extraction road network.

Cane can be moved directly from the field to the mill, or to transloading zones, by specially designed haulage tractors when the distance is within reasonable radius. For long distances and better roads, rigid or articulated trucks matched to appropriately designed trailers are used (Figure 11.11). The mass allowed to be transported and the speed of rigs is usually governed by local legislation and has resulted in variations from country to country. Naturally the tonnage hauled per prime mover is critical to final costs, and recent improvements in design and scheduling has resulted more efficient operations (Lyne 2007). Poorly designed and operated rigs result in problems such as cane spillage,
overloading/underloading, damage to roads, accidents, high fuel consumption, high tyre wear and high maintenance costs.

![Figure 11.11. A well designed road haulage vehicle fitted with a load monitoring system.](image)

Where rail infrastructure is available this is a very efficient method of transporting cane, especially where the terrain is flat and sugarcane is grown in concentrated areas (Figure 11.12). Furthermore, rail transport is usually more easily scheduled than road transport, especially when there are a large number of smaller growers involved.

Unfortunately, the capital costs involved in establishing rail links, or converting from road transport to rail, are usually prohibitive. The decision may depend on whether second-hand track can be found. However, with recent increases in fuel costs, rail transport should be seriously considered, especially in new projects. Studies have shown that after the break-even point (about 10 years in some cases) rail provides appreciably lower cost cane transport.

Examples where narrow gauge operates within estates are Hippo Valley in Zimbabwe, Umfolozi in South Africa, and TPC in Tanzania. In Australia, rail is the principal haulage system, with over 90% of the rail systems being privately owned.
General examples of harvesting and haulage systems include:

- **Australia**: Mechanized harvesting directly into bins and then mainly into rail trucks; 70% green; still burnt in cooler wet areas; 90% transport by narrow gauge railway network.
- **Brazil**: About 60% harvested manually, the balance mechanically. Approximately 50% of mechanical cut is green; plans are in place to fully introduce green cane mechanical harvesting by 2017. The large majority of the cane is transported to mills using rigid trucks pulling two or more trailer combinations.
- **Philippines**: Majority of cane still handled manually. Transported by two wheeled bull powered carts or hand loaded road trucks. Approximately 20% by rail.
- **Colombia**: Still high percentage cut by hand because cane is harvested all the year round, in wet and dry conditions.
- **Hippo Valley, Zimbabwe**: Manually cut and 80% by rail.
- **Triangle, Zimbabwe**: Manually cut, loaded into rigs and by road to the mill.
- **Dwangwa, Malawi**: All cane burnt, hand cut, and hauled in chains by tractor drawn Mascane trailers that are side loaded by winch in the fields. Offloaded by gantry cranes.
- **Nchalo, Malawi**: Most of the cane is burnt, hand cut and transported by landtrain (Figure 11.13). An increasing percentage is green to provide fuel for the boilers (from the trash).
- **South Africa**: Mostly burnt and cut by hand. Transported to the mill by specialized tractors, and rigid or articulated lorries matched to road legal trailers. (Lyne 2009)
11.2.2 Transloading

Cane is transloaded because of factors such as distance to the mill and vehicle payload capacity. Various methods and equipment are used to transload both whole stick and chopped cane (Figure 11.14).

Transloading zones are located where it is necessary to change from one mode of transport to another, such as in steep areas or where road transport changes to rail.

In steep areas, transloading zones are strategically positioned to limit infield transport distances to approximately 1 km. Bezuidenhout and Meyer (2005) showed that this should be kept to a
minimum, with a maximum of 1 km, but closer to 0.5 km where possible. Zones are positioned just off the haulage routes. They need to be big enough to temporarily store the cane and safely permit the haulage tractors, transloading equipment and road haulage vehicles to maneuver safely. Zones need to be carefully sited and constructed to ensure adequate control of water and flow of vehicles. The surface needs to be hardened and maintained in such a manner as to prevent accumulation of water.

Zones often operate 24 hours per day, therefore the provision of adequate lighting becomes an issue, especially in remote areas. It is also necessary to provide suitable protection against the weather, and toilet facilities.

Equipment used to transload whole stick includes scotch derricks, self-propelled mobile cranes, tractor mounted mobile cranes, truck mounted grabs, overhead gantry cranes, and transfer stations (chopped into billets).

Billeted cane is transloaded using rear tip trailers, side tip trailers and/or transfer stations (Figure 11.15).

![Figure 11.15. Typical portable billeted cane transfer station.](image)

11.2.3 Factors affecting haulage systems

**Cane cultivars**

Cane cultivars are mainly selected for qualities such as high sucrose, drought resistance, disease resistance and longevity. However, for mechanization the attributes required include non-brittle cane, resistance to lodging, minimal tops and trash, and self-trashing cultivars. This conflict therefore results in some cultivars being very difficult to handle under mechanization.

**Soil compaction**

The potential for compaction from haulage equipment is large, as illustrated in Table 11.1 (Swinford and Boevey 1984).
Table 11.1. Summary of cane and sucrose yields for first and second ratoon crops.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1st ratoon</th>
<th>2nd ratoon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tc/ha</td>
<td>ts/ha</td>
</tr>
<tr>
<td>Nil</td>
<td>80</td>
<td>7.9</td>
</tr>
<tr>
<td>Moderate</td>
<td>69</td>
<td>6.1</td>
</tr>
<tr>
<td>Moderate</td>
<td>58</td>
<td>5.2</td>
</tr>
<tr>
<td>Severe</td>
<td>63</td>
<td>5.8</td>
</tr>
<tr>
<td>Severe</td>
<td>61</td>
<td>5.6</td>
</tr>
</tbody>
</table>

The results in Table 11.1 were obtained using a single axle trailer fitted with single 1 100 x 20 (8 ply) tires with total axle masses of 3 700 kg (moderate compaction) and 5 700 kg (severe compaction).

Soil compaction studies conducted by the Bureau of Sugar Experiment Stations (BSES) in Australia (Braunack2000), the Sugar Cane Research Centre of Columbia (CENICANA) (Torres and Pantoja2005) and the South African Sugarcane Research Institute (SASRI) (Johnston and Wood 1971) have reported similar results. It is clear that cane and sugar yields are materially reduced in first and second ratoons by compaction, especially severe compaction.

Further results are documented from the soil compaction workshop convened in 2001 in South Africa (Anon 2001). Negative changes in soil physical parameters of a virgin soil due to compaction by commercial sugarcane haulage vehicles are discussed by van Antwerpen et al. (2007).

When operating haulage equipment infield it is important to minimize compaction by reducing total vehicle mass, using large diameter high flotation tires travelling only in designated places, and being aware of the soil type and moisture interactions. In green cane the trash blanket reduces the risk of soil compaction due to the cushioning effect of the trash (Meyer 1997).

Field layout
The economic viability of sugarcane production is closely allied to the degree that operations can be mechanized. In steep areas the conservation structures must therefore not obstruct the operation of machinery. The cane must be grown on the contour, but use must also be made of parallel layouts and broad based contours. A row length, depending on soil type for erosive reasons, should be selected between 200 and 400 m.

An efficient mechanized system (Fig.11.16) will be well planned and laid out before planting, and the following taken into consideration:

- Land flat to undulating (slope < 10 degrees)
- Straight, equally spaced long rows
- Row spacing and profile to be ‘best fit’ for mechanization, agronomy and irrigation
- Consistent block sizes to match daily delivery requirements
- Drains to run parallel to the cane rows – no cross drains
- Headlands and deep drains to be planned for easy access to and from the block
- Removal of all stones, stumps and roots
- Layout to suit the irrigation system.
Figure 11.16. Field layout ideally suited to mechanization.

Cane quality
Immediately following burning or cutting, the quality of sugarcane starts to deteriorate and continues until the cane is crushed (Gomaz et al. 2007). The deterioration in the quality of sugarcane involves the loss of sucrose content and the formation of other products such as ethanol, dextran and oligosaccharides. This leads to monetary losses for the grower where the cane payment system is based on cane quality, as well as the miller, since the negative products formed in the deterioration process interfere with the milling of the cane, causing exhaustion and crystallisation problems (Morel du Boil 1995).

Research has shown (Wood 1976) that under hot, humid conditions chopped cane deteriorates far more rapidly after harvest than does whole stick cane. Green cane deterioration for both whole stick and chopped cane is slower than that of burnt cane.

One of the main objectives of a harvesting and haulage system is therefore to reduce the burn/cut to crush period to a minimum. In practice this period can vary from under 3 h in highly mechanized systems to over 100 h in some manual systems. The Tablelands mill in Queensland claims a seasonal average of 2 h (fully mechanized and all vehicles are scheduled).

Spillage
Loss of cane during the transport process is a major problem in most areas and, in addition to the loss of revenue to the grower and miller, is a serious hazard on the roads, and pollutes drains and waterways. Losses of over 5 % are not uncommon, which translates into huge quantities of cane spillage considering the large tonnages of cane moved each year. High losses are not acceptable and where this is a problem it can be rectified by correct trailer design, matched to good loading techniques and smooth roads.

Legislation and technology
Where cane haulage occurs on public roads, the local traffic rules and regulations have to be obeyed to prevent accidents and damage to the infrastructure. This prevents the use of long road trains and huge trailers which are in operation on some private estates such as Nchalo in Malawi (Anon 2000).
Prescriptive regulations specify items with which the haulage vehicles must comply before being allowed on the roads. Examples of these include maximum length, width and height, power to weight ratio, braking requirements, axle loading and gross mass.

In South Africa (Lyne 2000 and 2009) it has been recognized that the regulations do not address the vehicle dynamics, and some vehicles which do comply are not as safe as they should be. The current system restricts innovative design and provides little incentive to use new technological developments. To overcome these limitations, Performance Based Standards (PBS) have been proposed and are being evaluated. The new approach will result in less damage to the roads and safer vehicles, whilst allowing greater payloads. Before hauliers will be allowed to operate a PBS vehicle they will have to demonstrate their willingness to comply with a self-regulating Road Transport Management System (RTMS) which results in a consistent payload, capable drivers, well maintained vehicles, and a productive system. There is an upcoming ISO standard which is very similar to the South African RTMS system to achieve responsible and sustainable transport systems.

The move from burnt to green cane has altered the bulk density of cane being hauled and calls for bigger, lighter bins to handle the same mass. A 10 t bin has been successfully introduced in Australia (Santarossa et al. 2007) based on polypropylene biaxially-orientated integrally-extruded geogrid with rigid junctions and stiff ribs as a sling to carry the load.

In South Africa, onboard weighing systems have been implemented that prevent under and overloading and ensure the load is correctly positioned over the axles (Lagrange 2008; Cole 2006).

**Scheduling**

Generally there are three stakeholders involved in moving cane from field to mill, the grower, hauler and miller, and cooperation between them is the key to deriving maximum benefit from vehicle scheduling. These benefits come in the form of fewer no-cane stops, better cane quality from reduced burn/cut to crush times, reduced time in mill yard queues, reduced time infield and on zones, and increased utilization of vehicles in a reduced fleet size (Lyne and Meyer 2005).

An exercise carried out at Sezela in South Africa (Giles et al. 2005) showed that the number of vehicles needed to move cane to the mill could be reduced by 50% under an ideal scheduling system. Applying scheduling to a mill supply area has its problems and various techniques are being tested and used around the world. Examples of these include linear modeling in Louisiana State (Salassi et al. 2009), FREDD scheduling in Australia and South Africa (Giles et al. 2006), Mackay Sugar transport system in Australia (Markley et al. 2006), sugarcane CTC system in Brazil (Cerri et al. 2008), SHIRT real time supply chain information for harvest managers in Australia (Rose et al. 2009), CLAMMS scheduling system in South Africa, and CAPCONN, a mathematical model and visualization methodology used to analyze the physical flow of the cane (Stutterheim et al. 2006).

Problems associated with implementing a scheduling system include:

- Too many non-homogeneous vehicles
- Various load types, sizes and requirements
- Bad practices and poor operator behavior
- Poor communication
- Machinery availability.

**Row spacing**

Generally wider row spacing is preferred for mechanization which must be compatible with the wheel tracks of the infield equipment to avoid cane stool damage and compaction.
Unfortunately, research work in South Africa (Boyce 1968) clearly showed that wider row spacings resulted in a reduction in the plant crop yield. Where the cane is still cut by hand and haulage is carried out by small agricultural tractors, a row spacing of between 1.4 and 1.5 m is generally used.

However, the ideal row width to suit an intensive mechanized system would be in the region of 1.85 m. Unfortunately this demand does not suit the agronomic and irrigation requirements of 1.5 m. The mismatch of wheel and row spacings and the heavy harvesting and haul-out machinery passing down every inter-row result in serious compaction and stool damage, which causes yield decline. Compacted soil calls for numerous tillage passes before replanting and between ratoons.

Initial attempts to grow cane in 1.8 m rows, both single and dual rows, were disappointing (Hurney et al. 1979).

However, later work (Garside et al. 2009) shows that under good growing conditions and using accurate controlled traffic it is possible to achieve acceptable yields with 1.8 m dual rows.

Further work is needed to resolve this problem, which is further complicated by the results being achieved under high density planting (Bull et al. 2000).

11.2.4 Summary of social, financial and environmental risks and benefits of each practice

Types of loading and transport systems used globally vary according to a number of major factors such as the cutting system, the terrain, the annual tonnage handled, the distance from the mill, the mill receiving facilities, scheduling, and appropriate legislation. Many systems have therefore evolved to suit the various local demands, and Table 11.2 gives some of the options in use and examples of two existing systems.
Table 11.2. Available harvest and haulage options.

<table>
<thead>
<tr>
<th>Description</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-harvest</td>
<td>Dry off Ripeners</td>
</tr>
<tr>
<td>Burn/trash</td>
<td>Burn Trash</td>
</tr>
<tr>
<td>Cut</td>
<td>Manual cutting Hand held cutters Tractor mounted cutters Whole stick harvesters Chopper harvesters</td>
</tr>
<tr>
<td>Cane presentation</td>
<td>Bundle Windrow</td>
</tr>
<tr>
<td>Infield loading</td>
<td>Manual Self-loading trailers Grab loaders Slewing loaders Direct from chopper</td>
</tr>
<tr>
<td>Zones, offloading</td>
<td>Self-offloading trailers Mobile cranes Fixed cranes</td>
</tr>
<tr>
<td>Zones, loading</td>
<td>Mobile cranes Fixed cranes Grab loaders Slewing loaders</td>
</tr>
<tr>
<td>Infield haulage</td>
<td>Infield tractor trailer Direct field to mill tractor trailer Direct field to mill trucks</td>
</tr>
<tr>
<td>Road haulage</td>
<td>Tractor trailer Specialized tractor trailer Truck tractor trailers Truck tractor containers Rigid truck</td>
</tr>
<tr>
<td>Rail</td>
<td>Infield Main line</td>
</tr>
</tbody>
</table>

**KEY**
- South coast South Africa
- Ubombo Swaziland

The major factor affecting the sugar industry at the moment is whether or not to burn the cane before harvesting. From an environmental and social viewpoint, the advantages favor green cane, but from a quality and cost of harvesting and transport point of view it is favorable to burn. However, the environmental and social issues outweigh the other issues and the trend now is towards green cane. Some countries are introducing legislation which sets target dates to eventually ban burning of sugar cane, e.g. 2017 in the State of Sao Paulo, Brazil. More green cane results in more mechanization. It should be noted that, where appropriate, green cane harvesting does result in a healthier environment (less pollution), an improved moisture regime, and the leaves do have significant energy value.

With the trend towards more mechanization, the potential for greater compaction and stool damage exists. The various ways of limiting this threat in the field include having row widths and field layouts that suit the agronomic, irrigation and machinery needs, reducing vehicle mass, using high flotation large radius tires and only travelling in designated places. The use of GPS type equipment can assist with controlled traffic.

From a financial aspect, there are big potential savings to be made in current haulage systems by making use of innovative machinery designs and harvesting and scheduling programs. The harvesting program optimizes the sequencing of cutting the fields, and the harvesting schedule...
optimizes the equipment needed to get that cane to the mill in the shortest possible time. Studies in South Africa (Giles et al. 2005) have shown, for example, that over 50% of existing vehicles delivering cane to a particular estate could be parked off if an effective scheduling system were introduced. In addition to the obvious financial benefits of streamlining the fleet there is less fuel burnt, better safety on the roads, less congestion, driver benefits, and better mill turnaround times.

The move from burnt to trashed cane has created new problems for the hauler, in that the density of green cane is less than burnt cane. The outcome is that trailers have to have a greater volume in order to move the same mass. This problem is being handled innovatively and, for example, South Africa is introducing performance based standards which incentivize the hauler to design and operate rigs which are safer on the road, do less damage to the roads, reduce or eliminate spillage and allow greater payloads.

Transloading zones are located where it is necessary to change from one mode of transport to another, such as in steep areas or where road changes to rail. The downside of transloading zones is that they introduce an additional component to the haulage chain which increases costs, damages the cane and increases the cut to crush times. Other potential negatives with loading zones include increased pollution from spillage and dust. If spillage is not dealt with timeously it builds up and starts to ferment, resulting in unacceptable pollution. Operating on loading zones at night is also more dangerous than in the daytime, and extra precautions need to be taken to prevent accidents.

**Box 11.2 Summary of good management practices related to transport**

**Zone offloading options**
- Mobile cranes
- Fixed Cranes
- Grab loaders
- Slew loaders.

**Infield haulage options**
- In field tractor trailer-from field to a loading zone within 1 km
- Direct field to mill tractor trailer-within reasonable distance and good payload (multiple trailers)
- Direct field to mill trucks-when trucks are able to travel in field due to firm underfootings.

**Road haulage options**
- Tractor trailer – only when close to the mill
- Specialized tractor trailer – within reasonable to the mill
- Truck tractor/trailers
- Truck tractor/containers
- Rigid truck.

**Rail options**
- Infield
- Main line.
11.3 References


Meyer E (2003). Green cane harvesting is the future. The Link Vol. 12, No. 3. Published by the South African Sugarcane Research Institute, Mount Edgecombe, South Africa.


CHAPTER 12 AGROCHEMICALS AND FARM SAFETY – PETER TURNER

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12. AGROCHEMICALS AND FARM SAFETY

12.1 Agrochemicals

12.1.1 Background

The agrochemicals referred to in this chapter include fungicides, nematicides, insecticides, herbicides, growth regulators and ripeners. Fertilizers and soil amendments were covered in Chapter 6. Agrochemicals in agriculture have helped significantly in crop production Dehne et al. (1994) report that crop protection practices reduce the overall loss potential of 50 % to actual losses of about 29 %: 10 % attributable to pathogens, 2 % to viruses, 8 % to animal pests and 9 % to weeds (1996-1998 on a regional basis for 17 regions). However, agrochemicals have had adverse effects on the environment and human health, and this was highlighted by Rachel Carson in her book Silent Spring (Carson 1962). In parallel with increases in chemical use, there have been simultaneous increases in awareness of negative side effects and concurrent continuous efforts to produce safer products for humans and the environment. Governments, pesticide manufacturers and non-government organizations (NGOs) have all played a role in improving the value of agrochemicals and their safe use by means of regulations and guidelines covering all aspects of their manufacture and use (Croplife International, FAO 2006, Stockholm, Basel, Rotterdam conventions). In spite of this, various public interest groups have repeatedly highlighted poisonings, unsafe practices and negative environmental impacts from the use of agrochemicals (Pimmental 2005; Lehtonen and Goebel 2009).

A number of world forums have been convened and conventions signed to improve the management and safe handling of pesticides. A recent forum has set out to engage all interested parties in the formulation of a strategic approach to international chemicals management and to obtain all stakeholders’ commitment to the system (Weinberg 2008). Good practice in agriculture in respect of chemical use is surely to comply with the latest internationally accepted guidelines and to comply with international convention. These guidelines cover a wide range of aspects from registration, manufacture, packaging, handling, transport, storage and application of products to disposal of containers and obsolete product (FAO 2007, Croplife 2010). Despite good regulations, treaties, conventions, laws and guidelines covering all aspects of agrochemical use the practical circumstances of using hazardous chemicals makes it difficult to comply with the safest practices. Examples of areas of difficulty are (1) practical protective clothing for hot climates, (2) the lack of infrastructure and enactment of regulations in developing countries, (3) disposal of wash water from daily washing of protective clothing, (4) cost of compliance with chemical storage requirements and (5) emergency treatment facilities. Problems remain in a lack of adequate legislation and its enforcement in many countries. Crop protection chemicals are likely to continue to play an important role in sugarcane production, but there should be continuous efforts to minimize undesirable environmental effects, while at the same time ensuring safety of operators and the public in an economically viable manner. Systems such as integrated pest, weed and crop management can be used to reduce reliance on crop protection chemicals. Also, the use of genetically modified crops can substantially reduce the need for crop protection chemicals and should therefore not be disregarded as an option to improve the safety of pest, disease and weed control practices for humanity and the environment (Barfoot and Brookes 2009). Organic sugar production has been implemented in Fiji and on a large estate in Brazil, but its practicality and economic viability may restrict its uptake on a wide scale (Lehtonen and Goebel 2009).
12.1.2 Pesticide regulation

National law
To ensure safety for operators, the public and the environment, it is important for agrochemicals to undergo thorough testing on efficacy and potential toxicity to humans and the environment before they are used. This has been an integral part of the development of products, and legislation in most countries has required that products be registered for use and that they be labeled with full information about the risks, protective clothing required, toxicity class, suitable conditions for application, acceptable methods of application, and product handling, mixing, and disposal of empty containers. Toxicology tests and residue test results are required in the registration applications, and countries with advanced and well structured regulatory and registration systems provide a standard which has often been used as a default by countries that do not have their own regulatory facilities. Most countries have developed laws to control the use of potentially dangerous or toxic chemicals. For example, in South Africa agricultural remedies are controlled under Act 36 of 1947 (SASA 2002), and in the United States a government department dedicated to environmental protection manages the registration procedure for agrochemicals (www.epa.gov, US EPA). Chemical companies wishing to register products are required by law to provide evidence of the product’s efficacy and safety and to provide relevant information on the label. There has been some standardization of label information to comply with legal labeling requirements, and Croplife International, the global representative of crop protection chemical companies, provides guidance to its members on all aspects of product development and use, including labeling.

Not all countries have a comprehensive regulatory system governing agrochemicals. In 1985 the Food and Agriculture Organization of the United Nations established an ‘International Code of Conduct for the Distribution and Use of Pesticides’ which provides guidance for countries without existing legislation on how to set up regulatory systems, as well as a comprehensive set of guidelines for all aspects of the management of pesticides. This code was revised in 2002 and more recently updated in 2006 (FAO 2006).

FAO International Code of Conduct on the Distribution and Use of Pesticides (www.fao.org) has become the international reference for information on the safe handling of pesticides. It covers all aspects of their distribution and use, and is backed by a series of guideline documents on specific aspects. It is suggested that following this code would constitute good practice for pesticide management. Some introductory comments to the code are provided in Box 12.1.

Box 12.1 Background to The International Code of Conduct on the Distribution and Use of Pesticides (FAO 2006)

Extracts from the introduction to the code:

“The International Code of Conduct on the Distribution and Use of Pesticides was one of the first voluntary Codes of Conduct in support of increased food security, while at the same time protecting human health and the environment.”

“The Code established voluntary standards of conduct for all public and private entities engaged in, or associated with, the distribution and use of pesticides, and since its adoption has served as the globally accepted standard for pesticide management.”

“Experience over the last 15 years has shown that the Code, in conjunction with its supplementary technical guidelines, has been instrumental in assisting countries to put in place or strengthen pesticide management systems. Surveys show that the number of countries...
without legislation to regulate the distribution and use of pesticides has greatly decreased; awareness of the potential problems associated with pesticide use has grown significantly; involvement in various aspects of pesticide management by NGOs and the pesticide industry has been strengthened; and further successful Integrated Pest Management (IPM) programs are being implemented in developing countries.”

“However, in spite of these positive signs, there are still major weaknesses in certain aspects of pesticide management, predominantly in developing countries. For instance, national pesticide legislation is not widely enforced due to lack of technical expertise and resources; highly hazardous or sub-standard pesticide formulations are still widely sold; and end-users are often insufficiently trained and protected to ensure that pesticides can be handled with minimum risk.”

Arguably the most useful and important supporting guidelines are those dealing with standardization of labeling. The International Code of Conduct on the Distribution and Use of Pesticides provides guidelines on good labeling practice and harmonization of labels has been effected by the use of standard sets of pictograms (FAO 1995).

However, the establishment of the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) (United Nations 2005) has resulted in the requirement for adaptation of the FAO guidelines to accommodate the GHS, specifically for pesticide use. A guideline document, 'The Implementation of the Globally Harmonized System (GHS) of Classification and Labeling of Chemicals', addresses this issue and indicated that the FAO good labeling practice guidelines will be updated to accommodate these changes. However, in practice national laws determine what is or is not required and chemical companies write the labels to comply with these requirements in order to achieve registration. Only when governments demand the same standard, or when chemical companies voluntarily follow a standardized system, will there be complete harmonization.

Ensuring all pesticides used in agriculture have a standard classification and labeling system means that in principle these standards can be applied globally. The hazard classification system used is that of the WHO Recommended Classification of Pesticides by Hazard (WHO 2009). On the label the hazard class is depicted by means of a color code (Fig. 12.1). Safe use procedures for handling, storage, mixing and applying are depicted by a series of standard pictograms and supported by text. Protective clothing requirements are also indicated by means of pictograms (Fig. 12.2). Innovative designs of protective clothing have recently been introduced to the market to further protect workers when applying harmful chemicals (Fig. 12.3). Acceptable weather conditions for application, acceptable application equipment and volumes and rates of application are stated, as are methods of safe disposal of containers. The most important action a user needs to take in order to apply the product safely is to follow the label instructions fully.
Group IA is very toxic.

Group IB is toxic

Group II is harmful

Group III requires caution

Group IV no special markings

Figure 12.1. Color codes for pesticide labels (Croplife SA).

Figure 12.2. Pictograms for pesticide labeling (Croplife SA).
Figure 12.3. Examples of innovative protective clothing design: rubberized leggings and neck protection added to caps.

For the wider management of agrochemicals it is suggested that the detailed sets of guidelines which support the FAO International Code of Conduct on the Distribution and Use of Pesticides could become the Good Practice model or at least be a credible basis from which to establish local good practices. The categories under which the guidelines fall are shown below and the number of individual guidelines is indicated in brackets (Box 12.2) (FAO 2011).

**Box 12.2**

Guidelines for the International Code of Conduct on the Distribution and Use of Pesticides

- Pesticide Legislation guidelines (1)
- Pest and Pesticide Management Policy Guidelines (1)
- Implementation guidelines: Registration – Pesticides (7)
- Implementation guidelines: Registration – Application Equipment (6)
- Implementation guidelines: Compliance and Enforcement (4)
- Implementation guidelines: Distribution and sales (6)
- Implementation guidelines: Use (3)
- Implementation guidelines: Training and awareness (1)
- Implementation guidelines: Prevention and disposal of obsolete stocks (10)
- Implementation guidelines: Post surveillance registration (2)
- Monitoring and observance of the Code of Conduct (3)

[www.fao.org](http://www.fao.org)

**Croplife International**

Croplife International is the global representative body for the plant science industry. Most countries require that crop protection products be registered for use and there are a number of legal requirements associated with registration such as the label information. Croplife International supports members by means of many publications and guidelines for companies and for users of crop protection products. A background to Croplife International as found on the website [www.croplife.org](http://www.croplife.org) is provided in Box 12.3.
Box 12.3

CropLife International is a global federation representing the plant science industry. On the industry’s behalf, it addresses international developments in crop protection and agricultural biotechnology.

CropLife International promotes approaches that enhance sustainable agriculture in the interests of farmers, consumers and the environment. It provides transparent information to its stakeholders and welcomes open dialogue with parties interested in the future of food and farming.

CropLife International is committed to supporting the safe and responsible use of the industry’s products in order to provide a secure, varied, healthy and affordable diet for consumers.

Box 12.4

An example of the guidelines provided by CropLife International:

Guidelines for the safe warehousing of crop protection products.
Guidelines for the safe transport of crop protection products.
Guidelines for personal protection when using crop protection products in hot climates.
Guidelines for emergency measures in case of crop protection product poisoning.
Guidelines on the safe and effective use of crop protection products.

www.croplife.org

International conventions

A number of international conventions apply to the management and use of agrochemicals and users of pesticides must be aware of their obligations. The chemicals restricted in terms of these conventions are listed in the relevant websites and the WHO Classification of Pesticides by Hazard. Few of these are used in sugarcane. The three conventions are The Stockholm Convention on Persistent Organic Pollutants (www.pop.int), the Basel convention (www.basel.int) and the Rotterdam convention (www.pic.int).

Strategic Approach to International Chemicals Management (SAICM)

“In 2006, governments and stakeholders adopted a new global policy and strategy called the Strategic Approach to International Chemicals Management (SAICM). The objective of the Strategic Approach is to change how chemicals are produced and used in order to minimize harmful effects on human health and the environment” (Weinberg, 2008). Participants in the International Conference on Chemicals Management (ICCM) agreed that the overall objective of SAICM is to, “achieve the sound management of chemicals throughout their life-cycle so that, by 2020, chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment.”
12.1.3 Agrochemicals used in sugarcane production

Specific insecticides, herbicides and ripeners are covered in separate chapters in this manual; this chapter considers agrochemicals in general. According to Lehtonen and Goebbel (2009) sugarcane farming does not require a lot of pesticides, and chemicals that are used are mostly herbicides.

12.1.4 Environmental and safety concerns with sugarcane pesticides

Agrochemicals in use in sugarcane have the potential to cause undesirable effects on the environment, and on the health of operators and communities. Negative environmental impacts include pollution of water, soil and air and consequent impacts on organisms in the water, soil and air. This can occur from drift after spraying or direct effects in the soil. Runoff of topsoil may carry agrochemicals into streams and ultimately into marine ecosystems. Agrochemicals may become bound to soil particles and held in the soil or leached through soil profiles, depending on their characteristics, such as solubility and adsorption. Chemicals may also differ in their persistence due to differing half-lives (degradation rates). Weather conditions can have an influence on the pollution potential of chemicals. Wind and low relative humidity increase drift and heavy rains cause leaching in sandy soils. Chemicals differ in their inherent toxicity to organisms in the environment and to humans but the degree of impact is also affected by exposure time, the absorption pathway and the formulation of the pesticide.

Box 12.5 Some toxic chemicals used in sugarcane

Aldicarb is used in Australia, Brazil and South Africa to control nematodes in sugarcane. Although it is rated as extremely hazardous, the risk it poses to the user is lower than similarly rated chemicals because the product granules are coated to prevent formation of dust, and are impregnated with Bitrex (denatonium benzoate) – a substance that induces vomiting – thus making accidental poisoning less likely. Also, strict stewardship conditions are imposed on users; they must be registered and trained and tight controls are in place to keep track of the chemical, up to the point of application. In South Africa many of the problems with aldicarb arise from misuse off-farm.

Paraquat is a toxic liquid herbicide which is effective on large weeds. The potential for inhalation and skin contact is high if incorrect application methods are used and if the required protective clothing is not worn. There is no proven antidote for paraquat (CDC 2011), which makes this a very dangerous chemical for accidental ingestion. In the USA this is a restricted use herbicide and can only be applied by licensed applicators. Formulations used in the USA are required to have a dye, a strong odour and an additive which induces vomiting. Its use has been banned in a number of countries and it’s use is not permitted for certification in various sustainability standards. (www.sanstandards.org) However the benefits and safety of its use if recommendations are strictly adhered to (www.paraquat.com) make this a classic example of a toxic product which can be used safely in well regulated circumstances but which under practical conditions in under regulated countries and hot climates can be a serious risk to operators health. (http://archive.pic.int/INCS/CRC7/k11)add3/English/CRC-7-11-Add-3_Berne%20Declaration-4-Paraquat%20in%20developing%20countries.IJOEH.%20pdf.pdf

These products must be used with extreme care and they should be targets for replacement as soon as safer products or alternative methods become available.
12.1.5 Minimizing negative impacts

Formulation
The safety of both the pesticide operator and the environment can be improved by the use of suitable formulations. Agrochemicals consist of an active ingredient and additives which allow for a stable product or formulation. The majority of formulations fall into one of the following groups: dry flowable (DF), emulsifiable concentrate (EC), suspension concentrate (SC), solution (SL), water dispersible granules (WDG), wettable powders (WP), and water soluble granules (WSG).

Powder formulations have the disadvantages of needing to be weighed where odd quantities are required (although convenient packaging usually avoids the need for weighing). Powders are more prone to dust and present a danger to operators handling the concentrates during mixing. Water soluble packaging can avoid the need for opening packets and exposing the product to wind.

Liquid products have the advantage of ease of measuring but carry the danger of exposure to operators when handling the concentrates and conducting mixing operations.

Granular products that are applied directly avoid the need for a water carrier and the associated risks of mixing and spraying. A disadvantage is the difficulty in achieving the even application which is particularly important for herbicides, although not as critical for systemic products such as some nematicides. However where these are diluted in water for application they still have the advantages of easier handling and measuring of the concentrated product. Well formulated granules can be measured volumetrically saving the need for weighing which may be required with powder formulations. Detail of the advantages of dry formulations is included in the chapter on weed control and is repeated below (NB Leibbrandt, Durban, 2011, personal communication).

Many old and new sugarcane herbicides are now available as dry formulations. The following is a list of advantages that these formulations offer the sugarcane grower:

- Much longer shelf life compared to SC formulations.
- Much easier to measure out granular quantities in the field – many come in 1 ha packs.
- Unlike liquids, dry concentrates can be pre-mixed for convenience prior to being taken to the field (e.g. to reduce error in the field, enough granulated herbicide can be volumetrically measured and pre-mixed in buckets (with lids), each for a full mixing tank).
- Far less risk of user contamination compared to liquids.
- Far less risk of user contamination following accidental spillages which can be swept up.
- No need to triple rinse empty herbicide containers.
- Due to higher active ingredient loading and lack of water, transport costs are lower.
- Dry formulations, on average, have less non-herbicidal ingredients that are necessary in liquid formulations (pollutants).

Dry formulations require less packaging and there are no drums to dispose of.

Application methods
To achieve successful control of pests, diseases or weeds requires that the chemical reaches its target. This may mean the dipping of seed cane for disease control, furrow applied granules for nematode control or full soil surface coverage when applying herbicides for pre-emergence weed control. In herbicides, even distribution is critical and the surface topography can have an effect on the subsequent successful control of target weeds. Application equipment differs, and the risk of human and environmental contamination and human safety varies between the options. All agrochemicals registered for use against a particular pest, disease or weed will have the application methods, and acceptable equipment for application, specified on the labels. There will be instances where choice of product and application system will substantially reduce the potential environmental risk and danger to operators. Automated systems for mixing and transferring spray solutions into tractor tankers reduce the risk to operators.

The range of equipment for chemical application includes manually operated knapsack sprayers, hand held controlled droplet applicators (CDAs), tractor mounted tanks with hand held lances, tractor mounted tanks with booms with or without drop arms, and aerial application. Each of these application methods has a separate set of risks to operators and the community. Choice of method needs to take into account efficacy in providing the pest, weed or disease control as well as the safety to applicators and the environment.

Various authors have reported on the development of safer methods of agrochemical application to avoid human exposure to toxic chemicals. These include the use of a closed system whereby the pesticide is removed from its container, the container rinsed and the pesticide and rinse solution are then transferred to a mixing tank through tight hoses, pipes and couplings (Yates et al. 1981). Information on the behavior of agrochemicals, such as water solubility, degree of binding in the soil and degradation rates, are critically important to farm management decisions (Rhegenzani et al. 2001). Drift and spray damage by glyphosate are minimized by good aerial application requiring effective equipment settings and the aircraft operating under suitable environmental conditions (Wallens 1984). Application of herbicides through a pivot irrigation system is an innovation currently being tested and, if successful, can lead to a substantial reduction in the number of man-hours of exposure to the chemicals (see Chapter 4 for further detail).

**Integrated Pest Management, Integrated Weed Management and Integrated Crop Management.** Although chemicals may provide a critical part of many successful programs to control weeds, pests or diseases exclusive use of chemicals has led to resistance or a complete elimination of natural predators in some instances. "The primary aim of pest management should be not to eradicate all organisms, but to manage pests and diseases that may negatively affect production of plantation crops so that they remain at a level that is under an economically and environmentally damaging threshold" (IFC 2007a). Integrated management control programs are discussed under the separate chapters on pests and weed control; these are important tools in limiting the requirements for synthetic and particularly toxic chemical applications.

**Genetically modified (GM) crops**
Widespread and continuing awareness of the potential dangers to the environment and society of the use of agrochemicals has forced agrochemical companies to spend more and more time and effort on not only conducting the legally required tests for environmental and human safety, but to strategically explore opportunities for changing the focus of their activities away from chemicals and towards alternative systems for pest control. One such approach has been to establish genetically modified crops with resistance to pests and diseases, which then eliminates the need for chemical applications. Herbicide resistance has been introduced into commercial sugarcane cultivars (Snyman et al. 2001). An example of the reduction in chemical use that can be achieved by growing GM crops is well illustrated by studies on other crops such as cotton (Barfoot and Brookes 2009).
12.1.6 Standards and certification

Application of international standards for environmental management, such as ISO 14001, provide evidence of a commitment to environmental good practices and also a means of measuring implementation of procedures to achieve the standard. ISO 9000, the quality management standard, also covers management of environmental aspects. Locally generated good management practice systems provide many industries with information tailored to their specific needs (SASA 2002; Maher 2007; Calcino et al. 2008). Certification schemes such as Fair Trade and Bonsucro are applicable to sugarcane, the latter being specific to cane. The schemes provide environmental, social and economic benefits driven by consumer demand for the certified product. Certification under such schemes, particularly those widely supported and crop-specific, would constitute good practice.

12.1.7 Summary of good practices for environmental and human safety

<table>
<thead>
<tr>
<th>Box 12.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>The IFC (2007b) lists a number of steps that can be taken to reduce the risk of poisoning or contamination of the environment when handling, diluting, applying and storing pesticides:</td>
</tr>
</tbody>
</table>

- Train personnel in the correct way to handle and apply pesticides. This is *THE* most important single step to take to prevent poisoning of farmworkers.
- Avoid the use of pesticides that fall under the World Health Organization Recommended Classification of Pesticides by Hazard Classes 1a and 1b and Hazard Class II.
- Use only pesticides that are manufactured under license and registered and approved by the appropriate authority and in accordance with the Food and Agriculture Organization’s (FAO’s) International Code of Conduct on the Distribution and Use of Pesticides.
- Use only pesticides that are labeled in accordance with international standards and norms, such as the FAO’s Revised Guidelines for Good Labeling Practice for Pesticides.
- Select application technologies and practices designed to reduce unintentional drift or runoff as indicated in an IPM program, and under controlled conditions.
- Maintain and calibrate pesticide application equipment in accordance with manufacturer’s recommendations.
- Establish untreated buffer zones or strips along water sources, rivers, streams, ponds, lakes, and ditches to help protect water resources.
- Avoid use of pesticides that have been linked to localized environmental problems and threats.
- Store pesticides in their original packaging, in a dedicated, dry, cool, frost-free, and well aerated location that can be locked and properly identified with signs, with access limited to authorized people. No human or animal food may be stored in this location. The store room should also be designed with spill containment measures and sited in consideration of potential for contamination of soil and water resources.
- Mixing and transfer of pesticides should be undertaken by trained personnel in ventilated and well lit areas, using containers designed and dedicated for this purpose.
Containers should not be used for any other purpose (e.g. drinking water). Contaminated containers should be handled as hazardous waste, and should be treated accordingly. Disposal of containers contaminated with pesticides should be done in a manner consistent with FAO guidelines and with manufacturer’s directions.

Purchase and store no more pesticide than needed and rotate stock using a ‘first-in, first-out’ principle so that pesticides do not become obsolete. Additionally, the use of obsolete pesticides should be avoided under all circumstances. A management plan that includes measures for the containment, storage and ultimate destruction of all obsolete stocks should be prepared in accordance to guidelines by FAO and consistent with country commitments under the Stockholm, Rotterdam and Basel Conventions.

Collect rinse water from equipment cleaning for re-use (such as for the dilution of identical pesticides to concentrations used for application).

Ensure that protective clothing worn during pesticide application is either cleaned or disposed of in an environmentally responsible manner.

Implement groundwater supply wellhead setbacks for pesticide application and storage.

Maintain records of pesticide use and effectiveness.”

An example of a more specific guideline for responsible use is provided below in Box 12.7.

### Box 12.7 Responsible Pesticide Use (excerpts taken and adapted from Responsible Pesticide Use: A Guide for Operators - Croplife South Africa 2007)

#### The Law
There are specific laws which deal with pesticides, e.g.:
- All pesticides must be registered with the Department of Agriculture.
- You may not use a pesticide for any purpose other than the one for which it is registered.
- If a pesticide is unlabelled and not in its original container, you may not possess it, use it for any purpose, buy it, sell it, hand it over to anyone or acquire it by any means.

#### Protecting the operators
Farmers or employers have to train workers on the risks of using pesticides. Correct protective clothing must be worn for application and for handling. Read the label before use and note requirements for protective clothing.

#### Protective clothing
- Overalls.
- Apron.
- Face shield.
- Safety goggles.
- Gloves.
- Boots (unlined) and wear trousers outside the boots.
- Lightweight cotton hats with brims (or cap with neck flap).
- Various respirators with specific instructions for use with different materials.

#### Washing facilities
- After using pesticides wash before eating, drinking, smoking and using the toilet.
- Wash at end of each operation or shift.
• Each operator should have their own soap, towels, water container (if no running water available) (Some large estates provide daily laundry service for operators).
• Do not allow wash water to contaminate or run into any water course, such as a river or sewerage system.
• Store spray clothing separately from other clothes.
• Maintain protective clothes and equipment
• Inspect and repair clothes and equipment regularly.
• Do not wear clothing that has not been washed.
• Wash gloves before removing from hands. Remove. Wash inside and outside. Allow to dry.

Toxicity
All pesticides are poisonous (toxic).
When we say someone has been ‘exposed’ to a pesticide it means that the pesticide has entered their body. This can happen in four ways:
• Skin (dermal)
• Lungs (inhalation)
• Mouth (ingestion)
• Eyes.

How dangerous the exposure will be will depend on three things:
• How much pesticide entered the body.
• How long the exposure was.
• The toxicity level of the pesticide.

The toxicity level is indicated on the label – red is most toxic
Symptoms which could be caused by poisoning:
• Headache
• Dizziness
• Nausea
• Tremors
• Vomiting
• Cramps
• Sweating
• Weak muscles
• Anxiety
• Blurred vision.

There should be a decontamination/first aid kit available within easy reach of operations and two operators in each team should be trained in first-aid.

Actions if someone has been exposed:
• Skin – take off contaminated clothing – wash the person.
• Eye – rinse immediately with cold clean water – cover eye with a sterile pad and take the person to hospital immediately – take the pesticide container or label with you.
• Mouth – check pesticide label –do not induce vomiting or give the person something to drink unless the label says so – take the person to a doctor immediately and take the label.
• Make sure that emergency numbers are available at all times.

Monitoring health:
All people who regularly use pesticides should have a routine medical check-up at employment and at regular intervals.
**Buying pesticides:**
Only purchase pesticides in original labeled containers, and ensure the seller can provide full advisory information.

**Transporting pesticides.**
Do not transport pesticides in the same compartment as foods, tobacco, animal feeds or other products that people will use. If unavoidable place in a separate box or container.

**Storing pesticides**
Pesticides must be locked away, preferably in a separate and specially built store.
For small amounts a trunk mounted on a wall out of the reach of children should be used.
It is a good idea to have two locks with keys located with two different people.
Store pesticides off the ground e.g. on pallets.
Keep very toxic (Group 1a) and toxic (Group 1b) products together.
Pack flammable products in between non-flammable products of the same group.
Follow the 'FIFO' rule: first in first out – this means using up the oldest products first.
There must be signs up warning of the dangers of pesticides.
Workers must understand these signs and need to be trained in emergency procedures.

**Spillages**
Any spillage should be reported immediately.
Keep unauthorized people and animals away from the spill.
Contain the spill by applying absorbent material, such as sand, then quickly clear away.

**Managing waste**
Triple rinsing of containers is recommended: 1. Empty the container into the spray tank, 2. Quarter fill container with water, close lid, shake well and empty into spray tank. 3. Repeat a further two times. 4. Puncture the container – make it unusable.
Take cut up or punctured containers to a recycling agency or bury them in a fenced off area away from where people or animals live.
Never allow anyone to re-use the containers for any purpose”. 

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**Prepared by PGBI Sugar & Bio-Energy (Pty) Ltd.**
12.2 Farm safety

12.2.1 Background

Good practices for safety management in sugarcane production are likely to revolve around established procedures for workplace safety management and common sense. There are a number of situations in sugarcane crop production where dangers of injury or health impairment exist. These include both physical hazards and chemical hazards. Options for reducing injuries or health impairment include (1) training of personnel in the safe use of equipment, (2) increased awareness of dangerous situations, (3) assessment of the risks involved in each operation, (4) use of protective clothing, and (5) attention to establishing procedures which limit the opportunity for injuries or exposure to harmful chemicals. There are a number of established occupational health and safety standards or systems which can be adopted by organizations to ensure all issues are addressed and to be pro-active in protection against accidents and harmful health incidents (e.g. OHSAS 18001).

Most countries have established legislation governing safety at work and obligations of employers, plus schemes such as accident insurance and workman’s compensation (e.g. in South Africa the Occupational Health and Safety Act No. 85 of 1993).

There is also an international trade union network, the International Union of Food, Agricultural, Hotel, Restaurant, Catering, Tobacco and Allied Workers Associations (IUF) which is composed of 336 trade unions in 120 countries and representing a combined membership of over 12 million workers. It aims to “actively promote the organization of the world's food resources for the common good of the population as a whole.” “However the IUF believes that much of the world's food is produced in ways that are not sustainable in the longer term from a social, economic or environmental viewpoint. Those working in agriculture are engaged in an industry that is not sustainable as measured by the loss of human life, injury and ill health. In 2002 the International Labor Organization (ILO) estimated that 355 000 fatal accidents take place every year. Previous ILO estimates suggest that over half of these fatal accidents take place in agriculture. Agricultural workers also suffer disproportionately in the 270 million workers injured each year and the 160 million who are suffering from work related diseases.” As a result the IUF “sees a safe, healthy and environmentally conscious workforce as an essential element of a profitable and sustainable agricultural industry and has developed a series of manuals to help union affiliates to tackle health, safety and environmental problems through their training program.” (ILO 2004). Manuals provided by the IUF are shown in box 12.8.

Box 12.8 IUF manuals

Manual 1 - An educator’s guide
Manual 2 - Health, safety and environment for grassroots members
Manual 3 - Health, safety and environment for worker H,S and E representatives
Manual 4 - Health, safety and environment fact sheets
Manual 5 - Pesticides and Health, safety and the environment
Manual 6 - How to ratify and use ILO convention 184 on Safety and Health in Agriculture.

Certifiable standards for occupational health and safety provide a means to confirm the following of good management practices. An example is the Sustainable Agriculture Network standard which includes a section on occupational health and safety (www.sanstandards.org).
12.2.2 Safety Management Systems (also see Section 3. Chapter 3.)

**Principles of safety management**

A number of principles for safety management are found in the literature, and a range of such principles includes:

- Safety audit or risk assessment
- Accident investigation and reporting
- Safety performance monitoring
- Safety education and training.

Others:

- Education
- Job site maintenance
- Safety equipment
- Communication.

Suggested steps in establishing a safety management system are illustrated in Box 12.9.

**Box 12.9 Suggested steps in establishing a Safety Management System**

(A) Follow these steps:

1. Understand legal obligations
2. Educate staff on the need for safety and a safety management system.
3. With staff involvement, identify the hazards and evaluate the risks (risk assessment).
4. With staff involvement and following any manufacturers specifications identify work place safety equipment needs such as guards for moving parts, protective clothing for operators and signage for communication of dangers.
5. With staff involvement formulate safe work procedures for all tasks.
6. Train all staff in safe work procedures relevant for their work.
7. Establish safety committees and elect or select safety representatives.
8. Establish incidents and accident reporting systems, as well as a regular monitoring and evaluation program.
9. Ensure communication by all staff and management is in place to address any safety issues.

(B) Take up a recognized Safety Management System or management system that incorporates health and safety (e.g. bsigroup 18001, ISO 9000) or become certified according to a recognized standard (e.g. Sustainable Agriculture Network standard, Bonsucro)

1. **Understand legal obligations**

Most countries have well established health and safety regulations and the International Labor Organization convention 184 is relevant. It is critical for any sugarcane farming operation to understand and be able to comply with all regional and national laws and international conventions. Some articles from Convention 184 appear in Box 12.10 ([http://www.ilo.org/public/english/st...](http://www.ilo.org/public/english/standards/relm/ilc/ilc89/pdf/c184.pdf))
## Box 12.10 Some articles from Convention 184 of the International Labour Organisation

**“Article 7**

In order to comply with the national policy referred to in Article 4 of the Convention, national laws and regulations or the competent authority shall provide, taking into account the size of the undertaking and the nature of its activity, that the employer shall:

(a) carry out appropriate risk assessments in relation to the safety and health of workers and, on the basis of these results, adopt preventive and protective measures to ensure that under all conditions of their intended use, all agricultural activities, workplaces, machinery, equipment, chemicals, tools and processes under the control of the employer are safe and comply with prescribed safety and health standards;

(b) ensure that adequate and appropriate training and comprehensible instructions on safety and health and any necessary guidance or supervision are provided to workers in agriculture, including information on the hazards and risks associated with their work and the action to be taken for their protection, taking into account their level of education and differences in language; and

(c) take immediate steps to stop any operation where there is an imminent and serious danger to safety and health and to evacuate workers as appropriate.

**Article 8**

1. Workers in agriculture shall have the right:

   (a) to be informed and consulted on safety and health matters including risks from new technologies.

   (b) to participate in the application and review of safety and health measures and, in accordance with national law and practice, to select safety and health representatives and representatives in safety and health committees; and

   (c) to remove themselves from danger resulting from their work activity when they have reasonable justification to believe there is an imminent and serious risk to their safety and health and so inform their supervisor immediately. They shall not be placed at any disadvantage as a result of these actions.

2. Workers in agriculture and their representatives shall have the duty to comply with the prescribed safety and health measures and to cooperate with employers in order for the latter to comply with their own duties and responsibilities”.


### 2. Educate staff on the need for safety and a safety management system

Education of all employees on the need for safety and a safety management system ensures awareness of the dangers at work and provides employees with the knowledge that the organization is responsible in its attitude to their health and safety, and that they also have a responsibility within the organization and to their fellow employees to act safely.

### 3. With staff involvement identify the hazards and evaluate the risks (risk assessment)

**Risk assessment**

Risk assessment may provide a means to identify, qualify and quantify the risks or hazards of any situation or activity and thus further allows for the establishment of mitigation measures or procedures or activities to minimize the risks. It also allows for a prioritization of risks according to a range of attributes such as reasons for the hazard, e.g. working on steep slopes; the impact, e.g. falling down the slope; the consequence, e.g. broken limbs, as well as factors such as the probability and expected frequency of occurrence. It also provides an opportunity to identify methods of avoidance, to establish training needs, and to design overall mitigation measures. Risk assessment is a fundamental requirement of health and safety management systems.
Physical hazards in sugarcane agriculture
Russell (2010) has shown examples of tasks with their associated hazards, impacts and consequences (Table 12.1) and further a scoring system (Table 12.2) to allow evaluation of the severity, probability and frequency of occurrence as well as options for mitigation which include containment, operational procedures, training and inspections. This results in a residual risk rating and consideration of appropriate control measures.

### Table 12.1 Examples of risk assessment for agricultural operations (Russell 2010).

<table>
<thead>
<tr>
<th>Task</th>
<th>Hazard/Aspect</th>
<th>Risk/Impact</th>
<th>Consequence</th>
<th>Severity 0-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basket trailers</td>
<td>Chain handling – working at heights</td>
<td>Falling to ground from trailer</td>
<td>Physical injury, fractures, fatality</td>
<td>40</td>
</tr>
<tr>
<td>Cane extraction</td>
<td>Steep slopes and terrain</td>
<td>Roll over – Vehicle accidents</td>
<td>Physical injury</td>
<td>40</td>
</tr>
<tr>
<td>Winching</td>
<td>Rotating PTO shaft</td>
<td>Contact with moving parts and pulled in</td>
<td>Severe injury, loss of limbs or fatality</td>
<td>40</td>
</tr>
<tr>
<td>Cane loading- Unloading Trailer</td>
<td>Work at heights</td>
<td>Falling</td>
<td>Injuries, fractures, fatalities</td>
<td>40</td>
</tr>
<tr>
<td>Nightshift + Zone</td>
<td>Poor lighting/Visibility</td>
<td>Falling and tripping</td>
<td>Injuries, sprains, fractures, fatalities</td>
<td>40</td>
</tr>
<tr>
<td>Cane burning</td>
<td>Fire</td>
<td>Burns to persons</td>
<td>Burn injury</td>
<td>40</td>
</tr>
<tr>
<td>Ridging</td>
<td>Mobile equipment on slopes</td>
<td>Tractor overturning</td>
<td>Physical injuries, fatality</td>
<td>40</td>
</tr>
</tbody>
</table>

### Table 12.2 Example of ratings of risk attributes of agricultural operations (Russell 2010).

<table>
<thead>
<tr>
<th>Task</th>
<th>Severity 0-50</th>
<th>Probability 0-5</th>
<th>Frequency 0-5</th>
<th>Risk Factor</th>
<th>Containment 0-5</th>
<th>Ops procedures 0-5</th>
<th>Training 0-5</th>
<th>Inspections 0-5</th>
<th>Mitigation</th>
<th>Residual risk rating</th>
<th>Rating</th>
<th>Control measures</th>
<th>Recommended additional control measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane extraction</td>
<td>40</td>
<td>3</td>
<td>6</td>
<td>215</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>15</td>
<td>14.3</td>
<td>High</td>
<td>Internal codes</td>
<td>Machine guarding</td>
</tr>
<tr>
<td>Winching</td>
<td>40</td>
<td>4</td>
<td>5</td>
<td>220</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>13.8</td>
<td>High</td>
<td>Internal codes</td>
<td>Machine guarding</td>
</tr>
<tr>
<td>Twin stack trailers unloading</td>
<td>40</td>
<td>4</td>
<td>5</td>
<td>220</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>13.8</td>
<td>High</td>
<td>Internal codes</td>
<td>Machine guarding</td>
</tr>
<tr>
<td>Cane loading – unloading trailer</td>
<td>40</td>
<td>3</td>
<td>5</td>
<td>215</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td>13.4</td>
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<tr>
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<td>4</td>
<td>168</td>
<td>4</td>
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<td>12.9</td>
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<td>Internal codes</td>
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<tr>
<td>Cane burning</td>
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<td>4</td>
<td>168</td>
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<td>4</td>
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<td>4</td>
<td>14</td>
<td>12</td>
<td>Medium</td>
<td>Internal codes</td>
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<tr>
<td>Ridging</td>
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<td>5</td>
<td>215</td>
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<td>5</td>
<td>4</td>
<td>5</td>
<td>18</td>
<td>11.9</td>
<td>Medium</td>
<td>Internal codes</td>
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</tr>
<tr>
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<td>5</td>
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<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>18</td>
<td>11.9</td>
<td>Medium</td>
<td>Internal codes</td>
<td></td>
</tr>
</tbody>
</table>

Field operations needing evaluation for risk
Some examples with associated possible consequences are:
• Seedcane production: harvesting, loading, chopping, hot water treatment, seedcane dipping in fungicide, transport (cuts, burns, general injuries).
• Planting: chopping in furrows, carrying seedcane on uneven terrain, covering with hoes (cuts, general injuries).
• Fertilizer application: wheelbarrow, knapsack, hand application, tractor spreader, loading fertilizer bins, application of ameliorants and liquid fertilizers (general injuries).
• Disease control: fungicides, roguing (exposure to chemicals).
• Pest control measures: light traps, pre-trashing, biocontrol agents release, breeding, management (exposure to conditions for insect breeding).
• Weed control: hand weeding, hoeing, applying herbicides, managing trash blanket (cuts, general injuries, herbicide exposure).
• Irrigation: moving pipes, moving risers, inserting siphon pipes; managing surface irrigation, laying drip tubing, managing drip systems (general injuries).
• Water supply: controlling pump stations, lining canals, building canals, risks associated with requirements for clean water for consumption and agricultural use (general injuries).
• Ripening and flower control: aerial application, marking of fields (chemical exposure).
• Harvesting: burning cane, fire control, manual cutting of trashed and burnt cane, stacking, loading (burns, smoke inhalation, cuts, general injuries).
• Mechanical harvesters: assistants, drivers (general injuries, contact with rotating parts).
• Loading, transporting cane (falling, general injuries).
• Labor trailers and transport (accidents, serious injury).
• Housing, workshops, chemical stores, alien invader control, fire control, animal control including snakes.
• Office environment, working hours.

Chemical hazards
Although much of the subject of agrochemicals and their responsible use has been covered in the first part of this chapter as well as in the chapters on Pests (Chapter 9), Weed Control (Chapter 4) and Ripeners (Chapter 10), the need for a risk evaluation as part of the Health and Safety Management System is essential. In this regard the management systems for Quality, Environment and Health and Safety should all be integrated as far as possible and there are guidelines in the International Standards Organization for this.

Potential hazards from chemicals include inhalation, dermal exposure and accidental ingestion and could occur during transport, storage, mixing, application, disposal or due to drift. Assessing the risks of each potential hazard in terms of the severity of the incident, frequency of occurrence, probability of occurrence as well as the options for containment, options for adjustment to procedures and training requirements would be of benefit.

Some examples of situations where hazards exist in respect of chemicals:

• Storage: broken containers, accidental spillage, fire.
• Mixing and handling: measurement, spillage, use of concentrate, volatile chemicals, torn protective clothing, faulty protective equipment, chemicals not in original containers.
• Application: Leaking equipment, faulty equipment, worn nozzles, incorrect pressure settings, unsuitable weather conditions, operators not suited to chemical application, steep slopes and uneven terrain, hot weather conditions and unsuitable protective clothing.
Other examples of operations with potential exposure to chemicals:

- Seedcane sett dipping in fungicides, additives to hot water treatment tanks, use of insecticides for grub control, nematicides for nematode control, pesticides for borer control or other pests (trash worm), herbicides for weed control, ripeners for ripening and chemicals for flower control.
- Transport of chemicals and operators to site, accidental spillage.

4. With staff involvement and following any manufacturers specifications identify work place safety equipment needs such as guards for moving parts, protective clothing for operators and signage for communication of dangers.
This step is likely to be covered by the comprehensive risk assessment but does require knowledge and information on the machinery or tools used for the tasks and their specified safety features and equipment as well as protective clothing requirements for operators.

5. With staff involvement formulate safe work procedures for all tasks
This should also be a direct consequence of the risk assessment process.

6. Train all staff in safe work procedures relevant for their work
This should also cover not only specific task related risks but also emergency procedures for fire or other general threats. First aid training should be undertaken by representatives of all work teams and it is common to establish a minimum number per team and to re train staff on an established schedule.

7. Establish safety committees and elect or select safety representatives
Health and Safety programs may stipulate the procedures and representation required.

8. Establish incidents and accident reporting systems, as well as a regular monitoring and evaluation program
Without knowledge of the occurrence of accidents and the circumstances of their occurrence the ability to improve safety and prevention of further accidents is limited. Standards may use benchmarks for accident reporting and companies also often include such detail in internal or external sustainability reports.

9. Ensure communication
Continuous communication with all stakeholders including employees and the community about the safety environment of an operation improves trust and should ensure that employees understand their own responsibilities in reporting unsafe conditions.

B. Take up a recognized Safety Management System or management system that incorporates health and safety (e.g. bsigroup 18001, ISO 9000) or become certified according to a recognized standard (e.g. Sustainable Agriculture Network standard, Bonsucro).

OHSAS 18001: 2007 Occupational health and safety management systems
www.bsigroup.com/OHSAS18001

OHSAS 18001 is the internationally recognized assessment specification for occupational health and safety management systems. It was developed by a selection of leading trade bodies, international standards and certification bodies to address a gap where no third-party certifiable international standard exists. OHSAS 18001 has been designed to be compatible with ISO 9001 and ISO 14001, to help organizations meet their health and safety obligations in an efficient manner. OHSAS 18001 can be adopted by any organization wishing to implement a formal procedure to reduce the risks.
associated with health and safety in the working environment for employees, customers and the
general public.

The International Standards Organization (ISO) [www.iso.org]
- ISO is the world’s largest developer and publisher of International Standards.
- ISO is a network of the national standards institutes of 160 countries, one member per country,
  with a Central Secretariat in Geneva, Switzerland, that coordinates the system.
- ISO is a non-governmental organization that forms a bridge between the public and private
  sectors. On the one hand, many of its member institutes are part of the governmental structure
  of their countries, or are mandated by their government. On the other hand, other members
  have their roots uniquely in the private sector, having been set up by national partnerships of
  industry associations.

Therefore, ISO enables a consensus to be reached on solutions that meet both the requirements of
business and the broader needs of society. The relevant standard which includes Health and Safety is
ISO 9001 Quality Management System.

Good Management Practices models
There are a number of Good, Better or Best Management practice models and some of these contain
reference to Health and Safety. An example is SuSFarMS [1], a sustainable sugarcane farm management
system, described by Maher (2007), which is “designed to encourage sustainable sugarcane
production through the implementation of better management practices (BMPs), which reduce the
negative impacts on the environment.” This includes reference to Health and Safety.

Sustainability standards
A number of sustainability standards have sections or aspects which address health and safety,
examples being Bonsucro (www.bonsucro.com) and Sustainable Agriculture Standards
(www.sanstandards.org).

Bonsucro has two principles which are largely relevant to social issues including health and safety
and criterion 2.3 addresses this specifically as, "To provide a safe and healthy working environment in
work place operations."

Sustainable Agriculture Network has a full section (6) titled, "Occupational Health and Safety" which
is introduced by: “All certified farms have an occupational health and safety program to reduce or
prevent the risk of accidents in the workplace. All workers receive training on how to do their
work safely, especially regarding the application of agrochemicals. Certified farms provide the
necessary equipment to protect workers and guarantee that the tools, infrastructure, machinery
and all equipment used on the farms is in good condition and does not pose a danger to human
health or the environment. Measures are taken on these farms to avoid the effects of
agrochemicals on workers, neighbors and visitors. Certified farms identify potential emergencies
and are prepared with plans and equipment to respond to any event or incident, as well as to
minimize the possible impacts on workers and the environment." (www.sanstandards.org)

Guidelines
A useful general guideline is the "IFC Environmental, Health and Safety Guidelines for Plantation Crop
Production". Details of this have been provided in box 12.6

The simplest route to a safe and healthy work place is surely to select an appropriate Safety
Management System or standard and abide by its requirements.
12.3 References


Nag PK and Nag A (2004). Drudgery, accidents and injuries in Indian agriculture. Occupational health research in Asia: Recent advances. Industrial Health 42, 149-162.

OHSAS 18001:2007 Occupational health and safety management systems www.bsigroup.com/OHSAS18001


Rotterdam Convention, Prior Informed Consent (PIC): http://www.pic.int


www.gov.za


Stockholm Convention on Persistent Organic Pollutants: http://chm.pops.int/


USA Government: Environmental Protection Agency www.epa.gov


CHAPTER 13 BIOMASS MANAGEMENT: ETHANOL & ELECTRICITY GENERATION – JERRY GOSNELL

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13. BIOMASS MANAGEMENT: ETHANOL AND ELECTRICITY GENERATION

This chapter charts the progress of sugarcane as it changes from a single product crop to a crop with multiple end products including ethanol and electricity. Changes in variety breeding policy, field practices, harvesting techniques and the use of vinasse are highlighted, together with the social and environmental aspects of these changes.

13.1 Co-products: ethanol and biomass for electricity production

13.1.1 Introduction

For centuries the main purpose of growing sugarcane was to make sugar, initially non-centrifugal, which is still made in many countries, and centrifugal sugar, the main product of commerce. During the 20th century, the production of ethanol has become popular for fuel, industrial and potable purposes. Brazil has shown the way, producing very large quantities, currently over 25 billion liters (25 million m$^3$) per annum and slightly more than half the sugarcane grown in Brazil is devoted to ethanol production.

It is sometimes hard to think of sugarcane as a plant that does other things as well as accumulating sugar. It is even more difficult to realise that sugar accumulation is not even the thing that it does best. Above all else, sugarcane, a C4 plant, is a producer of biomass and energy unequalled by any other plant when managed as a growth commodity. Leal (2007b) summarized the primary energy characteristics of sugarcane in Brazil as shown in Table 13.1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Energy (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 kg of sugar</td>
<td>2500</td>
</tr>
<tr>
<td>135 kg of stalk fiber</td>
<td>2400</td>
</tr>
<tr>
<td>140 kg of leaf fiber</td>
<td>2500</td>
</tr>
<tr>
<td>Total</td>
<td>7400</td>
</tr>
</tbody>
</table>

Table 13.1. Primary energy of sugarcane per tonne cane in Brazil.

As shown later, the energy contained in field residues approximately equals the energy in bagasse, which in the past has typically sufficed for factory requirements. Field residues can thus yield an enormous additional supply of energy, which can be used in the production of ethanol and export power.

13.1.2 Ethanol

Ethanol as vehicle fuel

Ethanol is quite different from conventional fuels derived from petroleum because of its high oxygen content, which comprises about 35 % of the weight of ethanol. Generally speaking, ethanol’s characteristics enable cleaner combustion and improved engine performance (Otto cycle), which contributes to reducing pollution emissions. Conventional gasoline engines may be used without any adjustment using blends with gasoline containing up to 10 % anhydrous ethanol. Engines must be adapted however in order to use the cheaper hydrated ethanol (with about 5 % water content). Flex-fuel vehicles (FFV), which now have a high penetration in the Brazilian market, may be driven with any blend of ethanol/gasoline.

In a comparison with pure gasoline, a careful analysis of the most relevant aspects of gasoline/ethanol blends such as octane rating, volatility, performance, phase separation, materials
compatibility (elastomers and metals) and tailpipe emissions (including carbon monoxide, nitrogen oxides, sulfur and aldehydes) demonstrates how this biofuel can be used without technical and environmental problems.

From an economic point of view, the opportunity cost of sugarcane bioethanol (compared to sugar and molasses), and the comparison of prices paid to bioethanol manufacturers in Brazil with international gasoline prices during the past decade, both confirm the attractiveness of this biofuel and reinforce the importance of promoting it on a competitive basis (and, where possible, with less governmental intervention). However, in order to adequately develop the bioethanol market and back its advantages, the State must assume important responsibilities, such as defining bioethanol standards and minimum levels in gasoline blends, as well as establishing a balanced tariff structure in the fuels market.

### Development of ethanol in Brazil

According to the Brazilian Development Bank and Centre for Strategic Studies and Management Science, Technology and Innovation (BNDES CGEE 2008), the historical development of bioethanol as a fuel in Brazil started in 1931 when, with the objective of reducing the impacts of total dependence on petroleum-based fuels, as well as of using sugar industry surpluses, the Brazilian government published Decree 19717 which specified a minimum content of 5% anhydrous bioethanol to gasoline. With the effects of the first oil crisis, the PROÁLCOOL (Programa Nacional do Álcool/National Alcohol Program) was instituted in 1975 with Decree 76593, with production goals (3 billion liters of bioethanol in 1980) and incentives to expand the production and use of bioethanol fuel, initially by increasing the amount of anhydrous bioethanol in gasoline. In 1979, with the oil crisis worsening, the PROÁLCOOL program gained new force and stimulated the use of hydrated bioethanol in engines adapted or specially made to work with this fuel. Under this scenario, bioethanol production surpassed goals, reaching 11.7 billion liters in 1985.

The combination of incentives adopted by PROÁLCOOL included the following points:

- The institution of higher minimum levels of anhydrous ethanol in gasoline (progressively increased to 25%).
- Guaranteed lower consumer prices of hydrated ethanol relative to gasoline (at the time, fuel prices throughout the entire production chain were determined by the federal government).
- Guarantee of competitive prices to the bioethanol producer, even in the face of more attractive international prices for sugar than for bioethanol (competition subsidy).
- Availability of credit lines at favorable rates for sugar mills to increase their production capacity.
- Reduction of taxes (on new cars and on annual registration fees) for hydrated bioethanol vehicles.
- Compulsory availability of hydrated bioethanol at gas stations.
- Maintenance of strategic stocks to ensure supply out of season.

From 2003, with the advent of flex vehicles and their overwhelming acceptance by consumers, the growth in the consumption of hydrated bioethanol in the national market recommenced, opening up new prospects for the expansion of the sugarcane agroindustry in Brazil, and adding to the possibilities for adding anhydrous bioethanol to gasoline mixtures in the international market. Since that time, the Brazilian sugarcane agroindustry has been expanding, reaching 25 billion liters in 2009. Fig. 13.1 shows the evolution of the production of sugarcane and bioethanol (anhydrous and hydrated) and sugar (Canaplan-Brazil 2011).
Development of biofuels in Europe

The rapid development of the use of biofuels in Europe during the last three years has been driven by the need to improve emission standards as well as to reduce dependence on imported oil.

Emission standards

Regulation 715/2007 introduces new common requirements for emissions from motor vehicles for passenger cars, vans and light duty commercial vehicles. The Regulation covers a wide range of pollutant emissions: carbon monoxide (CO), non-methane hydrocarbons and total hydrocarbons, nitrogen oxides (NOx) and particulates (PM). It covers tailpipe emissions, evaporative emissions and crankcase emissions.

Energy share

The Renewable Energy Directive (2009/28/EC of 23 April 2009), called the RED Directive, poses two key requirements for biofuels in the transport sector:

- EU Member States are required to meet 10% renewable energy share in the transport sector by 2020.
- Biofuels sustainability is required for feedstock and biofuels production as well as minimum greenhouse gas (GHG) savings per energy unit.

The Fuel Quality Directive (2009/30/EC of 23 April 2009), called the FQD, sets environmental requirements for petrol and diesel fuel in order to reduce their air pollutant emissions. These requirements consist of technical specifications for fuel content and binding targets to reduce the life cycle greenhouse gas emissions of fuels. The Directive places the responsibility of reducing GHG emissions on fuel suppliers, who will have to gradually reduce fuel greenhouse gas emissions.

Regulation on CO₂ from light duty vehicles is currently under Regulation 443/2009, which sets emission performance standards for new passenger cars as part of the Community’s integrated approach to reduce CO₂ emissions from light duty vehicles. Car manufacturers have to gradually reduce CO₂ emissions from passenger cars to reach new fleet averages of 130 g/km in 2015 and 95 g/km in 2020.
• The Regulation places the burden of complying with the target on car manufacturers and recognizes the role of alternative motor fuels (namely E85) and innovative technologies, by accounting for additional CO₂ reductions on overall emissions.

• Regarding E85 vehicles, the Regulation foresees that the CO₂ emission reduction may be applied where at least 30% of filling stations provide E85 and that E85 meets sustainability criteria, another reason for car manufacturers and fuel producers and distributors to work sharing a common knowledge basis.

These regulations are kept under review and can be accessed at: European Commission (2010). Joint Research Centre Institute for Environment and Sustainability: Reference Regulatory Framework.

**Energy balance:** This is normally represented by the Net Energy Ratio (NER), which is the renewable energy output of biofuel and co-products divided by the fossil energy input in the whole production chain. The NER gives a good indication of the capacity of biofuels to reduce dependency on fossil fuel energy. The energy balance for ethanol production in Brazil has been analyzed since the 1980s, and updated by Macedo et al. (2008), as shown in Table 13.2. In all the references, three levels of used energy were considered:

- Level 1: Energy consumed directly in the feedstock production and processing, such as fuels and electricity;
- Level 2: Energy required for the production of chemicals and materials (fertilizers, herbicides, seeds, chemicals, lubricants, etc.);
- Level 3: Energy embodied in the equipment and buildings and consumed in their maintenance.

**Table 13.2. Energy balance for the ethanol production chain for major mills in Brazil in 2005/06, expressed in MJ/t cane (extracted from Table 11 in Macedo et al. 2008).**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane production and transport</td>
<td>210.2</td>
</tr>
<tr>
<td>Processing to ethanol</td>
<td>23.6</td>
</tr>
<tr>
<td>Fossil energy in (total of above)</td>
<td>233.8</td>
</tr>
<tr>
<td>Renewable energy out</td>
<td>2185.2</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1926.4</td>
</tr>
<tr>
<td>Bagasse surplus</td>
<td>176.0</td>
</tr>
<tr>
<td>Electricity surplus</td>
<td>82.8</td>
</tr>
<tr>
<td>NER (Renewable output: ethanol + bagasse)/Fossil input</td>
<td>9.0</td>
</tr>
<tr>
<td>NER (Renewable output: ethanol + bagasse + electricity)/Fossil input</td>
<td>9.3</td>
</tr>
</tbody>
</table>

This means that the energy value of ethanol and surplus bagasse was 9.0 times the energy input from fossil fuels; where surplus electricity was included it was 9.3 times higher.

**Development of biofuels elsewhere**

Other countries have followed Brazil’s example and in the past decade substantial ethanol has been produced from sugarcane in other countries, mainly in South America, Africa and Asia. Large quantities of ethanol have been produced from other crops, notably heavily subsidised corn in USA, as well as sugar beet. However, as shown in Table 13.3, the Net Energy Ratios are far poorer than when sugarcane is used as the feedstock. Emissions avoided are also much lower, and criticisms abound that food crops have been used for energy. The escalation in the price of corn worldwide was probably related to the massive subsidised production of ethanol from corn in the USA.

Projections of expansion over five years are shown in Figure 13.2:
Most of the planned expansion in USA and Europe is from crops other than sugarcane which are far inferior in Net Energy Ratio and Greenhouse Gas abatement. Except for corn, the plants used are C3, which are inherently less photosynthetically efficient. In addition and importantly, energy is required to convert starch to fermentable sugars prior to distillation. Comparisons made by BNDES CGEE (2008) are given in Table 13.3.

### Table 13.3. Net energy ratios and emissions avoided for different feedstocks.

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Net energy ratio</th>
<th>% emissions avoided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>9.3</td>
<td>89 %</td>
</tr>
<tr>
<td>Corn</td>
<td>0.6-2.0</td>
<td>-30 to 38 %</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.97-1.11</td>
<td>19 to 47 %</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>1.2-1.8</td>
<td>35 to 56 %</td>
</tr>
<tr>
<td>Cassava</td>
<td>1.6-1.7</td>
<td>63 %</td>
</tr>
<tr>
<td>Lignocellulosic residues*</td>
<td>8.3-8.4</td>
<td>66 to 73 %</td>
</tr>
</tbody>
</table>

*Theoretical estimate; process under development

### Ethanol summary

The summary of the benefits and potential of production of ethanol from sugarcane given below is extracted from BNDES CGEE (2008):

1. Bioethanol can be used in combustion engines, pure or blended with gasoline, with good performance and using essentially the same distribution and storage systems as exist for gasoline.

2. Sugarcane bioethanol is produced using highly efficient capture and conversion of solar energy (NER of over 8). This product yields seven to eight thousand L/ha and provides significant surplus energy, both in the form of solid biofuels (bagasse and trash) and, most important, bioelectricity.

3. Sugarcane bioethanol, produced under Brazilian conditions, is competitive with crude oil at around US $50/barrel, with a production cost determined mainly by the feedstock.

4. Environmental impacts of a local nature associated with the production of sugarcane bioethanol on water resources, the soil, biodiversity, the use of agrochemicals, can be effectively attenuated to tolerable levels, less than the majority of other crops.

5. The use of sugarcane bioethanol enables an almost 90% reduction in greenhouse gas emissions, contributing in an effective way to mitigate climate change. Under current conditions, each
million m³ of sugarcane bioethanol mixed with gasoline reduces about 1.9 million tons of CO₂ entering the atmosphere.
6. The prospects for the technological development of sugarcane bioethanol agroindustry are significant and excellent employment opportunities exist.
7. In countries with sufficient availability of land, ethanol scarcely affects food production.

13.1.3 Power generation

Historically, many sugar mills deliberately designed low efficiency boilers/generators to avoid the problems of surplus bagasse, as there was no incentive to export electricity. Leal (2007b) describes how design of sugar factories has changed dramatically in the past 20 years, through the use of high pressure boilers and high efficiency turbo alternators together with minimizing power consumption in the factory (see Section 2 Ch 1.8.8). The next step (13.4), currently under development, is to bring in from the fields as much trash and leaves as economically possible. New factory design considerations need to include the prices payable for electricity, ethanol and sugar so that outputs can be optimized according to economics.

The ‘ball park’ potential for export of bagasse-based power is 100 kWh /t of cane processed. This figure is already being attained and exceeded in the more efficient sugar factories in Brazil, Guatemala, Reunion, Mauritius, and India where the price being paid for electrical power from sugar mills is economically attractive (Avram-Waganoff et al. 2010). Typical figures from Mauritian factories with steam pressure of 31 bar are around 40 kWh per tonne cane, so there is much room for improvement (Fig. 13.1 of Lau et al. 2005).

Many countries, e.g. Mauritius and Brazil, are seriously investigating sending large quantities of trash, (dry leaves, dead shoots, green leaves and tops) to the boiler station in order to increase power export.

13.1.4 Cellulose technology

Fig. 13.3, taken from BNDES CGEE (2008), summarizes the processes of cellulose technology and shows why sugarcane is the lowest cost crop for production of ethanol. It also introduces the concept of cellulosic biomass.

Box 13.1 Co-Products: ethanol and biomass for electricity production

Sugarcane, a C₄ plant, is a producer of biomass and energy unequalled by any other major crop. In recent years there has been a great change in emphasis, with ethanol for vehicle fuel and biomass for electrical energy becoming as important as sugar production in many areas. In the future cellulosic biomass (trash/ bagasse) may be used to produce a number of industrial products. The Net Energy Ratio (renewable output/ fossil fuel input) is over 9.0 for sugarcane ethanol, far in excess of that of most other crops.

Potential for bagasse-based cogeneration is about 100 kWh per tonne of cane export power from sugar mills which can be attained where the price being paid for electrical power from sugar mills is economically attractive.
Untreated dry bagasse contains 50% cellulose, 30% hemicelluloses and 20% lignin. Theoretically, 517 kg cellulose can be obtained per tonne bagasse (Gonzalez-Brambila et al. (2010). Much research has been carried out in recent years by a number of organizations to develop economic technologies for conversion of the cellulose group to a number of industrial products including paints, films, resins, coatings and composites as well as ‘sugary solutions’, i.e. glucose, fructose, sucrose and other sugars). Some of this work is reported by Aguilar et al. (2010) and Sainz et al. (2010), but, as the technology is still in the future, we will not consider it further here.

13.2 Variety breeding for ethanol and biomass

Since C₄ plants, notably sugarcane (and related plants such as Napier grass and Miscanthus), are known to be the best converters of sunlight to biomass, in recent years a lot of work and discussion has centred on breeding cane for energy (high brix and high fiber).

13.2.1 Recent directions in plant breeding

This subject was the main topic at the ISSCT Co-Products workshop in Brazil in 2006. A summary from Leal (2007a) is shown in Table 13.4.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber % cane</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>DM %</td>
<td>21</td>
<td>35</td>
</tr>
<tr>
<td>Brix % cane</td>
<td>8</td>
<td>19</td>
</tr>
</tbody>
</table>
When the target production is ethanol rather than sugar, the plant breeder should be maximizing Total Fermentable Sugars (TFS) rather than sucrose. As TFS is a somewhat complex analysis and data from past trials is scant, investigations were carried out in Zimbabwe by Cackett and Rampf (1981a) to establish a relationship between TFS and Brix. It was found that there was a correlation coefficient of 0.987 (n=374) and for most purposes therefore, breeders can use brix % cane as a valuable indicator of TFS. Since most ethanol producers in Brazil and elsewhere in the past were also producing sugar, little progress has actually been made world-wide to develop commercially successful varieties for ethanol production. However, there are now many existing and planned projects producing only ethanol, so varieties for these may be developed in the future.

If the target production is exclusively power export from cogeneration, plant breeders are looking for maximizing biomass, which can most easily be obtained through high fiber varieties (which of course reduce extraction thus affecting sugar and ethanol production). Plant breeders in Japan, Barbados and Thailand have had considerable success in this area, but as yet no commercial varieties have emerged, probably because most projects exporting power are also mainly sugar/ethanol producers. It is of interest to examine experiment results and Reunion Island is close to achieving commercial success with high energy canes.

**Japan:** Sugarcane breeders have utilized inter-specific and inter-generic crosses (with *Sorghum bicolor*); Terajima et al. (2007) reported that hybrid 99GA112 produced 24.8 % fiber with 14.4 % brix and 10.8 % pol.

**Barbados:** New multipurpose cane (MPC) varieties with very high fiber content developed at the West Indies Central Sugar Cane Breeding Station in Barbados have been found to produce more biomass per hectare and a wider range of brix values when compared to the traditional sugar cane varieties (Rao PS et al. 2007). Also known as 'fuel cane', the high fiber and high biomass yielding, early generation inter-specific hybrid (EGISH) variety WI79460 produced over 110 tonnes cane/ha, 150 t biomass/ha and 46 t fiber/ha, maintaining yield in plant and ratoon crops. This variety had 25.5 % fiber and 12.4 % brix in cane, and 81.6 juice purity (Rao PS & Albert-Thenet 2005).

**Thailand:** To improve the added value of the sugarcane crop, a selection program was initiated to develop cultivars with improved fiber content. This produced multipurpose cultivars with improved fiber content and sugar yield. The highest fiber % cane of 19.3 was obtained with MPT 99-648, while MPT 00-478 gave fiber yield of 21.9 t/ha (Rao MS et al. 2007).

**Reunion Island** - data from Corcodel and Roussel (2010): A new approach to cane evaluation, which is approaching commercial success, is based on the energy content of cane. Cane energy content and energy yield per hectare and per tonne of cane will become important parameters, according to Botha (2009). Cane cultivars should therefore be optimized for maximum energy production. R 92/0804 is a promising new energy cultivar which has been tested against the standard R 579; results are given in Table 13.5.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Yield t/ha</th>
<th>Sugar % cane</th>
<th>Fiber % cane</th>
<th>Purity</th>
<th>Tons sugar/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>R 579</td>
<td>88.1</td>
<td>13.09</td>
<td>14.77</td>
<td>89.5</td>
<td>11.53</td>
</tr>
<tr>
<td>R 92/0804</td>
<td>123.2</td>
<td>12.60</td>
<td>19.02</td>
<td>88.8</td>
<td>15.52</td>
</tr>
</tbody>
</table>

The energy content of sugarcane and cane products was calculated using Net Calorific Value (NCV) which can be calculated from the chemical reaction on combustion. The NCV of sugarcane was calculated as the sum of the NCVs of fiber, sucrose, glucose and fructose. The net calorific value of...
the cane fiber was calculated from a bagasse equivalent energy using bagasse NCV of 4.23 kWh/kg. The NCVs of reducing sugars (glucose and fructose), ethanol and sucrose were 3.17, 6.20 and 3.56 kWh/kg respectively. Details are given in Corcodel and Roussel (2010).

A comparison of the net energy content of the cultivars in Reunion Island is given in Table 13.6.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Fiber % cane</th>
<th>kWh/t cane</th>
<th>kWh/ha</th>
<th>Electricity production (kWh/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R 579</td>
<td>14.77</td>
<td>1 100</td>
<td>96 868</td>
<td>154</td>
</tr>
<tr>
<td>R 92/0804</td>
<td>19.02</td>
<td>1 261</td>
<td>155 336</td>
<td>198</td>
</tr>
</tbody>
</table>

These preliminary results show that R 92/0804 can increase the overall energy content/ha by 50%, which will result in an appreciable increase in electricity production. Even allowing for consumption in the factory, the figure of 198 kWh/t cane (total production) is exceptionally high compared with the expected norm of 100 kWh/t cane (export), see 13.1.3, and typical actual figures taken from Lau et al. (2005) of 40 kWh/t cane (export). This is no doubt partly due to the installation of very high pressure boilers (80 bar) and modern 30 and 32 MW turbo alternators, as well as the high fiber in the cane.

The sugarcane industry in Reunion Island is moving forward. Bagasse now has value, scheduled for payment to growers for the 2009 crop, a sign that sugarcane will no longer be cultivated for sugar alone. This new value will be complementary to the sugar value, which is still the main energy component of cane.

13.2.2 Future strategies in plant breeding

Hassuani et al. (2005b) concluded from a number of trials that it is possible to select varieties maximizing the total amount of biomass and also high sugar content. Commercial varieties combine high millable stalk yield with reasonable biomass yield. This is not the case with high biomass yield ‘non-commercial’ clones. It was therefore recommended that high biomass varieties should be selected from within groups of promising commercial type varieties.

Norris (2009) has similarly summarized changes in variety breeding policy (Table 13.7).

<table>
<thead>
<tr>
<th>Initial strategy</th>
<th>Current strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>High total biomass and dry matter/ha</td>
<td>High total biomass</td>
</tr>
<tr>
<td>Very high fiber (difficult to billet)</td>
<td>Higher fiber than traditional varieties</td>
</tr>
<tr>
<td>Low sugars and moisture content</td>
<td>High total sugars</td>
</tr>
<tr>
<td></td>
<td>More aggressive root systems (drought and lodging resistance)</td>
</tr>
</tbody>
</table>

Problems likely to arise from high fiber varieties include difficulty in using normal chopper harvesters – modifications may become necessary. In addition, the very high trash load in-field will cause problems unless a high percentage is removed to the factory.
13.3 Towards good pre-harvest field management practices

13.3.1 Ethanol

A number of field practices may need to be reconsidered when ethanol is the target rather than sugar.

**Row spacing**
This subject has been researched world-wide on numerous occasions and conclusions were neatly summarized by Thompson (1978): “There can be little doubt that the maximum production of biomass can be achieved at very close spacings if the crop is to be harvested before sucrose accumulation becomes a criterion of any consequence.” While 1.5 m spacing has been commonly used for sugar production, recent trends towards dual rows at 1.8-1.9 m spacing are favored because of damage to stools by mechanical equipment and the importance of matching row spacing to mechanical track width (Garside et al. 2009). Where production of ethanol and electrical energy are the main targets, closer spacing may become more important, since this will produce higher TFS and total biomass. On large estates the problem of mechanical damage remains but on small farms using light equipment, close spacing may be preferred.

In Zimbabwe, Cackett and Rampf (1981b) investigated in detail the changes in field management practices required when ethanol production is the target rather than sugar. These are summarized below.

**Length of harvest season**
One of the main factors determining the start of crop is the low sucrose typically occurring during late summer. Since brix levels are fairly high at this time (resulting in low purity), Total Fermentable Sugars (TFS) levels are also relatively high. This means that for ethanol production, harvesting could theoretically start up to six weeks earlier. While this would be of enormous benefit to the distillery, earlier harvesting is unfortunately often precluded by wet soil conditions.

**Nitrogen levels**
Trial results from 25 crops under irrigation in Zimbabwe showed that increasing nitrogen levels from 0 to 200 kg/ha resulted in an appreciable reduction in recoverable sugar % cane for early season harvest, which was not the case in late season harvest. Consequently, for production of sugar, lower levels of N were recommended for early season harvest. High levels of N did not adversely affect TFS, and high levels of N for harvest in the early season were thus recommended for production of ethanol.

NB: N application should be split, otherwise fertilizer use efficiency is low and in Southern Africa there is a risk of greater infestation by the African stalk borer, *Eldana saccharina*, in high risk regions.

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**Box 13.2 Variety breeding for ethanol and biomass**
When the target production is ethanol rather than sugar, the plant breeder looks to maximise Total Fermentable Sugars (TFS) rather than sucrose. Little success has so far been achieved in selecting commercial varieties, partly because most industries, notably Brazil, produce sugar as well as ethanol. If the target production is exclusively power export from cogeneration, plant breeders are looking to maximise biomass, which can most easily be achieved through high fiber. Development of such ‘high-energy’ varieties is beginning to show results, notably where payment for bagasse/fiber is made in addition to sucrose.
Chemical ripeners
The main benefit from the use of chemical ripeners is to convert reducing sugars to sucrose. It can therefore be expected that the benefit from ripeners would be much lower for TFS production and this was reported by Cackett and Rampf (1981b). In an average of 15 crops using Polaris, Embark and Ethrel, they recorded 13.4 % increase in recoverable sugar t/ha compared with 5.5 % increase in t TFS/ha. The small increase in TFS obtained with ripeners was explained by Donaldson (2002) who found a reduction in fiber mainly due to the effect of ripener on fiber production between spraying and harvest. Further work needs to be done to evaluate whether the small increase in TFS is justified against the cost of spraying ripeners.

Topping height
Cane stalk analyses from the base upwards show that the top has much lower purity with higher reducing sugars than the base. Cackett and Rampf (1981b) found that, for production of fermentables, optimum topping height is higher by one internode for early and mid-season harvest. However, for late season harvest and for flowered cane, the optimum topping height remained unchanged.

Post harvest deterioration
Much of the reduction in cane quality after burn/cut is due to inversion of sucrose to reducing sugars. Consequently, the delay from burn/cut to crush is of less importance with ethanol production than with sugar production. However, there is a post harvest loss of TFS due to respiration, with loss of CO₂ and decomposition from bacterial action. Field management practices should therefore not be changed.

Age at harvest
Up to a point, increasing age of cane at harvest results in improved ripening, i.e. conversion of invert sugars to sucrose. Thus it is likely that harvesting fast growing, early maturing varieties at a younger age would be advantageous when growing cane for ethanol.

13.3.2 Biomass for cogeneration through green cane harvesting
In many countries, e.g. Brazil and Colombia, legislation has been introduced to mandate green cane harvesting; in others, e.g. Australia, agronomic advantages have induced growers to move to green cane harvesting. These areas primarily grow rain-fed cane, and there have been major moves to mechanize harvesting due to the unpopularity and high cost of manual harvesting of green cane. An example of this major change can be seen in the state of São Paulo, Brazil, which in June 2007 sponsored a protocol that anticipates the legal deadline for the elimination of sugarcane burning (2014 for areas that can be mechanized and 2017 for other areas), while all new sugarcane areas must be harvested mechanically.

Today, 141 of the 170 mills located in the state of São Paulo are implementing the protocol as well as 13 000 sugarcane independent suppliers, and 47 % of the harvest is already mechanized. The elimination of sugarcane burning must be gradual, since mechanization will inevitably result in unemployment. The sugarcane industry is working together with international organizations, NGOs and the state government to re-qualify the 200 000 sugarcane cutters of the São Paulo state.

Harvesting techniques are discussed in 13.4, but the changes in policy affect aspects of rattoon management discussed in this section.
Sugarcane producing countries worldwide can be divided into three categories:

1) Developed countries in which nearly all the cane is chopper harvested green cane.
2) Developing countries which are undergoing transition from manual cutting to chopper harvesting green cane.
3) Undeveloped countries where manual cutting will continue for the foreseeable future, since labor is cheap and employment opportunities scarce. In addition, costs of importing machines and creating the required support structure are high. In most cases, furrow irrigated cane fields will continue to be burnt until the problem of irrigating in the presence of large amounts of trash has been satisfactorily resolved.

13.3.3 Benefits and problems arising from converting from burnt to green cane harvesting

The most noticeable characteristic is the large amount of residual trash left in the field after unburnt harvesting. The agronomic effects of the trash left in unburnt sugarcane fields harvested mechanically should be taken into account.

The benefits and problems from changing from burnt to green cane harvesting are described by van Antwerpen et al. (2001), Hassuani et al. (2005b), Kingston et al. (2005) and Purchase et al. (2008) as follows.

Several benefits of leaving the trash in the field (trash blanketing) have been observed:

• Protection of the soil surface against erosion caused by raindrop impact and wind.
• Reduced soil temperature variations because the soil is protected from direct action of solar radiation.
• Accumulation of organic carbon in the surface 2-5 cm of soil and increased biological activity in the soil.
• Increased water infiltration into the soil.
• More water available due to the reduction in evaporation from the soil surface resulting in higher cane yield under dry conditions.
• Weed control, with the result that the use of herbicides can be reduced or eliminated, thus reducing costs and contamination of the environment. In Brazil, Hassuani et al. (2005b) reported on a number of trials in which varying percentages of trash were removed and observations made on weed growth. The majority of annual weeds were efficiently controlled by trash quantities between 7.5 and 9.0 t/ha (dry matter) evenly distributed on the soil. Savings in weed control costs obtained from converting to green cane in South Africa could be as much as US $87/ha (Wynne and van Antwerpen 2004).
• The nutritional benefits of retaining trash, as discussed in 13.3.5.
• The trash blanket saves CO₂ emissions compared with burning; unfortunately, this is vitiated by gradual decomposition and release of CO₂ during the subsequent crop, unless the trash is removed to the factory for burning in the boilers.

Problems associated with the maintenance of a trash blanket are:

• Difficulty with furrow irrigation is a major drawback when moving to green cane harvesting; in many areas burning has been the general practice because of the need to have a clear inter-row furrow for irrigation. This may change by achieving a more uniform residue of tops and leaves through the use of chopper harvesters, as successfully done in Ledesma, Argentina. This technique needs to be tested and accepted generally; otherwise satisfactory methods need to be developed to clear all or part of the trash.
Figure 13.1 Green furrow irrigated cane showing water moving underneath the dry trash at Ledesma in Argentina (photo: JH Meyer, 2011).

Piling the trash and irrigating in alternate inter-rows has been successfully done in the Burdekin, Australia, as well as in Malawi and Zambia, but may not be satisfactory under very hot dry conditions. (See 6.3.1).

- Fire hazards during and after harvesting.
- Difficulties in carrying out ratoon fertilization under the trash blanket: losses of N occur when fertilizer is broadcast over the trash.
- Change in weed species, mainly large seeded vines, requiring selective control of weeds through the trash blanket (Kingston et al. 2005).
- Delayed ratooning and the occurrence of gaps with a heavy trash blanket causing a reduction in cane yield when temperatures are low and/or the soil is very wet after harvesting; the soil temperature can be 1-3 °C lower at 10 cm depth than under burnt conditions.
- An increase in population of pests (notably soil insects and froghopper) that shelter and multiply under the trash blanket.

In addition to trash removed for burning in boilers, trash should be removed (or burnt before harvest where permitted):

- Nearby inhabited areas or roads due to the fire hazard.
- Before cane replanting in fields infested by soil pests, where control demands the complete removal of the ratoons and trash through the frequent overturning of the arable soil.
- In regions of very wet and cold winters with frequent occurrence of rain during the harvesting period, especially if planted in soils with deficient internal drainage.

13.3.4 Quantities of trash

A world survey by Kingston et al. (2005) showed typical figures of 17 tonnes residue dry matter for a 100 t/ha cane crop. Norris (2009) reported that while many countries have reported figures of 10-15 t d.m./ha for a 100 t/ha cane crop, figures of 15-25 t/ha have been reported from others including Colombia, Swaziland and NSW, Australia.

In South Africa, Donaldson et al. (2008a) found that trash quantities vary substantially with variety and season of growth, and up to 20 t trash/ha have been recorded. For northern irrigated regions of South Africa, a ratio of fresh cane to trash dry matter of 9:1 can be expected, i.e. for a 100 t/ha cane crop, 11 t trash d.m. would be an average figure.
In Argentina, Romero et al. (2007) found that trash yields varied from 7 to 16 t/ha, and the ratio of dry trash to cane yield varied from 12 to 23 %. In Brazil, Hassuani et al. (2005a) found trash levels of 7 to 15 t/ha dry matter.

The average energy content of cane residue components for a crop of 105 t cane/ha, with bagasse included as a comparison, was reported by Norris (2009) (Table 13.8).

Table 13.8. Energy content of field residues after harvest and after air drying.

<table>
<thead>
<tr>
<th>Component</th>
<th>Tons fresh weight/ha</th>
<th>Initial moisture content (%)</th>
<th>Dry matter (tons/ha)</th>
<th>Total energy (GJ/ha)</th>
<th>Collection moisture content (%)</th>
<th>Tons air dry weight/ha</th>
<th>Total energy (GJ/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tops</td>
<td>9.2</td>
<td>80</td>
<td>1.8</td>
<td>13</td>
<td>42.6</td>
<td>3.2</td>
<td>28</td>
</tr>
<tr>
<td>Green leaf</td>
<td>14.0</td>
<td>66</td>
<td>4.7</td>
<td>59</td>
<td>36.3</td>
<td>7.5</td>
<td>75</td>
</tr>
<tr>
<td>Dry Leaves</td>
<td>10.8</td>
<td>12</td>
<td>9.5</td>
<td>162</td>
<td>12.0</td>
<td>10.8</td>
<td>162</td>
</tr>
<tr>
<td>TOTAL</td>
<td>33.9</td>
<td>52.5</td>
<td>16.1</td>
<td>234</td>
<td>25.0</td>
<td>21.4</td>
<td>265</td>
</tr>
<tr>
<td>Bagasse</td>
<td>31.5</td>
<td>51</td>
<td>15.4</td>
<td>226</td>
<td>15.4</td>
<td>226</td>
<td></td>
</tr>
</tbody>
</table>

It can be seen that the fresh residue left in the field after harvest has approximately the same energy as bagasse, which has traditionally been sufficient for sugar milling requirements; this is an enormous increase (i.e. double) in the energy available. The usual practice is to allow the residue to air-dry, which results in lower transport costs as well as further increasing the total energy/ha. Under hot dry irrigated conditions, however, it is imperative to remove the trash quickly to allow irrigation of the ratoon crop to proceed.

13.3.5 Quality of cane residues

Table 13.9 shows comprehensive analyses of residues carried out in four areas of Brazil with average results (Table 110, p 162 in Hassuani et al. 2005b).

Table 13.9. Typical Brazilian chemical analyses of cane residues on dry matter basis.

<table>
<thead>
<tr>
<th>Component</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry leaves</td>
<td>0.32</td>
<td>0.02</td>
<td>0.34</td>
<td>0.42</td>
<td>0.19</td>
<td>0.11</td>
</tr>
<tr>
<td>Green leaves</td>
<td>0.99</td>
<td>0.11</td>
<td>1.69</td>
<td>0.31</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>Tops</td>
<td>0.49</td>
<td>0.09</td>
<td>3.0</td>
<td>0.17</td>
<td>0.15</td>
<td>0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>% dry matter</th>
<th>kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry leaves</td>
<td>37.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Green leaves</td>
<td>15.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Tops</td>
<td>1.6</td>
<td>0.3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>54.7</td>
<td>4.4</td>
</tr>
</tbody>
</table>

In South Africa, cane residue analyses of variety N14 are shown in Table 13.10, taken from Thompson (1991).
Table 13.10. South African analyses of cane residues.  
Mean of P, 1R, 2R and 3R for August and October harvests.

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead trash</td>
<td>0.27</td>
<td>0.02</td>
<td>0.27</td>
<td>0.35</td>
</tr>
<tr>
<td>Green foliage including tops</td>
<td>0.64</td>
<td>0.09</td>
<td>1.68</td>
<td>0.27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>% dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead trash</td>
<td>27.5</td>
</tr>
<tr>
<td>Green foliage including tops</td>
<td>49.6</td>
</tr>
</tbody>
</table>

From Tables 13.9 and 13.10, it can be seen that the N, P and K contents (% dm) were very similar in Brazil and South Africa for both dry leaves/dead trash and for green leaves/foliage; however, the total nutrients in kg/ha for green foliage was much higher in South Africa than Brazil, possibly because of higher green foliage under irrigation.

Should fertilization of subsequent ratoons be changed following conversion from burnt to green cane harvesting and also after removal of trash to the factory?

Nitrogen: Donaldson et al. (2008b) state that it is tempting to assume that fertilizer amounts can be reduced for cane crops following green cane harvesting compared with burnt cane. However, this does not appear to be the case. Vitti et al. (2010) in Brazil used $^{15}$N isotope trash and found that 73% of the total N present remained in the trash, 22% in the soil and only 4% was recovered by the plant in the first ratoon, rising to 9.6% in the second ratoon. Other researchers confirm that little of the N in cane trash is available to the following crop. The potential recovery of N from trash is dependent on the initial C/N ratio of the trash and the rate of trash breakdown, with a more rapid turnover occurring on sandy soils compared to heavier soils (Wood 1966).

Potash: On the other hand, Hassuani et al. (2005b) found that 85% of the K in trash was available to the ratoon after burning. One would expect that fertilizer application of the ratoon crop should be adjusted to allow for the disappearance of K with removal of the trash, a cost to be balanced against the benefit of sending the trash to the factory. However, experimental evidence to confirm this appears to be lacking.

Phosphate: Quantities of P removed are small and can be neglected.

Further work is required on possible increases in fertilization where trash is removed.

The use of cane residues in boilers may have a potential for slagging, or ‘glass’ formation by some mineral elements. As shown in Table 13.11, the content of P, K, Ca and Mg in leaf residues is much higher than in bagasse; this is also the case for Na and Mn, although the quantities are insignificant. This issue needs to be taken into account on an individual factory basis. Comparisons of chemical analyses of cane residue and bagasse in Brazil are given in Table 13.11 (taken from Table 8, p 25 in Hassuani et al. (2005b).

Table 13.11. Comparison of chemical analyses of cane residues and bagasse (g/kg).

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry leaves</td>
<td>0.22</td>
<td>2.24</td>
<td>3.36</td>
<td>1.26</td>
<td>0.091</td>
<td>0.107</td>
</tr>
<tr>
<td>Green leaves</td>
<td>0.87</td>
<td>11.04</td>
<td>2.78</td>
<td>1.32</td>
<td>0.095</td>
<td>0.076</td>
</tr>
<tr>
<td>Tops</td>
<td>1.09</td>
<td>24.5</td>
<td>1.86</td>
<td>1.50</td>
<td>0.088</td>
<td>0.001</td>
</tr>
<tr>
<td>Bagasse</td>
<td>0.22</td>
<td>1.41</td>
<td>0.50</td>
<td>0.30</td>
<td>0.033</td>
<td>0.004</td>
</tr>
</tbody>
</table>

These results are fairly similar to those in Table 13.9, but represent different areas/varieties in Brazil.
A new approach, suggested by Wynne and van Antwerpen (2004) and developed by Purchase et al. (2008) at the South African Sugarcane Research Institute, was to develop a decision support program (DSP). This presents an economic summary of the comparison between burning and trashing with allowance for 79 variables in input costs. Under South African conditions with variable, tending to low rainfall, green cane harvesting was found to be superior in most instances.

Box 13.3 Towards pre-harvest good field management practices
Agronomic practices such as row spacing, nitrogen level, length of harvest season, chemical ripeners, topping height and age at harvest may change when the emphasis is on ethanol rather than sugar production.

The most significant method of increasing biomass for energy is to harvest cane green and send large quantities of trash to the boilers. A 90-100 t cane/ha crop contains 10-15 t/ha dry matter of trash which approximately doubles the energy currently available to the boilers from bagasse. Many parts of the world have moved from burning to green cane harvesting and can begin to take advantage of this possibility. Advantages include protection of the soil surface, moisture conservation, and reduced erosion, reduced weed control costs and CO₂ emissions. However in developing industries with cheap labor still available, the additional harvesting costs of green harvesting are a major disadvantage; other problems include difficulties in furrow irrigation, carrying out ratoon fertilization and delayed ratooning due to lower soil temperatures especially in wet conditions. The removal of nutritional elements, notably K from the field may result in a cost of replacement fertilizers and may also cause slagging problems in the boilers.

13.4 Harvesting techniques to maximize biomass deliveries to the factory
To maximize biomass delivery to the factory without affecting factory recovery, there are two options: one is to develop satisfactory dry-cleaning systems at the feed table which is discussed in Section 2 Chapter 1.2.3 through 1.2.5.

This subject requires much more development and cost investigation, and has the potential to transform the economy of sugarcane. At present it appears that the best systems involve separation of trash from chopper harvested green cane in-field and separate delivery of trash after drying and compaction to the boiler station. There is great potential in modifying harvester cleaning efficiency which is affected by the harvester fan settings. This can vary from 75% to 5%, as shown by Brazilian work quoted by Purchase et al. (2008).

13.4.1 Trash collection from chopper harvested cane
Baling
Hassuani et al. (2005b) reported that Copersucar Technology Center started a project in 1991 to study the recovery of sugarcane trash after green cane harvesting. Much excellent development work has been done on this topic, although it is not widely used as yet.

Field drying of trash is required to reduce transport costs and to increase the total energy available, which increases by approximately 20% if the moisture is reduced from 60% to 30% (Purchase et al. 2008). Under irrigation it is imperative to restart irrigation as soon as possible after harvest, which
conflicts with the need to maximize field drying of trash. Raking of the trash is usually carried out; although it is possible to bale the trash in non-windrowed areas, the raking operation is important to improve baler performance and to reduce damage to the pickup system, avoiding direct earth contact.

Conventional balers can be used. Tests were performed with small and large cylindrical bales and small and large rectangular bales. The choice of a given baling system depends on bale characteristics such as bulk density, integrity (handling/weathering), ease of recovery and handling (form and size), ease of stacking for transport and storage, and size to optimize truckload. The results indicated that the rectangular balers were most likely to succeed, firstly because of the higher operational baling performance (>9 t/h), secondly because of better ability to deal with pieces of cane, and thirdly because of better space utilization by the bales in the transportation truck. Difficulty in recovering large numbers of small rectangular bales from the field and stacking in the truck, indicated that large rectangular bales of 0.8 m width x 0.875 m height x adjustable length should be used.

![Figure 13.2 Sugarcane trash rotobales in Brazil (photo: C Norris, 2009).](image)

Problems associated with trash recovery include:

- Recovery system width not compatible with lines of cane width and soil irregularities.
- Time limitations after harvesting due to cane growth and tillage operations and necessity to irrigate.
- The need for longer drying periods after rainfall on the trash.
- Soil that is added to the trash during the raking operation and trash recovery.
- Choking problems in the baler recovery system due to the presence of quantities of whole cane stalk left in the field by the harvesters.
- Bale plugging inside the baler in the presence of high moisture content and soil in the trash.
- Excessive field traffic with soil compaction and sugarcane stool damage.
- Lack of reliability of the baler, especially of the twine tying system.

It is important to use adequate equipment for bale recovery from the field, loading, transport and unloading. Studies of the layout of the bales in the transportation truck body should be carried out to determine truck and bale length to optimize the transported volume and reduce the number of bales. The truck should tow one or two trailers (the maximum allowed by law to maximize transport load). A system of bale breaking and shredding at the mill needs to be designed and constructed at the boiler station.
**Bulk collection:** According to Norris (2009) bulk collection of residues is operationally much more successful than baling. This requires higher capital resources (particularly transport); however, delivered cost of trash is lower than cost of any baling options for transport distances <20 km. Because tops contain a high nutrient content, another development is to cut off the tops (which will fall to the ground), turn off the trash extractor fans on the chopper harvester and allow all the cane and trash to go into the in-field trailers and then separate the billets from the trash at field edge. A prototype separator is being developed in Australia; this has been tested and is working well, and it remains to mount it onto a movable trailer. The advantage of this method is that the tops are left in the field and a product of a higher calorific value is sent to the factory. In addition, the recovery rate is higher.

**Whole stalk harvested cane**
Norris (2009) reports that green cane whole stalk harvest is standard practice in many cane growing areas, including parts of the Philippines, India, China, Indonesia and Thailand. Attempts to send trash to the factory involve it being raked by hand and then baled. However, field trials indicated that baling hand harvested residues can present difficulties because of high levels of cane stalk. This also introduces some fuel quality considerations.

**13.4.2 Costs of switching from burnt to green harvested cane**
Comprehensive examination of aspects of conversion from burnt to green cane and costs related to trash removal from fields to mill have been made by Purchase et al. (2008) and Norris (2009). Compared with burnt cane, cutting and stripping unburned cane increases harvesting costs, typically by a factor of 2, because of reduced cutter work rate. Detailed ergonomic studies show that most of the increase in work is associated with the action of stripping the cane. The ‘generic’ cost of manual cutting burnt cane is approximately $3.50/t. Doubling this cost and attributing the additional cost to the recovered dry trash (10%) gives a trash cost of app $35/t or approximately $2.90/GJ. After harvest, residues must be windrowed to allow collection. Windrowing, baling, collection, transport and shredding costs total approximately US $10-15/t or $0.90-1.35/GJ for field dried residues (Norris 2009).

The cost of coal has doubled in recent years and is approximately $3.00/GJ. In industries which currently cut the cane unburned, the cost of trash collection is well covered by the value of the trash ($0.90-1.35 vs. $3.00/GJ). For ‘burnt cane industries’ a move to green cane harvesting increased costs by around $4.00/GJ. This is not economically viable unless significant other off-sets/benefits are clearly evident (or energy alternatives increase in cost).

Purchase et al. (2008) developed an economic model to assess costs and benefits of trash removal in South Africa. Based on current and likely future costs of coal, the coal equivalent value of trash is likely to exceed R300/t d.m. In irrigated areas the cost of delivering trash to the factory (raking, baling, bale loading, infield haulage, transport and unloading) is estimated at R140/t. Allowing for cost of bale breaking and shredding, there would be a good profit in sending the trash to the factory. Interestingly, the same exercise on rainfed cane did not show a benefit. Clearly these conclusions must be reviewed as coal prices change, or for that matter any of the other input costs. Depending on the amount of trash remaining, weed control and fertilizer replacement costs may have to be taken into account (see 13.3.3 and 13.3.5).

---

**Box 13.4 Harvesting techniques to maximize biomass deliveries to the factory**
Trash collection from fields after harvest with chopper harvesters can be done with rectangular or rotary balers or by separation at field edge. The technique is not successful with manual cutting or whole stalk harvesters.
13.5 Vinasse: composition, utilization and effects on soils

Vinasse (also known as stillage or distillery slops) is produced at about 13 liters for each liter of ethanol produced from molasses, and lower (to 8) from cane juice. It cannot be discharged into watercourses as it results in death of fish and other aquatic biota. This is because the high organic matter content results in a very high Chemical Oxygen Demand (COD), typically 80-120 000 mg/L and Biological Oxygen Demand (BOD) around 40-60 000 mg/L. However, vinasse has a high nutrient value, importantly potassium, so it is a valuable fertilizer.

13.5.1 Composition of vinasse

The composition of vinasse varies greatly; it depends on whether molasses, cane juice or a mixture is the product used for distillation. It is also affected by agronomic factors in the growth of the cane, notably soil fertility and fertilizer application. The organic matter content of vinasse is very high and, as this contains most of the N fraction, it is necessary to supplement with inorganic N fertilizer and also phosphate where required. Typical analyses from Brazil and Colombia are shown in Table 13.12.

<table>
<thead>
<tr>
<th></th>
<th>Brazil, adapted from Rocha et al. (2007)</th>
<th>Colombia, Tejada et al. (2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Molasses</td>
<td>Cane juice</td>
</tr>
<tr>
<td>pH</td>
<td>4.2 - 5.0</td>
<td>3.7 - 4.6</td>
</tr>
<tr>
<td>Total solids</td>
<td>81.5</td>
<td>23.7</td>
</tr>
<tr>
<td>BOD</td>
<td>65</td>
<td>15-33</td>
</tr>
<tr>
<td>N</td>
<td>0.4 - 1.6</td>
<td>0.15 - 0.70</td>
</tr>
<tr>
<td>P</td>
<td>0.04 - 0.13</td>
<td>0.01 - 0.09</td>
</tr>
<tr>
<td>K</td>
<td>3.1 - 6.5</td>
<td>1.0 - 1.7</td>
</tr>
<tr>
<td>Ca</td>
<td>0.3 - 3.7</td>
<td>0.09 - 1.10</td>
</tr>
<tr>
<td>Mg</td>
<td>0.25 - 0.92</td>
<td>0.12 - 0.30</td>
</tr>
<tr>
<td>S</td>
<td>2.13</td>
<td>0.20 - 0.25</td>
</tr>
<tr>
<td>Carbon</td>
<td>11.2 - 22.9</td>
<td>5.7 - 13.4</td>
</tr>
<tr>
<td>C/N</td>
<td>16.0 - 16.3</td>
<td>19.7 - 21.1</td>
</tr>
<tr>
<td>O.M.</td>
<td>63.4</td>
<td>19.5</td>
</tr>
<tr>
<td>Cu</td>
<td>5.18</td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>8.53</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>16.9</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>2.72</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2.75</td>
<td></td>
</tr>
</tbody>
</table>

13.5.2 Direct application in irrigation water or by tanker trucks

Brazil’s ethanol production is increasing annually; some 25 billion liters were produced in Brazil in 2009, equivalent to 325 billion liters of vinasse. On irrigated estates, direct mixing with irrigation water is the most economic means of disposal. Plastic lined canals, which may be more than 20 km long, are used to convey the vinasse to the fields. The alternative of trucking and application to fields is widely used under rainfed conditions in Brazil. Some vinasse can also be used on farm roads to reduce dust and create a hard surface, but does have the disadvantage of causing vehicle corrosion.
13.5.3 Effect of vinasse on cane yield and quality

In work carried out by the Zimbabwe Sugar Association Experiment Station, Matibiri (1996) reported large benefits over nine ratoons from annual applications of vinasse at levels up to 2% in irrigation water as shown in Table 13, which reports the mean of nine ratoons and means of four levels of nitrogen (applied in split plots). Each ratoon received 44 kg P and (surprisingly) 50 kg K/ha.

<table>
<thead>
<tr>
<th>Vinasse Concentration %</th>
<th>0</th>
<th>0.25</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>m³ stillage applied/ha</td>
<td>0</td>
<td>30</td>
<td>55</td>
<td>103</td>
<td>196</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>57</td>
<td>70</td>
<td>80</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>Estimated recoverable sugar % cane</td>
<td>13.18</td>
<td>13.05</td>
<td>13.08</td>
<td>12.72</td>
<td>12.15</td>
</tr>
<tr>
<td>ERS yield (t/ha)</td>
<td>7.5</td>
<td>9.2</td>
<td>10.6</td>
<td>11.6</td>
<td>12.1</td>
</tr>
<tr>
<td>Total fermentable sugars % cane</td>
<td>13.64</td>
<td>13.70</td>
<td>13.83</td>
<td>13.78</td>
<td>13.58</td>
</tr>
<tr>
<td>Total fermentable sugars (t/ha)</td>
<td>8.1</td>
<td>10.0</td>
<td>11.5</td>
<td>12.6</td>
<td>13.6</td>
</tr>
</tbody>
</table>

Vinasse application resulted in substantial increases in cane yields, with some reduction in recoverable sugars, but no reduction in total fermentable sugars. A summary of the interaction between N and vinasse level is shown in Table 13.14.
Table 13.14. Cane yield in t/ha in the ninth ratoon.

<table>
<thead>
<tr>
<th>Nitrogen level kg/ha</th>
<th>0</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinasse 0 %</td>
<td>46.6</td>
<td>120.5</td>
</tr>
<tr>
<td>Vinasse 2 %</td>
<td>112.0</td>
<td>142.3</td>
</tr>
</tbody>
</table>

With the 2 % concentration (twice the recommended level), soil K increased from 0.45 me % at the start of the trial to 1.37 me % after nine ratoons; this had not yet reached the critical level (1.8 %) at which K could become a problem. Soil Ca dropped from 12 to 9 me % and electrical conductivity increased from 34 mS/m to 43 mS/m after nine ratoons, which is still far below the critical level of 200 mS/m. Vinasse application caused a hardening of the topsoil and increased the formation of clods but did not adversely affect infiltration of water.

In Brazil a general guideline is not to apply more than 300 m³/ha annually (lower on sandy soils) (Donzelli et al. 2005). Penatti et al. (2005) conducted a trial over six ratoons and results are presented in Table 13.15.

Table 13.15. Effect of vinasse and N application on cane yield (t/ha) in Brazil.

<table>
<thead>
<tr>
<th>Vinasse application (m³/ha)</th>
<th>0</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kg N/ha</td>
<td>95</td>
<td>110</td>
<td>119</td>
<td>126</td>
<td>112.5</td>
</tr>
<tr>
<td>50 kg N/ha</td>
<td>111</td>
<td>117</td>
<td>124</td>
<td>130</td>
<td>120.5</td>
</tr>
<tr>
<td>100 kg N/ha</td>
<td>120</td>
<td>121</td>
<td>127</td>
<td>128</td>
<td>124.0</td>
</tr>
<tr>
<td>150 kg N/ha</td>
<td>122</td>
<td>121</td>
<td>127</td>
<td>127</td>
<td>124.3</td>
</tr>
<tr>
<td>Means</td>
<td>112.0</td>
<td>117.3</td>
<td>124.3</td>
<td>127.8</td>
<td>120.3</td>
</tr>
</tbody>
</table>

Appreciable increases in yield were obtained with vinasse application and savings in costs of N as well as P application were achieved.

13.5.4 Effect of vinasse application on soils

Application of vinasse results in appreciable increase in K concentration in the soil; initially this is in upper soil levels, but Fig. 13.4 (Penatti et al. 2005) shows that K can leach down to 100 cm within four years of application of vinasse.

Figure 13.4. Soil K content at four soil depths after six months (left) and four years (right) of three levels of vinasse application and control.

Fortunately the COD and BOD problems are effectively eliminated through application to soil. Wang et al. (1995) reported that after an application of 300 t/ha of vinasse with a COD of 94 400 ppm, the drainage water at 60 cm contained only 65 ppm; similarly BOD was reduced from 33 500 to 4 ppm.
In summary, the benefits of applying vinasse directly as a fertilizer onto fields are as follows:

- Very low cost of major nutrients, notably K but also N, P, Ca, Mg and S as well as micronutrients, principally Cu, Mn and Zn.
- Increase in organic matter results in improvement of soil structure stability and increase in Cation Exchange Capacity and water retention.
- Assists in the reduction of Al, Na and other toxic elements.
- The low pH of vinasse (around 5) beneficially increases the ratio of fungi to bacteria in the soil food web. However, with the decomposition of the carbon component of stillage in time, the pH of soils will increase because of increase in base saturation, as has been reported for acid soils in Brazil (Penatti et al. 2005).
- Vinasse promotes deep root development of the crop, also increases nutrients at depth (Ca to 75 cm, Mg to 250 cm, S and K to 350 cm).
- A reduction in smut incidence due to the smut spores germinating rapidly in the presence of stillage before ratooning occurs, was reported by Matibiri (1996).

Aspects requiring attention include:

- Careful management of soil nutrient status is essential to ensure that salinity and K levels in the soil do not rise to critical levels. In Brazil the law requires that a K balance assessment that takes the soil K status into account, is made to determine how much vinasse can be returned to the fields. It is essential to regularly monitor soil and leaf analyses on fields receiving vinasse application. The critical foliar level is 1.7 %. Soil critical level varies with the Cation Exchange Capacity of the soil and in general should not exceed 15 % of CEC; it is often taken as 1.8 me % on most soils, but higher on vertisols. Provided monitoring is done, regular applications can be made for many years without adverse effects.
- High K levels can adversely affect Ca and Mg uptake in the soil. Whitbread et al. (2004) found that soil K was significantly and positively correlated with K content in cane juice in the factory while high K in cane juice adversely affects molasses exhaustion and can contribute to high ash content in sugar.
- Proper maintenance and repair of the vinasse distribution system is necessary to prevent stillage leaks, and regular monitoring of streams for leaks is required.
- All pumps/pipelines in contact with undiluted vinasse must be made of non-corrosive materials (e.g. stainless steel or PVC). For vinasse diluted in irrigation water, normal aluminium pipes and brass sprinklers are used, while for centre pivots, poly liners are required in galvanised iron pipes.
- Raw vinasse is pumped to settling ponds which must be large enough to hold vinasse when no irrigation occurs, e.g. after rain. These dams gradually fill up with sludge which must later be removed mechanically and can be beneficially applied to fields.
- Domestic water for field villages must be supplied with fresh water.

13.5.5 Use of vinasse in land reclamation

As shown in Table 13.16, Tejada (2010) reports success in reclamation of vertisols with salinity and sodicity problems in Colombia. Application was 1 500 m$^3$/ha vinasse (five times the normal recommended level). Electrical Conductivity, ESP and Exchangeable Na were greatly reduced, while Organic Matter and CEC increased. Exchangeable K was well above acceptable levels and presumably must be flushed out.
Table 13.16. Effect of high levels of vinasse on soil reclamation.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil depth cm</td>
<td>0-30</td>
<td>0-20</td>
</tr>
<tr>
<td>pH</td>
<td>8.0</td>
<td>8.4</td>
</tr>
<tr>
<td>EC mS/m</td>
<td>270</td>
<td>47</td>
</tr>
<tr>
<td>Exch. Na Me %</td>
<td>4.58</td>
<td>1.56</td>
</tr>
<tr>
<td>ESP</td>
<td>24.51</td>
<td>5.74</td>
</tr>
<tr>
<td>Exch. K Me %</td>
<td>0.76</td>
<td>2.34</td>
</tr>
<tr>
<td>CEC Me %</td>
<td>18.69</td>
<td>27.16</td>
</tr>
<tr>
<td>OM %</td>
<td>1.95</td>
<td>3.15</td>
</tr>
</tbody>
</table>

13.5.6 Vinasse Evaporation

Evaporation of vinasse to Condensed Molasses Solubles (CMS) which contains 45-50 % solids has recently been developed in southern Africa to overcome the cost of transport of raw vinasse from the distillery to distant farms. Typical vinasse has a total solids content of 12 %, while CMS at 50 % solids occupies one-fourth of the volume, thus substantially reducing transport costs (Lyle 2006). Unfortunately, high cost stainless steel evaporators and high energy costs for evaporation are required at the distillery to make CMS.

CMS has high K levels and, to replace the potassium removed by the crop, a typical application of CMS would be 3 000 kg/ha which also applies 4-6 kg P/ha; this necessitates the addition of phosphoric acid to CMS where the soil P status is shown to be deficient. Most of the N contained in CMS is in the organic form and is not immediately available to the crop, so additional N is required, which is normally added in the form of urea or ammonium nitrate. Due to its high organic matter, CMS, which is strongly buffered at a pH of around 5, will also greatly reduce the risk of N loss by volatilization as ammonia from urea. The high carbon content in the organic matter of CMS provides long term benefits to soil fertility, as discussed above. Other nutrients such as Ca, Mg, S and trace elements are not normally required to be supplemented. Standard mixes are offered or mixes can be carried out on a field-by-field basis according to soil analysis.

The benefits of applying CMS are the same as those of applying stillage, and savings in fertilizer costs of up to 20 % have been quoted.

Figure 13.5 Left: CMS applicator spraying in field. Right: CMS applied on the cane rows (photos: B Lyle, 2006).
Table 13.17 shows results of a comprehensive trial carried out at Simunye in Swaziland by Turner et al. (2002) and Sugarcane Research Services (2005). CMS was applied at rates between 3 and 6 t/ha for five successive ratoons (4th to 8th) on a shallow Mayo soil. Three t CMS/ha supplied the crop requirement of 150 kg K/ha. Mean results from four ratoons are given in Table 13.17.

**Table 13.17. Effect of CMS on cane yield and quality in Swaziland from Sugarcane Research Services (2005).**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>K kg/ha</th>
<th>Cane t/ha</th>
<th>Sucrose % cane</th>
<th>Sucrose t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic (adequate N and P)</td>
<td>0</td>
<td>84.9</td>
<td>15.7</td>
<td>13.3</td>
</tr>
<tr>
<td>CMS 3 t/ha</td>
<td>150</td>
<td>88.3</td>
<td>16.0</td>
<td>14.2</td>
</tr>
<tr>
<td>CMS 6 t/ha</td>
<td>300</td>
<td>91.4</td>
<td>15.9</td>
<td>14.6</td>
</tr>
</tbody>
</table>

The effect of CMS was not significant in any of the crops but there was a clear trend towards an increase in cane and sucrose yields. As shown below, K levels in the soil increased but, after four years of application, were still far below the critical level.

- No K applied: 0.28 me %
- 150 kg K/ha (CMS 3 t/ha): 0.35 me %
- 300 kg K/ha (CMS 6 t/ha): 0.49 me %

No other notable effects and no deleterious effects on soil salinity or sodicity were found in this trial. However, as with vinasse, careful management of soil and foliar nutrient status must be monitored when CMS is applied.

**13.5.7 Other mechanisms for disposal of vinasse**

Biomethanation is a form of anaerobic digestion which reduces the BOD by as much as 90% and the COD by 65%, and produces a methane rich biogas which can be used to fuel a gas turbine to produce useful energy in the form of electricity or for other purposes. Anaerobic digestion has low energy consumption compared with aerobic digestion. The residual water containing valuable nutrients is disposed of, in a similar manner to vinasse. Biogas fermenters on vinasse are fairly widely used in Brazil and biogas is available at select garages. Further details will be found in Section 2 Ch. 3.3.6.

Widely used in Brazil, vinasse fortified compost is applied at planting by banding the compost in the furrow at rates from 10 to 20 t/ha. The composting process uses filtercake as the base material with vinasse, lime, gypsum and chicken litter applied with regular turning over. The compost generally matures and is ready after 50 days, when the C/N ratio falls below 18. Vinasse or water is applied to cool the decomposing rows of compost to ensure that temperatures are maintained in the 60 to 65 °C range (JH Meyer, pers. Comm., E: jmeyer@netactive.co.za).

A development reported by Oliviero et al. (2010) is Granular Mineral Biofertilizers in which vinasse, together with filter cake and boiler ash, can be converted to solid granular biofertilizers, known as BIOFOM. See Section 2 Chapter 3.4.4.
13.6 Social and environmental risks of ethanol and biomass production

SuSFarms (2006) has clearly enunciated two sets of fundamental principles:

Social principles
The rights and well-being of employees and the local community are upheld and promoted. A working environment that is safe and without risk to the health of employees is provided and maintained.

Environmental principles
Natural assets are conserved, critical ecosystem services are maintained and agricultural resources are sustainably used:

Society derives many essential goods from natural ecosystems such as fodder, fuel-wood and pharmaceutical products. In addition, these natural ecosystems also perform critical life-support services such as:

- Purification of air and water.
- Mitigation of floods.
- Generation and preservation of soils and renewal of their fertility.
- Pollination of crops and natural vegetation.
- Dispersal of seeds.
- Nutrient recycling.
- Control of agricultural pests.
- Maintenance of biodiversity.

13.6.1 Ethanol

Land utilization
The massive increases in ethanol production in Brazil have been criticized because of alleged deforestation. Zuurbier (2008) states that in fact sugarcane has replaced pasture land (45 %) and other crops (50 %), with 1 % replacing citrus and less than 1 % in reforestation and forest land. Interestingly, food crops have also increased, some like soya beans substantially.

Throughout Africa, most apparently unused land is found to be ‘owned’ traditionally and it is essential to enter into negotiation diplomatically with local chiefs and villagers for agreement to develop the land. Compensation for existing crops and livestock grazing will be required and it is advisable to make available suitable land, with irrigation if required, for the villagers to grow vegetables as well as to offer them work opportunities on the estate.

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Box 13.5 Vinasse composition, utilization and effects on soils

Large quantities (13L/L ethanol) of vinasse are produced. This cannot be discharged into natural waterways due to high **BOD** and **COD**. Vinasse contains large quantities of nutritional elements, notably K, and is accordingly a valuable fertilizer with beneficial effects on cane. It can be used in a number of ways. In irrigation areas, it can be economically mixed with irrigation water. Alternatively it can be evaporated to **CMS** and applied mechanically, made into compost or anaerobically digested (biomethanation). Care must be taken not to apply too much vinasse to limited areas and regular soil analyses should be made.
In several countries in West Africa, sugarcane development will require removal of woodland, including a valuable resource, Shea-butter trees (*Vitellaria (=Butyrospermum) paradoxa*). Rural women extract the vegetable fat from the fermented fruit stone and sell it as food and for cosmetic purposes. Replanting of Shea-butter trees on unutilized land such as road verges, shallow soils and valleys is a very important activity for the developer. In addition, a clear policy of maintaining riparian vegetation along stream banks must be developed.

**Energy**

The Net Energy Ratio of ethanol from sugarcane exceeds 9 (Table 1 in Macedo *et al.* 2008). The conclusion from this table is that the future of bioethanol world-wide should be from sugarcane (or allied C4 grasses). All other crops need to be subsidized as their NER is at best 2 and sometimes less than 1, i.e. more energy is consumed than produced, usually because the starch conversion to TFS has significant energy requirements. They also require financial subsidies.

**Greenhouse gas (GHG) mitigation** is a measurable characteristic of a biofuel that is important because of its influence on global warming. The cost per unit of mitigation can easily be calculated and is valuable for comparison with alternative mitigation processes.

The GHG lifecycle analysis (LCA) derives mainly from non-energy related emissions that must be taken into account such as CO$_2$, methane and NO$_2$ emissions from cane burning, fertilizer, and soil carbon stock modification due to land use change. Table 13.18 presents a GHG LCA for Brazilian conditions for anhydrous ethanol; the emissions due to direct and indirect land use change are not included due to the dependence on local conditions (soil, climate, previous use of the land, specific agricultural practices, etc.), and the cause/effect relationship in the case of indirect land use change emissions.

**Table 13.18. Lifecycle GHG emissions (kg CO$_2$ equivalent/m$^3$ anhydrous ethanol) for major mills in Brazil in 2005/06, extracted from Tables 13 and 14 in Macedo *et al.* (2008).**

<table>
<thead>
<tr>
<th>Total emissions (kg CO$_2$ equivalent/m$^3$ anhydrous ethanol) (A)</th>
<th>436</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuels</td>
<td>210</td>
</tr>
<tr>
<td>Trash burning</td>
<td>84</td>
</tr>
<tr>
<td>Soil emissions</td>
<td>143</td>
</tr>
<tr>
<td>Avoided emissions by use of ethanol and co-products (B)</td>
<td>2323</td>
</tr>
<tr>
<td>Net avoided emissions (B-A)</td>
<td>1886</td>
</tr>
</tbody>
</table>

**Greenhouse gas emissions**

Table 13.18 shows that the net reduction in GHG emissions is 1886 kg CO$_2$ equivalent per m$^3$ anhydrous ethanol. As the equivalent figure for hydrous ethanol was 1764, an average of 1800 kg CO$_2$ eq/m$^3$ ethanol has been taken on Brazil’s production of 25 million m$^3$ ethanol annually. BNDES-CGEE (2008) quotes a similar figure of 1.9 t CO$_2$ saved per t ethanol. It thus appears that the savings in GHG emissions from ethanol production is close to 50 million t CO$_2$ equivalent, which includes savings in countries importing ethanol from Brazil, as well as in Brazil itself.

**Productivity**

Sugarcane typically has achieved very high levels of productivity: 7000 L ethanol/ha and 6.1 MWh energy/ha (Zuurbier 2008).
Environmental evaluation of disposal options for vinasse

Although vinasse has the potential to be an environmental disaster, when correctly managed it is a very valuable fertilizer for sugarcane. It is worth noting that savings in fertilizer reduces the energy consumption for growing the crop. Table 13.19 shows the energy demand and emission factors for agricultural products (Macedo et al. 2008).

### Table 13.19. Energy demand and emission factors for agricultural products.

<table>
<thead>
<tr>
<th>Fertilizer/herbicide</th>
<th>Energy demand (MJ/kg)</th>
<th>Emission factor (kg CO₂ eq./kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>56.3</td>
<td>3.97</td>
</tr>
<tr>
<td>P</td>
<td>7.5</td>
<td>1.30</td>
</tr>
<tr>
<td>K</td>
<td>7.0</td>
<td>0.71</td>
</tr>
<tr>
<td>Herbicide</td>
<td>355.6</td>
<td>25.00</td>
</tr>
</tbody>
</table>

Application of vinasse would be expected to save about half of the N and the entire K fertilizer energy demand and emission factor.

Rocha et al. (2007) has compiled a comprehensive life cycle analysis of the four main options used in Brazil, taking into account human health impacts, ecosystem quality and resources depletion. Using a scale of Pt from 0.0 to 2.0, the results were:

- Fertigation without evaporation
- Transport by channels: 0.30
- Transport by trucks: 0.55
- Fertigation with evaporation
- Transport by channels: 1.75
- Transport by trucks: 2.00

Fertigation without evaporation, as generally used in Brazil, is the most environmentally friendly option due to the high energy requirement for evaporation. Canals conveying vinasse are also now lined with plastic to prevent seepage and groundwater contamination.

**Employment**

Assuming that the ethanol does not replace sugar production, additional employment opportunities will be created by the new areas under sugarcane and also industrial work in distilleries.

### 13.6.2 Biomass production

**Conversion from burning to green cane harvesting**

This is the main environmental issue for biomass production. Worldwide there is a big move to green cane harvesting, one of the reasons being the demand for additional biomass for energy production. This issue is described in 13.3 and 13.4, but other environmental factors are again mentioned here. The manufacture of herbicides has significant energy demand and emissions. If all or most of the trash is left in-field after green cane chopper harvesting, herbicides are not usually required. In most cases the efficiency of trash removal is around 60% and the remaining trash would normally be sufficient to eliminate or minimize the application of herbicides. Apart from the massive additional energy obtained by using trash at the boiler station, and the smaller advantage of eliminating herbicides, green harvesting has other environmental advantages.

Elimination of aerial particulate matter is important, both for health reasons and the social issue of ‘smuts’ fall-out on housing and washing lines in the vicinity.
A major problem with switching to green cane harvesting is social. In many undeveloped countries cane cutting provides important opportunities. It was noted in 13.3.2 that the full conversion of the Brazilian sugar industry will put 200,000 cane cutters out of work and steps are being taken to re-qualify them, and some of course will find employment in the enlarged harvester fleet. Unfortunately this option is often not possible in undeveloped countries, many of which will continue to burn cane at harvest for the foreseeable future.

As mentioned in 13.4.1, manual green cane harvesting with manual trash removal is practiced in many countries. Expansion of this option for the sake of biomass production in undeveloped countries could provide substantial additional employment; unfortunately baling hand harvested residues can present difficulties because of high levels of cane stalk.

Increase in biomass production has few or no adverse social effects.

### Box 13.6 Social and environmental risks of ethanol and biomass production

- Extreme care needs to be taken to avoid social or environmental problems in developing new land.
- Conversion from manual to mechanical harvesting can reduce employment, requiring retraining of workers.
- Ethanol from sugarcane avoids 89% of greenhouse gas emissions compared with fossil fuels, with a saving of 1.9 tonnes CO₂ avoided per tonne ethanol.
- The ‘triple bottom line’ of high profitability, social justice for employees and a sustainable environmental policy are vital components of the future of sugarcane.

### 13.7 Conclusions and the way forward

It is clear that the sugarcane industry of the future will be a much more complex business as befits the most efficient converter of incoming solar radiation into materials usable for the world. In most continents, new estates are planned for the triple goal of sugar, bioethanol/other biofuels and power export into the national grid.

The ‘triple bottom line’ is also a vital part of the future: a high degree of profitability must be supported by social justice for the employees and local residents as well as a sustainable environmental policy.

Looking into the crystal ball there are new developments already happening or on the horizon:

- Production of ethanol from the bagasse and trash of sugarcane, generating 20% more ethanol, with the same biomass.
- Extractive fermentation by vacuum: this is a new system of extraction of ethanol produced in the current fermentation process, with a reduction in the generation of vinasse.
- Biodiesel production integrated into the sugar and ethanol production units. This is already a reality with biodiesel being produced by the Barralcool Mill in Mato Grosso State, Brazil, with a capacity of 50,000 tons of biodiesel per year.
- Cellulosic biomass utilizing the 50% of bagasse that is cellulose to convert into various industrial applications.
13.8 References


Canaplan-Brazil (2011) www.canaplan.com.br


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14. DECISION SUPPORT SYSTEMS FOR SUGARCANE PRODUCTION MANAGERS

14.1 Introduction

This chapter deals with the systems that support managers in sugarcane production. A sugarcane production system is complex (Bezuidenhout and Bodhanya 2010) and requires the stakeholders to consider the multiple interrelated and interdependent factors impacting on the sustainability (triple bottom line) of their business. In turn, decision making becomes a complex process and, to facilitate the challenges faced by managers, Decision Support Systems (DSSs) or Decision Support Programs (DSPs) are tools which have been developed to enable one to consider various scenarios and quantify their impact.

There are a great many decision support systems available which consider different elements in the supply chain and these usually enable each element to be ‘optimized’ for a particular set of circumstances. There are a few holistic systems which consider segments or the whole of the supply chain and the interrelationships between the elements within the segment. The systems enable one to simulate, explore and evaluate the systems, such as harvest scheduling, irrigation or transport. These will be discussed, beginning with crop establishment and ending at the mill gate. There are also tools that enable one to manage risk and uncertainties, a vital aspect of an agricultural operation where there are factors such as weather, pests, sugar price and policy which are out of the control of many stakeholders.

Research institutions in each country are usually the custodians of these systems; however, there are some which are commercially available. It is not practical to list all the systems available, but examples will be given of the various types.

While it is important for each stakeholder in the supply chain to maximize their own sustainability it is critical that the overall supply chain operates at maximum effectiveness, and this may require some compromise with the individual elements. When managing an element such as harvesting, it is important to consider the whole production system as a Supply Chain or an Integrated Production System. For example, a harvesting DSS may indicate that it is economic to burn at harvest; however, this will have many negative impacts on the system as a whole and these need to be considered.

The most important factor or metric for the sugarcane production enterprise as a whole is a steady supply of good quality fresh cane to the mill. This will ensure that the mill runs effectively and maximizes the sustainability of the whole sugarcane system, and all stakeholders will benefit from this. Each person in the supply chain should bear this in mind and collaborate with all others to ensure that each person, stakeholder or element benefits and results in a ‘win-win’ situation.

This is not an easy process. It is a complex adaptive system tending towards equilibrium, and each mill area will tend towards a different system. The equilibrium will change as circumstances change; usually external circumstances with issues such as subsidies, input costs, and profitability or viability. Therefore, although a DSS may help to optimize a system, each and every situation will be unique and needs to be considered differently.

The main purpose of a DSS is to improve sustainability, and an important component is the economics of the system. One should focus on the elements of the system that will make the biggest impact on the costs and, very simply, these are made up of overhead costs which include capital and running or operating costs.
Overhead costs are the costs involved in owning capital items, and here the aim is to reduce the amount of equipment to the minimum by maximizing its utilization. Because the logistics may not be running effectively there could be too many harvesters, too many infield units, too many tractors, etc., and if there are many ‘no-cane’ stops the mill will have to have a larger capacity than necessary. For example, in South Africa and for many different reasons, some mills were running three times as many vehicles as were needed (Giles et al. 2005). One habit that sugarcane production systems seem to develop is that whenever there is a capacity problem, more equipment is purchased, when the real problem is management – and here a DSS can play a valuable role in quantifying and demonstrating alternative solutions.

Running costs. Usually, one can only ‘fine tune’ the system and plan and manage elements such as crop establishment, crop maintenance, harvesting and transport more effectively.

One should always prioritize improvements by starting with the one that has the largest impact on the system as a whole. In all of the above, decision support systems play a valuable role in informing managers.

14.2 Decision Support Systems

A DSS is usually a software package based on a mathematical model of a particular system, such as an irrigation system. The system is modeled and all the relevant parameters and variables are included in such a way that one can vary the value of the parameters and observe the impact, the response or the performance of the system. For example, with an irrigation scheduling DSS, one could examine how various irrigation practices affect issues such as water use, electricity consumption or yield. One would populate the system with known or assumed information; the DSS would then model the process and provide an output in tabular or graphic form. One can then change the value of the input parameters and examine the impact on the process. A valuable aspect of this is to carry out a sensitivity analysis to determine which parameters have the most effect, and therefore which parameters to focus on and manage carefully. Another valuable aspect is the ability to carry out ‘what if?’ exercises. Models enable one to ensure that the correct questions are being asked and that the real issues are being addressed.

The models used in a DSS are usually empirical, mechanistic, stochastic or a mix of the three. An empirical model is based on experimental observations and would only apply to conditions similar to those where the measurements were taken. A mechanistic model attempts to emulate the actual physical process taking place and can therefore usually be used to emulate a wider set of conditions. Stochastic is where some randomness is introduced into the model to simulate a random breakdown or weather condition. These factors need to be considered when using a DSS.

Most models can be used as a DSS, as they enable one to explore many aspect of the system being modeled. This means that one will often find a model that can be used as a DSS when it is not publicized as such. Because of local factors such as agro-climatic conditions, the DSS is not always generic, but is often specific to a region. One would therefore contact the local research institutions or consultants to obtain the systems relevant to that particular region and industry.

Experience shows that although researchers and scientists throughout the world (Newman et al. 2000; van den Berg 2007) spend an enormous amount of time and energy developing DSSs, they do not get used very effectively by practitioners. Jakku et al. (2007) attempted a participatory approach to improve the adoption and use of DSSs. However, there is still a low adoption rate, probably because of the complexity of the sugarcane production system.
Every effort should be made by managers to use DSSs because they provide a valuable tool to manage the complexity of sugarcane production and, because no two systems are alike, there is no single recipe or ‘silver bullet’. There are always special circumstances, mainly driven by the relationships of the stakeholders (personal, financial, political) which will make mill areas different, and this makes DSSs important and valuable tools to explore unique solutions and will go a long way to improve the sustainability of the area. Although it is also unlikely that a single solution will fit everyone in one area, there could be a number of solutions that would work at a single site. There will always be a number of compromise solutions to result in a win-win situation for all members of a single enterprise.

This chapter focuses on sugarcane production systems and does not consider the factory. However, the factory is a vital element of the supply chain, and it must be emphasized that to operate effectively a mill relies on a steady supply of good quality fresh cane. Production managers need to take this into account to ensure that the system as a whole functions effectively. There are many factory systems available and one example is given. Loubser (2002) developed an empirically based DSS to consider the impact of deterioration after burning or cutting cane on the production of raw sugar. This enables one to quantify the loss incurred by the burn/harvest to crush delay.

14.3 Crop Models

A substantial effort has been directed at the development of crop growth models. Some of the more popular models are QCANE (O’Leary 1999) and APSIM-Sugarcane (Keating et al. 2003) in Australia, MOSICAS (Bernardes et al. 2007) in Brazil, CANEGRO (Singles and Bezuidenhout 2002) in South Africa and DSSAT v4.5 (2011) (Decision Support System for Agrotechnology Transfer) in the USA.

CANEGRO, which is the sugarcane model used in the DSSAT crop growth modeling system, is available internationally and thus CANEGRO probably has the widest distribution. The crop models are software packages integrating the effects of soil, crop phenotype, weather and management options that allow users to ask ‘what if’ questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist’s career. It has been used for more than 15 years by researchers in over 100 countries. The DSSAT system combines crop, soil and weather databases which can be used by the crop models, including CANEGRO. The user can then simulate multi-year outcomes of crop management strategies for sugarcane at any location in the world. Version 4.5 is able to carry out seasonal and sequence analyses that assess the economic risks and environmental impacts associated with irrigation, nutrient management, climate change, soil carbon sequestration, climate variability and precision management.

The models attempt to be mechanistic, with some reliance on empirical techniques; they are reasonably robust and can be used in different countries as long as the local agroclimatic and soils information is used. van den Berg and Smith (2005) carried out a thorough discussion of the use of growth models to support DSS. Models such as these use up to 100 variables, including daily weather data and management information for establishment, maintenance and harvesting. They can be used for detailed ‘what if’ analysis to support both tactical and operational decisions.

14.4 Crop production

In addition to the growth models there are many systems to assist managers with varieties, nutrition, pest control and irrigation, ‘CROP-9-DSS’ is an expert system which facilitate a wide range of management issues including nutrition, pests and irrigation (Ganesan 2005).
Tarumoto (2009) recognized that the sugar industry is a very complex system, and developed a simulation model to examine the effect of new cultivars and crushing season. The model considers:

- Change in sucrose by week
- Disposition of cultivars and planting date
- Harvesting schedule
- Estimated sugar production
- Costs.

The model can be useful for discussions between grower and miller regarding cultivars and season dates.

### 14.4.1 CanePro SQR

CanePro (2011) is a commercially available holistic planning program and an agricultural management tool. It is more a planning tool than a DSS. The user populates the system with all the input information required and it then provides powerful query facilities. It does have growth model and irrigation scheduling facilities and can therefore be used effectively as a DSS.

CanePro should be used in conjunction with other DSSs for other elements within the CanePro systems. For example, once a system is planned with CanePro, one could use the system to select the irrigation system, or the optimum number of vehicles for harvesting and haulage.

For CanePro to be a useful tool it has to either replace and improve upon existing systems, or provide functionality enabling an estate to increase production or reduce costs. Typically, at an estate level, CanePro could be used to replace functions being performed in spreadsheets or other systems, e.g. yield estimates, harvest planning, irrigation scheduling, saving of field history data, labor time and attendance, and payroll.

The advantage of having a tool such as CanePro over many other independent systems (typically user-created Excel spreadsheets) is that all agronomic data is centralized in one database. With independent systems (often maintained by different users on local hard disks) there is always the danger that the various systems are not updated immediately with changes made in another system, increasing the risk of incorrect timing of agricultural operations.

Where CanePro is very useful as a management tool:

- **Improved Agricultural Decision Making**
  CanePro’s powerful graphical reporting features allow management to quickly identify promising trends or problems to make informed agricultural decisions, e.g. cultivar selection, appraise manager performance, etc.

- **Increased Yields through Harvest and Replant Planning**
  Improve sucrose yields using CanePro’s harvest and replant planners by optimizing harvest sequence to take advantage of seasonal quality and age trends.
- **Improved Yields through better Irrigation Management and Control**
  Improve the distribution and timing of irrigation events to reduce water stress and increase yields. Manage the irrigation supply network to best match demand within the constraints of the supply network.

- **Improve the reliability and control of labor and vehicle activity capture**
  This is done through CanePro’s security and database auditing functionality. Reduce the opportunity for fraudulent transactions and place responsibility for data sign-off on immediate superiors.

- **Management would no longer have to spend time waiting for and compiling reports.**
  Management would be able to generate reports directly from CanePro.

- **Central company database**
  By sharing master tables between departments, data capturing and reporting errors are reduced, and operational mistakes can be avoided. For example, if the harvesting manager changes the order in which fields are harvested, the ripening manager will immediately see this change and adjust the ripening schedule accordingly. A centralized database gives management an integrated picture of the entire agricultural operation, at any level in the operational hierarchy.

- **Continuity**
  Employees come and go. If their knowledge and data is secured in a company database, their work is not lost to their successors.

- **Benchmarking**
  Capturing all agriculture-related information into a single system simplifies benchmarking between estates/divisions. Benchmarking yield and production standards between production units allows senior management to identify problem areas and poor management.

- **Activity costing**
  The entire company could standardize on a fixed set of employee and vehicle activities. This would allow comparative activity costing between the different estates and divisions.

### 14.4.2 Cultivars

Work has been carried out to develop tools to assist in the selection of appropriate cultivars, and Ramburan et al. (2010) showed that a DSS could be very effective in matching an appropriate cultivar to a particular agroclimatic zone.

This tool was developed as a simple DSS to assist managers to select cultivars which would be appropriate for a particular location. The system characterizes cultivars according to commercially important factors which can be matched to a particular agroclimatic zone, especially soil, climate, and pest and disease parameters (Ramburan et al. 2010). It accounted for Genotype and Environment (GxE) interaction where the environment is characterized by a comprehensive number of factors that interact with the cultivar. These include:
The system was validated and found to agree very well with expert opinion. There will be further development of this system.

14.4.3 Nutrition

The various crop models can be used as DSSs to analyze the impact of various nutritional regimes. The South African Sugarcane Research Institute developed a Crop Nutrition Pack which some growers and extension staff (D. McElligott, Mt Edgecombe, SA, 2010, personal communication) consider valuable in helping to manage nutritional requirements.

14.4.4 Herbicides

Bezuidenhout et al. (2002) described a system that was developed as an information management tool for weed specialists and provide technology transfer for decision support. The system standardizes record keeping for experiment results, related insights and observations to improve the sustainability and uniformity in weed research programs. The computer based system is able to consider more factors than in previously developed manual field guides and therefore provides more comprehensive advice under complex scenarios. The user-friendly interface streamlines the interaction with growers and enables better herbicide management. The system is an improvement over herbicide guide booklets, and is anticipated to expand in the future (Bezuidenhout et al. 2002). This simplifies the difficulty in providing advice for the wide range of herbicides available, particularly taking into account the weed spectrum, time of year, soil clay content and organic matter. In addition, certain herbicides can cause phytotoxic effects and, by combining results into a single system, this provides a valuable support system.

14.4.5 Pesticide

CAB International (2011) has a Crop Protection Compendium which is recognized as the world’s most comprehensive site for crop protection information. It has datasheets on over 3 500 pests, diseases, natural enemies and crops, and also has information on more than 20 000 other pest species. The Crop Protection Compendium is an, “encyclopedic, mixed-media tool that draws together scientific information on all aspects of crop protection. It features extensive global coverage of pests, diseases, weeds and their natural enemies, the crops that are their hosts and the countries in which they occur” (CAB International 2011).

The features include fast and easy navigation between text, images, maps and databases, making it a valuable support tool for researchers and crop managers, for managing all kinds of pests. This makes it a ‘one stop shop’ for pest control.
14.4.6 Irrigation

Irrigation has attracted considerable research and there are a multitude of systems available for irrigation scheduling. All make use of local weather data and long term records to establish the amount of water from rainfall. One should therefore identify systems local to the particular area.

The systems enable one to examine the impact of different irrigation installations, different water application strategies, and different methods of estimating or measuring crop water use on water requirements, electricity use, yield, costs and economic margins.

Most of the crop growth models also have irrigation management systems built into the DSS. Despite this, most irrigation systems are poorly managed and over-irrigation is far too common.

The use of the DSS needs to be encouraged. The following are examples of available systems.

Sashed: A water conservation and demand management tool for irrigated sugarcane, developed and described by Lecler (2004a). This is a spreadsheet based management tool for irrigation scheduling and cane yield forecasting. It aims to ensure maximum water use and accounts for runoff, drainage, effective rainfall and evaporation under conditions of excess, adequate or deficient soil water. Crop growth is related to temperature, and the model therefore accounts for regions, early, late and mid-season crops.

A decision support tool named Irriecon v2 was developed by the South African Cane Growers’ Association and the South African Sugarcane Research Institute (SASRI) (Armitage et al. 2008). This is an economic analysis tool which can be used to evaluate the viability of an irrigation system and enables one to carry out ‘what if’ exercises with different irrigation schemes, and different water and electricity use strategies. It is a spreadsheet based tool that can be used to determine detailed capital, operating and marginal costs of various irrigation scenarios. It takes into account factors including fertilizers, herbicides, planting, harvesting and haulage operations. The irrigation is simulated using the ZIMsched 2.0 irrigation systems model (Lecler 2004b).

SIRMOD III is a package developed in the USA to simulate the hydraulics of surface irrigation systems at field level, to enable one to select sizing and operational parameters to maximize application efficiency. Support of the SIRMOD III software can be obtained by written questions or comments directed to the author (Walker 2010).

Schmidt (2001) discussed the use of DSPs to evaluate the impact of sugarcane production and irrigation strategies on water resources and profitability. He illustrated the use of a number of DSPs, developed at or used by SASRI, in a case study for the Mhlathuze catchment. The work showed that the DSSs were useful in a case study to assess the effectiveness, water requirements and limitations of different irrigation strategies in a particular region. This again demonstrates the value of decision support systems in a production enterprise.
14.5 Harvesting

If the important operation of harvesting is not managed effectively, much of the value of the crop can be quickly lost. Value can be lost by not base cutting or topping effectively, damaging and not collecting the stalks, introducing delays between burning, cutting and crushing, delays that increase season length and including extraneous matter in the delivery. There are a number of systems available to assist management of these tasks effectively.

14.5.1 Harvesting schedule

Stray (2010) and Stray et al. (2010) discussed a computerized sugarcane harvest scheduling DSS known as a tactical harvest scheduling problem (THSP). The system enabled the setting and evaluation of a seasonal harvesting schedule in the light of all the factors affecting a harvesting program. The system considered multiple complex factors including the effects of various pests, lodging, varying degrees of frost, accidental fires and partial harvesting. He proved that the system was very effective in managing the impact of these various factors in ensuring that maximum revenue was recovered by the producers, but did not consider the impact on the mill. In particular, the program would be valuable in assisting managers with limited knowledge and experience.

Gajendra and Pathak (1994) developed a DSS to assist managers of chopper harvesting systems in Thailand. A chopper harvesting operation is expensive and complex, with many factors to be considered. The system calculates the various harvesting costs and productivity and shows the transport requirements for different scenarios.

Higgins et al. (2004) considered the complex issues of synchronizing the harvesting operation with cane transport, and developed a tool to maximize efficiency and economic return.

Cane supply

Le Gal et al. (2003) reported on a simulation tool called MAGI developed to analyze the sucrose yield from a cane supply area. MAGI was used as a decision support tool to enable millers and growers in designing and assessing new ways of scheduling the cane supply to optimize the sucrose yield from an area by changing delivery allocation rules and season duration.

The mill area was divided into regions according to variations in cane quality that were related to agro climatic differences. The benefit varied between seasons as the weather conditions varied and, by simulating different seasons, these authors showed that although the benefits varied, a modified cane supply strategy did result in a consistently improved sucrose yield. An analysis showed that the modified cane supply did have an impact on cane payment, and some growers were disadvantaged because of different delivery strategies. A consequence of the strategy was therefore, that the cane payment system would need to be revised to ensure that some growers were not disadvantaged by the system, and that the gains were shared amongst all growers.

14.5.2 Trashing DSP

Despite the many benefits of green cane harvesting (trashing), sugarcane is often burnt prior to harvest to increase the productivity of cutters and reduce the cost of the harvesting process. Without tangible evidence, it is difficult to argue that the benefits of green cane harvesting often outweigh the extra cost of harvesting and the conditions under which this occurs. It is therefore difficult to persuade operators to trash cane (harvest green cane), and a trashing DSS was thus developed to explore all the factors affecting the harvesting process and determine the preferred option. van Antwerpen et al. (2008) discussed the use of a trashing DSP developed by Wynne and van Antwerpen (2004) to investigate the economics of trashing cane at harvest instead of burning.
This is a well thought out and comprehensive DSS which account for all the factors that impact on this important issue. Most of the factors are relatively easy to model; however, although there is general agreement that one of the many benefits of surface residue (a result of trashing) is improved soil health – and this is one aspect which is difficult to model and quantify. This system works with approximately 500 variables to create a setup that represents a particular farm and enables one to explore different ‘what if’ scenarios. The variables include the sugarcane price, the cost of fertilizers and herbicides, and labor requirements. Variables selected for the sensitivity analysis were cane age at harvest, yield in tonnes cane per hectare per month, the number of seasons that trashing was practiced, weather conditions, size of the farm and the value of the trash.

The model can be run to determine the viability of carrying out trashing, and it shows the conditions where trashing would be the wise and economic choice to make. One would, however, have to consider the impact on the mill. With increasing concerns about environmental issues, this DSS is likely to become extremely important in the future and useful in deciding the appropriate practice.

14.6 Loading and transport

These are expensive components of the production operation, and involve the harvesting, loading, transport and mill receiving components of the supply chain and the many stakeholders in the system. Transport also has a large impact on cane quality and the consistent supply of cane to the mill. This segment of the supply chain requires a great deal of collaboration, and there are many internal and external factors which influence the effectiveness of the operation. It is therefore a segment which can derive a significant benefit from a DSS where the various scenarios can be tested and the outcomes quantified.

Like irrigation, cane delivery and transport scheduling has generated a great deal of attention from researchers in an effort to reduce the cost of transport and to ensure a consistent supply of cane to the mill. As mentioned previously, a consistent supply of fresh cane to the mill is one of the more important parameters of the supply chain.

Although transport or supply scheduling system probably has the most impact on the supply chain as a whole, there are many tools to support most aspects of the transport operation.

14.6.1 Vehicle scheduling

In many sugar industries the cane transport system is over-fleeted, with too many interdependent people and no formal structure in place to manage the system. This results in a cyclic pattern of delivery which varies from vehicle queues at the mills to no-cane stops, both of these being detrimental to the system. One requires more vehicles than necessary, the mill cannot operate effectively because of a varying cane supply and the season length has to be extended. All of these reduce profitability and in most cases a system is necessary to achieve regular delivery.

Giles et al. (2005) carried out a case study at a mill area in South Africa and found that, with a formal system in place, there was a potential to significantly reduce the fleet and save in the order of R15 million per year. There are many tools available to analyze and solve the problem. Two possible options are Asicam (Weintraub et al. 1996) used in the Chilean forestry industry and FREDD (Agtrix 2011) developed in the New South Wales sugar industry. Both of these systems enable one to explore the opportunities available, and can be classified as DSSs.
The Agtrix (2011) traffic scheduling system FREDD, is both a DSS and an operational tool which enables a continuous supply of sugarcane to the mill resulting from improved fleet management. The ‘just in time’ transport scheduling software aims to reduce transport costs by minimizing the number of trucks needed to maintain supply. Because FREDD enables one to ask ‘what ifs’ to discuss and develop a plan and also operates in real time, FREDD enables clients to respond immediately to changes in:

- Crushing rate
- Average payload
- Traffic conditions
- Truck or plant breakdowns and other delays.

When combined with Agtrix (2011) telemetry in the harvesting fleet, FREDD can inform the transport or mill where cane is ready to load, while the ETA Calculator can accurately predict projected supply.

The Tableland mill in Queensland uses FREDD and provides the benchmark for a transport system. They use 10 trucks to move 750,000 t in 26 weeks at an average distance of 25 km. Each transport unit hauls nearly 75,000 t, which is substantially more than most other sugar mills (C Norris, Mt Edgecombe, SA, 2010, personal communication). This is the kind of benefit one can achieve with the use of a support system. Giles et al. (2009) reported that the introduction of the scheduling system at four mills in South Africa had been a ‘resounding success’ with returns on investment which were greater than 10:1. The DSS capabilities of FREDD played a significant role in demonstrating to the role players the benefits of the system by being able to model the system and consider various scenarios.

Higgins and Muchow (2003), Higgins et al. (2004) and Higgins and Davies (2005) carried out studies in Australia and developed models and systems to provide solutions for capacity planning in sugarcane transport, looking at alternative cane supply arrangements and a framework for integrating the complex harvesting process with the transport system. All of these systems improved performance and reduced the cost of the transportation operation.

Hoekstra (1973) used a Monte Carlo simulation to study the impact of random variables on the number of vehicles required to deliver loose cane to the mill offloading equipment. These included variables such as mill stoppages, the number of vehicles loaded at the time of the breakdown, the pattern of arrival times of the vehicles, the crushing times of the cane and the number of loads of cane at the offloader. The results showed that the variables did not have a serious affect on the number of vehicles required.

14.6.2 Vehicle selection

There are support systems available to analyze transport requirements and select appropriate vehicles. Hellberg Transport Management (2011) markets the TransSolve software suite, which simplifies the process of selecting the correct vehicle for an application and predicting the costs of running the vehicle. TransSolve is an example of a powerful tool that can be used to customize the transport operation and carry out ‘what if’ exercises to ensure an optimum solution. This is a commercial tool which has an extensive range of customers worldwide.

The Loading module is a graphical design tool that enables the user to configure a vehicle, including accessories and trailers, to calculate correct load distribution, remaining within maximum dimensions and masses. The package dynamically simulates a specific vehicle or combination over any route to predict fuel consumption, trip time and productivity, typically to within 5% accuracy. TransSolve also combines information from the other modules with user inputs to accurately...
determine total operating costs, per unit, of virtually any operational scenario. One can simulate different vehicles, different options such as gear ratios or braking systems, and different routes (the short, steep route or the longer, less hilly route).

Roberts et al. (2009) used TransSolve to carry out a desktop study to demonstrate and compare the haulage costs of different vehicle configurations and combinations and the risks involved, such as the effect of changing parameters. However, numerous other opportunities also exist, such as innovations to reduce tare and thereby increase payload on the haulage cost. The information obtained from this study can be used in the future to help role players decide on the vehicle configuration which would best suit their needs and shows the value of using a DSS to assist management decisions.

14.6.3 Zone placement

Bezuidenhout et al. (2004) developed a model and used it in a case study to show the value of assisting managers to quantify and correct their on-farm road and zone layout to minimize their transport costs. New loading zones were suggested which reduced the cost of the transport operation.

Bezuidenhout and Meyer (2005) reported on the development of a user-friendly Decision Support Program/System (DSP/DSS) based on the above model. The DSP is in Excel and includes menus, navigation bars and a help facility. By specifying a road’s current traffic profile, the system will determine whether, and up to where, a road needs to be upgraded and where loading zones should be located.

14.6.4 Shortcuts

The cost of transport is directly related to the distance traveled and it was felt that in the sugarcane industry there were opportunities to build alternative road routes to reduce the distance required to haul the cane. Route planning involves the determination of a path between any two or numerous points in space, based on design objectives, such as minimum construction cost, maximum travel speed, safety and minimum environmental impact. Because of the significant costs of transport in the sugar industry, Harris et al. (2008) developed a model, named FastTrack, to investigate route planning opportunities in this industry.

FastTrack looks at all the factors which influence the cost of road infrastructure and transport costs and with the use of GIS tools, looks at alternative shorter routes to reduce the transport costs. A case study was carried out to demonstrate the tool and show the savings that could be realized.

14.6.5 Compaction

Soil compaction caused by infield vehicles is a complex process which is likely to impact cane production; however, because of complex soil mechanics and the many factors that influence it, the damage is difficult to quantify. Marx et al. (2006) used a model named SOCOMO (van den Akker 2004), as the basis to develop an easy to use system of investigating the impact of wheel traffic under various conditions.

Bezuidenhout et al. (2006) then used the DSS in an attempts to link long term simulations of soil moisture content, derived using the ACRU agrohydrological model (Schulze, 1995), to simulations of soil compaction obtained using the SOCOMO model. Soil moisture content and compaction were simulated for a reference soil and a reference agricultural vehicle. The spatially reported results
display a discrete traffic season, during which chances of causing severe compaction damage are significantly reduced. This reference traffic season could be used to strategically determine when vehicles should enter sugarcane fields.

14.7 Supply chain

Stutterheim et al. (2006) developed the model CAPCONN, an integrated supply chain modeling tool to provide a suitable approach for supply chain management and planning. The aim of the work was to demonstrate an integrated sugar supply chain model framework from field to the back-end of the mill. The system enabled one to vary the performance, capacity or costs of any element in the supply chain and determine its impact on the cost of the end product, raw sugar.

According to Stutterheim et al. (2006) the CAPCONN model provides a suitable diagnostic framework to analyze and investigate sugarcane supply chains. Bottlenecks are highlighted and the model facilitates capacity manipulation for efficiency improvements under different harvesting methods.

CAPCONN was successfully used to investigate the economic impact in terms of the production cost of raw sugar in a mill area, of a change from manual to mechanical harvesting.

14.8 Bio-energy

With the continuing increase in energy costs and carbon emissions there is also an increasing interest in the production of bio-energy from sugarcane. However, according to Botha and van den Berg (2009), many questions remain regarding the extent to which agronomic practices need to be adapted, and the related economic impacts and tradeoffs are quantified.

They addressed these issues by developing a model chain consisting of a cane growth model, the economics of trash model (Wynne and van Antwerpen 2004), and the farm and sector-level models of the Bureau for Food and Agricultural Policy (BFAP 2008). They modeled realistic farms for three South African production regions (irrigated north, midlands and coastal dryland). The model emulated current practices which were varied to suit different mill processing strategies, including sugar production, electricity cogeneration from bagasse with or without trash, and bio-ethanol production (Botha and van den Berg 2009). Yields were simulated using historical weather data for the period 1998 to 2007.

Four plausible macro-economic scenarios for 2008 to 2017 were compared and the results showed which scenarios were profitable under which conditions. This type of model could be used to consider various alternatives of bio-energy production and used as an interactive tool to contribute to farm and mill level discussion and decision making regarding bio-energy production.

14.9 Miscellaneous

There are some items which can be included in a miscellaneous category.

14.9.1 Carbon footprint

With the increasing concern of the impact of emissions on the environment researchers have developed a host of ‘carbon calculators’ which are available and enable one to estimate the emissions from their operations. A reliable method is discussed by Rein (2010) and can be used to determine the carbon footprint of sugar production.
14.9.2 GIS applications

GIS and its query facilities make useful tools to study the impact of various factors on the sugarcane production system. For example, Schulze et al. (2008) produced the Agrohydrological Atlas for South Africa, which contains detailed primary and derived data relating to agricultural systems. The information is all in a GIS, and the information can be queried for details such as appropriate areas to grow sugarcane and the impact of climate change on sugarcane production areas.

14.10 Conclusions

The sugar industry is a complex system operating in a highly competitive environment and with client pressures to reduce its carbon footprint. This means that to remain sustainable, managers have to make informed decisions; one has to be proactive and explore every opportunity to improve production, reduce costs and be environmentally friendly. One can no longer rely on tradition or experience alone, quantified options, ‘what if’ questions and different scenarios have to be explored.

Decision support systems provide a valuable tool to achieve this. There are many available to optimize individual elements of the supply chain, and others to examine larger segments of the chain. Many have proved their worth in case studies and every effort should be made utilize these management tools.

The decisions can be long term and strategic, medium term tactical decisions to support the strategy, or day to day operational decisions. In the case of FREDD in vehicle scheduling, they could be minute by minute decisions as disturbances to the daily plan take place.

There are a huge number and a wide range of systems available, mostly from research institutions although more and more are being marketed and supported commercially. Although some are generic and can be applied internationally, others such as cultivar selection would have to be locally applied.

Adoption has proved to be a serious limiting factor and a number of reasons have been given for this. However, despite this, they are generally valuable tools and managers should be proactive and utilize them to improve their enterprises. The ability to carry out a sensitivity analysis cannot be underestimated; determination of the factors which have the largest impact on the system enables one to focus on the correct issues and get an improved return on investment. Managers can also be informed and make the right decision at the right time, while keeping future scenarios in mind, minimize their inputs and risk and maximize their outputs.

Although there has been an emphasis on ensuring that individual elements of the supply chain are not optimized at the expense of the whole system, most of the DSPs mentioned do focus on sugarcane production without considering the impact on the sugar recovery system. This is because researchers tend to concentrate on either sugarcane production or milling; and seldom on both. One needs to take this into account and ensure that the factory receives a steady supply of fresh, high quality sugarcane.
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http://www.cabi.org/cpc/.
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Prepared by PGBI Sugar & Bio-Energy (Pty) Ltd.


Walker WR (2010). SIRMOD III. Professor, Department of Biological and Irrigation Engineering, Utah State University, 4105 Old Main Hill, Logan, UT 84322-4105, wynnwalk@cc.usu.edu.

SECTION 2 - SUGARCANE PROCESSING MANAGEMENT - DR P REIN
CHAPTER 1 CANE PROCESSING, PRODUCTION OF SUGAR, ETHANOL & POWER

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1. CANE PROCESSING, PRODUCTION OF SUGAR, ETHANOL AND POWER

A raw sugar mill processes sugarcane to raw sugar and/or ethanol. Molasses is a co-product of sugar manufacture, unless ethanol is produced on site, in which case the sugars in molasses are fermented and a spent wash known as vinasse is generated. Various strategies exist to deal with the large amounts of vinasse produced. Electricity may also be produced and exported where feasible and profitable using surplus bagasse as fuel.

In the processing of sugarcane, residues are generated, in particular filter cake, boiler residues, effluent water and miscellaneous wastes. Sugarcane processing has the advantage that no toxic or hazardous residues or wastes are produced. In a refinery, usually autonomous and separate from the mill, raw sugar is refined to white sugar. In the process different residues are generated, such as filter cake, some cleaning and regeneration chemicals and some spent solid adsorbent. In some countries like Brazil a direct consumption sugar referred to as ‘plantation white sugar’ is produced directly in the sugar mill without the need of a refinery.

Odors are not usually a problem in sugar manufacture, except in the case of poorly controlled waste water treatment plants or badly managed yards producing compost from factory residues. Particulate emissions from boilers are probably the most important emission needing appropriate removal plant and equipment. Gaseous emissions in most cases are not an issue. Sugar mills and ethanol distilleries are particularly fortunate in being able to utilize bagasse as a fuel to supply all their energy needs. This represents a great cost saving and results in products with a very small carbon footprint.

Sustainable operation implies efficient use of all resources, water, energy, raw materials, capital and time. This requires diligent operation by skilled operators, and recycle and re-use of all these resources where appropriate. These issues are all important in identifying good management practices.

It is important that the sugar companies and owners of mills and/or distilleries should have well defined statements on the following:

- Mission
- Vision
- Values.

These statements should contain the commitment of the company to the issues covered in this Manual of Good Practices.

1.1 Cane quality

1.1.1 Effect of cane quality on recoverable sugar and capacity

Effect on recovery of sugar
The quality of the cane influences the amount of sugar which is extracted in juice from the cane as well as the quality or purity of the juice. Clean fresh cane is the ideal feed to a mill, because this facilitates extraction of sugar from the cane and yields the highest purity juice for processing. The fiber content has the largest effect on extraction. If the fiber content is higher, the quantity of bagasse is greater and the loss of sucrose in the bagasse is increased correspondingly. Various studies have led to the development of a series of ‘reduced extraction’ formulae, which attempt to account for the fiber content. A number of corrected extraction formulae have been published,
which correct the extraction $E$ for different values of the fiber content $w_{F,C}$ and sucrose content $w_{S,C}$ in cane, and the most commonly used are summarized in Table 1.1.

### Table 1.1. Various equations for reduced extraction illustrating effect of sugar content $w_{S,C}$ and fiber content $w_{F,C}$ on extraction relative to standard values (from Rein 2007).

<table>
<thead>
<tr>
<th>Originator</th>
<th>Reference</th>
<th>Reduced extraction equation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced extraction (Deer)</td>
<td>Hugot (1986)</td>
<td>$100 - \frac{(100 - E) \cdot (100 - w_{F,C})}{7 \cdot w_{F,C}}$</td>
<td>No effect of $w_{S,C}$; standard $w_{F,C}=12.5$</td>
</tr>
<tr>
<td>Reduced extraction (Mittal)</td>
<td>Hugot (1986)</td>
<td>$100 - \frac{12.5 \cdot (100 - E)}{w_{F,C}}$</td>
<td>No effect of $w_{S,C}$; standard $w_{F,C}=12.5$</td>
</tr>
<tr>
<td>Whole reduced extraction (Mittal)</td>
<td>Mittal (1969)</td>
<td>$100 - \frac{(100 - E) \cdot w_{S,C}}{w_{F,C}}$</td>
<td>Standards $w_{S,C}=12.5$, $w_{F,C}=12.5$</td>
</tr>
<tr>
<td>Corrected reduced extraction (Rein)</td>
<td>Rein (1975)</td>
<td>$100 - 0.1834 \cdot \frac{(100 - E) \cdot (100 - w_{F,C}) \cdot (w_{S,C}/13)^{0.6}}{w_{F,C}}$</td>
<td>Standards $w_{S,C}=13$, $w_{F,C}=15.5$</td>
</tr>
</tbody>
</table>

Once the juice has been extracted from the cane, the recovery of sugar from the juice is largely a function of the purity of the juice, or rather the impurity or nonsucrose content. The quantity of nonsucrose dictates directly the quantity of molasses produced and the sucrose lost in molasses is normally proportional to the quantity of molasses (although it is affected by the nature of the impurities (Rein 2007)).

Recovery of sugar from sugar in juice can be estimated from the ‘SJM formula’, which is derived from a simple mass balance. This formula is normally represented by an equation written as follows:

$$\text{sugar recovered} = \frac{100 \cdot S \cdot (J - M)}{J \cdot (S - M)} \%$$  \hspace{1cm} (1.1)

where $S$, $J$ and $M$ represent the purities of the sugar produced, the juice being processed and the molasses respectively. This relationship is often used to estimate the recovery of sugar, but takes no account of sucrose losses other than that in molasses.

Carp proposed a recovery formula based on the SJM formula, assuming a molasses purity of 30 (Rein 2007). Assuming also that 4% of the sucrose in the raw juice would be lost elsewhere in the factory, his equation was obtained as:

$$\text{sugar recovered} = \frac{9600 \cdot (P_j - 30)}{P_j \cdot (P_S - 30)} \%$$  \hspace{1cm} (1.2)

Winter proposed a modified version of Carp’s formula, based on the assumption that one part of nonsucrose holds 0.4 parts sugar in molasses:

$$\text{g sugar recovered from 100 g juice} = w_{S,J} - 0.4 \cdot (w_{P_S,J} - w_{S,J})$$  \hspace{1cm} (1.3)

or, written in a different form:
sugar recovered = 100 \cdot \left( 1.4 - \frac{40}{P_j} \right) \% \quad (1.4)

This formula can also be derived from the SJM formula assuming a sugar purity of 100 and a molasses purity of 28.57. Both these equations assume that the purity of the juice $P_j$ is the only factor affecting the recovery of sugar.

A similar formula has been in use in Australia since 1888 to estimate recoverable sugar from cane, which is termed Commercial Cane Sugar or CCS. The equation is:

$$CCS = w_{SC} - 0.5 \cdot (w_{DS,C} - w_{SC})$$  

(1.5)

CCS is expressed in g/100 g cane and $w_{SC}$ and $w_{DS,C}$ are the sucrose and dissolved solids (Brix) contents in cane. It indicates that the recovery of sucrose is reduced by a quantity equal to half the nonsucrose in cane. It takes no account of the fiber content of the cane.

**Prediction of Overall Recovery (OR)**

An Overall Recovery (OR) is calculated as the product of Extraction (E) and Boiling House Recovery (BHR).

$$OR = E \cdot BHR / 100$$  

(1.6)

The equations of Deer and Rein in Table 1.1 imply that the loss in extraction, (100 − E), is proportional to $w_{F,C}/(100 − w_{F,C})$. Thus the relationship between a standard extraction $E^*$ and the extraction E at a fiber content ($w_{F,C}$) of 14 g fibre/100 g cane is:

$$\frac{(100 − E^*) \cdot (100 − w_{F,C})}{w_{F,C}} = \frac{(100 − E) \cdot (100 − 14)}{14}$$  

(1.7)

Assuming a standard (good) extraction of 96.75 % with a fiber content of 14 g/100 g cane, the values result in round numbers which simplify the equations. Then the standard extraction $E^*$ is given by:

$$\frac{(100 − E^*) \cdot (100 − w_{F,C})}{w_{F,C}} = \frac{(100 − 96.75) \cdot 86}{14}$$  

(1.8)

Rearranging gives:

$$E^* = 100 - \frac{20 \cdot w_{F,C}}{(100 − w_{F,C})}$$  

(1.9)

BHR can be calculated from the SJM formula, but incorporating an allowance for a reasonable undetermined and filter cake loss, using a factor of 0.98 for that purpose. If a final molasses purity of 33.3 is assumed, the SJM recovery also results in whole numbers, which approximates to the CCS formula used in Australia (although that applies to cane and not juice). Then we have:

$$BHR^* = \frac{100 \cdot (P_j − 33.3)}{P_j (100 − 33.3)} \cdot 98$$  

(1.10)

or

$$BHR^* = 98 \cdot \left( 1.5 - \frac{50}{P_j} \right)$$  

(1.11)

where $P_j$ is the raw juice purity. This approach has the advantage that it does not rely on the pol or sucrose content of cane, which is often unreliable, but on the raw juice purity, which is usually measured accurately.

A Theoretical Overall Recovery (OR*) can be obtained by combining the two equations (1.9) and (1.11):
A Factory Performance Index (FPI) can be obtained as the ratio of the actual overall recovery OR to the Theoretical Overall recovery OR*: 

\[ FPI = 100 \cdot \frac{OR}{OR^*} \]  

Mills which are well operated can generally achieve a value of 100 or more for the FPI. It is a useful relationship for estimating how recovery of sugar is affected by cane quality.

**Effect on mill capacity**

There are three elements determined by cane quality to be taken into account which determine the sizing of a sugar mill:

1. The fiber content of the cane or the total amount of fiber to be handled determines the extraction plant size.
2. The total sucrose input determines the sizing of the high grade pan station.
3. The nonsucrose input into the mill sets the capacity of the low grade pan and centrifugal station.

In the case of ethanol production, the first item above is relevant, but the total fermentable sugars content of the cane determines the size of the distillery required.

Changes in cane quality are generally reflected in the changes in fiber and nonsucrose in the cane. Cane with excessive tops and leaves, for instance, will increase both these inputs significantly. Reductions in juice purity due to cane delays or any other causes also affect the input of nonsucrose. Deterioration of one of these cane quality parameters can lead to a situation where one part of the factory becomes a bottleneck while there is surplus capacity elsewhere in the factory.

Conversely, improvements resulting from reductions in extraneous matter or higher juice purities can lead to effective additional capacity, with no capital expenditure.

### 1.1.2 Management of cane supply

The ideal harvesting and transport arrangement results in cane that is clean and fresh when delivered to the mill. This leads to the minimum processing cost and the highest recovery efficiency.

Cane is often burnt before harvesting. This is an easy way of removing the leaves and results in much higher manual cane harvesting productivity. The main problem associated with this practice is the fall-out of sooty particulate matter over a wide area, and represents a nuisance factor to nearby residents. Burning also contributes to increased greenhouse gas emissions (see Section 1.8.2). The other major disadvantage is the fact that burnt cane deteriorates much faster than unburnt cane after cutting. There is a concerted effort in some countries, particularly Brazil and Colombia, to eliminate the practice of burning. It is generally believed that if burning is stopped, the cane has to be harvested mechanically, although in places like Swaziland it has been shown that manual harvesting of green cane is possible.
Mechanical harvesting is not possible in many cane growing areas because of the topology, where for instance steep slopes prohibit the use of large harvesting machines. There is however a growing trend to mechanical harvesting, and the majority of new projects allow for mechanical harvesting, and in some cases mechanical planting as well. The trash in cane received at the mill from mechanical harvesting is about twice that with manually cut burnt cane, which in most cases is a big disadvantage at the mill.

There are, however, some significant advantages to green cane harvesting, which results in a trash blanket being left on the fields. A comparison of the effects of green cane and burnt cane harvesting is well covered in Section 13.3.3 of this manual. In essence, leaving a trash blanket in the fields conserves moisture, reduces growth of weeds and improves the organic carbon content of the soil. It also usually leads to reduced cane delays, benefitting processing and recovery at the factory.

Negative consequences include slower ratooning in cooler climates and interference with furrow irrigation.

1.1.3 Cane delays

The delay between harvesting and crushing is affected by both the delay in getting the cane to the mill and by the delay in the mill cane yard. In the case of burnt cane harvesting, the delay between burning and cutting adds to the delay, since deterioration of the cane starts immediately after burning.

In Guatemala, where a large proportion of the cane is burnt and hand harvested, at some mills cane burning takes place twice per day so as to minimize the delay between burn and harvest. Cutting starts two hours after burning. This is a good practice compared with burning the day before the cane is to be harvested. In countries like Brazil, burning cane during the day is not permitted. This is a
good practice considering that the burn can be better controlled at night and the dispersion of sooty particulates is generally reduced.

Management of cane harvesting and transport by the mill rather than by the supplying growers is highly desirable in achieving a consistent supply of cane to the mill, with very low delays between harvesting and crushing, and no necessity for cane stocks to be kept on the ground. Where a mill owns the estates supplying a large proportion of the cane, all harvesting machines are owned and operated by the mill. In Queensland, most of the cane is delivered in small rail systems, operated by the mills. This gives the mills control over the cane supply. As an example, La Union mill in Guatemala has no cane in stock on the ground, but usually has about one hour’s stock on wheels. The mill runs the largest transport fleet in the country.

In the most common situation, where the growers are responsible for the cane supply, a system needs to be in place to schedule growers’ deliveries consistently through the season in a way that provides a consistent supply without leading to excessive delays. This is very difficult where there are a large number of supplying growers. It inevitably results in the mill having to store cane on the ground to allow for inconsistencies in deliveries, particularly when deliveries are made only during daylight hours. The additional delay between cutting and crushing which this represents inevitably results in some loss of recoverable sugars.

1.1.4 Effect of cane delays on recovery

Once sugarcane is cut it is subject to deterioration, largely due to the activity of microorganisms. This results in the loss of sugar and the formation of undesirable impurities. The extent of deterioration is determined by a number of factors, but in all cases the effect on the recovery of sugars and the processing of the cane is adverse. It therefore needs to be kept to a minimum.

Deterioration starts in burnt cane from the moment it is burnt, because the heat of the fire cracks the rind and exposes some juice. With unburnt cane, deterioration starts when the cane is cut. In green cane, this occurs only at the cut ends. Deterioration occurs more rapidly in chopper harvested cane, because there are many more exposed ends. The effect can be minimized by increasing the billet length and by ensuring that the cutters on the harvesters are sharp enough to get a clean cut; this ensures that the amount of juice exposed to the atmosphere is kept to a minimum. However, the length of the cane billet has a direct relationship with the density of the cargo and so a compromise between transport cost and risk of cane deterioration is necessary.

In Australia, where chopper harvesters were first widely used, systems of transport were developed to keep the transport delay down to less than 16 hours. Above that time, dextran formation occurred to the extent that the processing of cane was impaired. This should be the target maximum delay for all chopper harvested cane. In Brazil it is considered that 16 hours delay is unacceptable because the cane deterioration is very fast under their climatic conditions. The normal average delay for chopper harvested cane, when using trucks for cane transport, is five hours (E Marino, pers. comm. 2011).

Loss of recoverable sugar in cane was found to average about 1 % per day with whole stalk cane in South Africa (Cox and Sahadeo 1992), although some much larger numbers have been reported. La Union in Guatemala estimate losses of sugar due to cane delays at 2 % per day. In the light of these figures, a target should be set for cane delays with manual harvesting. With reasonable control over the cane supply, delays from harvesting to crushing should not exceed 36 hours. This could be extended to 48 hours when harvesting and delivery arrangements are complicated. Many mills set targets, but find difficulty in meeting them. A calculation on the cost of delays, based on the
potential loss, could help to get commitment to targets. The calculated losses should include direct
deterioration losses as well as losses due to lower recoveries caused by impurities arising from
deterioration, and may also affect sugar quality. The poor quality of the cane can also affect
fermentation if ethanol production is underway. Large amounts of bacteria, mainly *Leuconostoc
mesenteroides*, carried to the fermentation tanks can reduce the capacity of the fermentation plant
and negatively affect fermentation yield and the quality of ethanol produced.

1.1.5 Cane receipt and payment

All cane should be weighed on receipt at the mill. In a few industries, cane is paid for only on the
mass of cane delivered, particularly in places like India, where sampling cane from every grower is
not practicable. However, in most industries, the cane is sampled and analyzed, and payment is
made according to the mass of cane and its pol (or sucrose) content. In Brazil cane is paid for on the
basis of its mass and the total sugars content of the cane, rather than the sucrose content, because
of the production of ethanol. Where ethanol is not produced, the best cane payment systems pay for
recoverable sugar content of cane, which takes into account at least the purity of the juice. The use
of a recoverable sugar formula is most valuable, since it gives the grower an incentive to produce
good, clean and fresh cane. Examples of recoverable sugar content systems are given elsewhere
(Rein 2007). The features of a good cane payment system include the following:

1. The system should promote the profitability of the industry as a whole.
2. Growers and processors should split the proceeds from the sale of sugar on an agreed basis, so
   that they share the risk of variable sugar and/or ethanol prices.
3. The system should be simple and easy to understand.
4. There should be adequate reward to both growers and processors for their efforts.
5. The system should be fair and equitable.
6. The grower should be rewarded for his performance, good or bad, and should not be affected by
   the performance of the mill to which he supplies his cane.
7. The processor should be rewarded for his recovery of sugar from cane, good or bad, and should
   not be affected by the performance of the grower supplying the cane.
8. Allowance must be made for adjustments to be made to preserve equity between processors
   and growers following events outside the grower’s control, e.g. extreme adverse weather
   conditions.

Whatever system is chosen, the method of analysis and sampling procedures should be acceptable
to both grower and miller, and in most cases there is a requirement for an audit by an independent
party.

In most industries, the cane is sampled, while in others, samples of first expressed juice are used to
infer the analysis of the cane. To achieve representative sampling for payment or mass balance
purposes, it is not necessary to sample every consignment. With a good representative sampling
system, sampling of only one-third of the cane consignments will not lead to any loss in accuracy.

Cane is often sampled using a core sampler, but may otherwise be sampled from a hatch in the
prepared cane conveyor, with a suitable electronic tracking system to identify the consignment. The
latter system is more representative and subject to far less scatter, and is the preferred sampling
system. The major disadvantage of this approach is the need to keep the identity of each
consignment of any cane stored on the ground. If cane is not stored on the ground, this disadvantage
falls away. With possible future introduction of dry cleaning systems located at the mill it will,
however, be necessary to weigh and sample the cane prior to cleaning.
In general, the majority of the world cane industries prefer the core sampler and the press method for assessing the cane quality. It is simple, fast, can be easily audited by growers’ representatives and the cane is sampled before it is discharged either onto the feed tables or in the cane yard. Although conventional analyses of cane are usual, the use of NIR systems shows great promise in being able to provide quicker, cheaper and more reliable analyses (Schäffler et al. 2003). The use of NIR on shredded cane samples for payment is implemented at mills operated by Mackay Sugar and by other sugar millers in Australia (Pollock et al. 2007), and is used in about 60 % of the Australian mills. The NIR analyses require continual cross-checking with conventional methods of analysis and the procedures should be carefully controlled (Pope et al. 2004). The system requires good management (highly competent analytical chemists), and good technical/software back-up for the NIR equipment, and so may not be appropriate in some cases.

The use of NIR for analyzing the press juice from a core sample or the first expressed juice is being practiced in some mills, with savings in time and money.

1.1.6 Distribution of proceeds between millers and growers

In most industries, the distribution is related to the revenue obtained from the sugar and/or ethanol produced. In some cases this revenue pool may include proceeds from molasses sales as well. Therefore growers and millers share the risk or reward on sugar and co-products prices.

Generally, the growers receive approximately 60 % of the proceeds and millers 40 %. These numbers differ from one country to another, depending on local circumstances, including responsibility for cane transport, whether molasses and other co-products are included in the pool to be shared, and whether the revenues shared are from white or raw sugar. The approaches adopted in different countries are summarized by Todd and Forber (2005). There are three different approaches to sharing of the revenue (Rein 2007):

(a) **On an industrial basis.** All proceeds are pooled and, based on a pre-agreed split, a price/tonne of recoverable sugar in cane is calculated. This requires single channel marketing, where all sugar is sold by the industry or by individual mills at a predetermined price. With this arrangement, all growers in the industry receive the same price/tonne of recoverable sugar, growers delivering to a mill are not materially affected by the mill’s efficiency, and an individual mill keeps most of the benefit of improved mill performance.
(b) **On an individual mill basis.** All proceeds from an individual mill are split on a pre-agreed basis. The result is different cane prices at different mills. Another consequence of this system is the fact that the proceeds received by the grower are affected by the mill performance. This system tends to blunt the incentive which either party may have to improve performance, because the benefit will be shared with the other party. It is a disincentive for the miller to invest for improved performance and a disincentive for the growers to improve cane quality. Investment by the miller tends to focus on reducing costs, for which they retain the full benefit. However, it is easier to negotiate changes to cane payment systems on an individual mill basis.

(c) **Processing fee paid to miller/tonne of cane processed.** The cost of milling cane is generally proportional to the tonnes of cane crushed. To overcome the disadvantages in the previous two approaches, the miller is paid a processing fee for each tonne crushed from the proceeds of the cane. This is the basis of the Australian payment system. The formula for the price paid in per tonne cane is:

\[
\text{Price/t}_{\text{Cane}} = \frac{\text{Price/t}_{\text{Sugar}} \cdot (A \cdot y - C)}{100}
\]

where \( y \) is the recoverable sugar content of the cane and \( C \) is a constant, representing the recoverable sugar paid to the miller and the value of the constant \( A \) is close to unity. In Australia, the recoverable sugar is about 14 and the constant \( C \) is 4. Thus, roughly \( 4/14 = 0.285 \) is the fraction of the sugar price paid to the miller.

This formula provides strong incentives to the grower as he keeps the benefit of any increase in recoverable sugar content, and the miller keeps the benefit of any improvements he can make in mill overall recovery. The system has served the Australian industry well and is probably in part the reason for the efficiency of the Australian industry.

1.1.7 **Summary and good practice recommendations**

**Box 1.1 Cane Quality**
- The quality of cane delivered to a mill has a huge impact on sugar recovery and milling costs
- The delay between cutting and crushing with mechanically harvested cane should not be more than 16 hours
- With manual harvesting, the delay between burning and crushing, or between cutting green cane and crushing, should be less than 36 hours, particularly with burnt cane.
- If at all possible, the harvesting and transport of cane should be controlled by the mill.
- Cane stocks in the yard should be kept to a minimum, and preferably eliminated entirely (depending on the delivery system in place).
- Cane should be sampled and analyzed so that payment is made on the content of recoverable sugar in cane, or on total sugars content when ethanol is being produced
- An efficient transport scheduling system is necessary to minimize delays and make best use of transport vehicles.
- An appropriate cane payment system is necessary to adequately reward millers and growers and provide the right incentives for the optimum operation as a whole.
1.2 Cleaning of cane

Receipt of clean cane is a major advantage to the cane processor. This can be achieved by leaving soil and extraneous matter in the field (the preferred option), or by cleaning the cane at the mill.

1.2.1 Cane washing

Roughly half the mills in Brazil indulge in cane washing. This is gradually being phased out because of the high water usage involved. Attempts are also being made in Guatemala and elsewhere to reduce the extent of cane washing. Not only does cane washing use large quantities of water, it also results in material loss of sugars and creates an environmental problem.

Most cane wash plants consist of one or two cane tables inclined at an angle of 35° to 45°, with wash water sprayed onto the cane as it is transported up the cane tables. The water is collected underneath the cane tables, some of it is recirculated and some bled off to a treatment system. Some arrangements incorporate hydrocyclones in the circuit to remove the bulk of the mud from the recirculating water.

Vignes (1980) reported on results of whole stalk cane washing trials in Mauritius. Losses of sugar measured in water leaving the washing plant were estimated to be between 1.4 and 1.8 % of the sucrose in cane. Clarke (1991) reported that sucrose losses on washing whole stalk cane are between 1 and 2 % of the sugar in cane. Birkett and Stein (2004) did an extensive study of cane washing in Louisiana and their results may be summarized as follows:

- Sugar loss measured in the water leaving the wash system averaged 3.2 kg sugar/t cane when washing billeted cane. Based on the average recoverable sugar content of cane in Louisiana over the same period, this represents 3 to 3.5 % of recoverable sugar in cane.
- Sugar losses are very variable, with measured values ranging between 1 and 7 kg sugar/t cane.
- The loss when washing whole stalk cane is substantially lower, around 25 % of the losses with billeted cane.
- Ash removal is just over 50 %, with large variations.
- Measured entrainment of wash water into the extraction plant averaged 7.5 t/100 t cane.
- Sugar loss is independent of the amount of wash water used, with the wash water quantity varying between 0.4 and 14 m³/t cane at different mills.

The losses measured by Birkett and Stein (2004) are considered to be underestimates because they take no account of the microbial losses occurring in the system. Measurements at São Martinho indicate losses of up to 6.2 kg/t cane (Marino, pers. comm. 2011). Because of the substantial entrainment of wash water with the cane, the amount of imbibition used in extraction has to be reduced correspondingly. It is important to use the cleanest source of wash water for the last wash, to minimize the entrainment of breakdown products in the wash water, such as organic acids and dextran, into the extraction plant with the cane.

Apart from the losses of sugar, cane washing has other undesirable consequences. Eliminating cane washing at Cora Texas mill gave the following results (Monge and Schudmak 2002):

- Less lime was required both for juice liming and for control of the wash-water pH.
- Imbibition could be increased by 9 t/100 t cane.
- The mud to clarifiers increased by 25 %.
- Juice purity increased by 0.7 units, leading to an increased recovery of sugar.
- Evaporators required less cleaning.
- Extraction improved by about 1 %.
- Ash in bagasse increased and boiler efficiency reduced.
- Overall recovery increased by 10 kg 96 pol sugar/t cane (9.7 % additional sugar produced).

1.2.2 Management of water circuit

The quantities of wash water circulated over the wash tables are large. On average, mills in Louisiana circulate 3 m$^3$/t cane, although this varies widely between 0.6 and 10 m$^3$/t cane (Birkett and Stein 2004). The wash-water rate at Cora Texas mill was 7 m$^3$/t cane (Monge and Schudmak 2002). Baikow (1982) reports that the minimum quantity of water required is 4.4 to 5.9 m$^3$/t cane and Vigne (1980) reported figures between 2 and 2.6 m$^3$/t cane. In general, wash-water is recirculated rather than used on a once-through basis. Management of the wash water system is complicated by the need to settle out the field soil and control the pH and the odor, both of which are a consequence of fermentation of sugar in the system. In Louisiana, the mills practicing cane washing are able to store all the water used in large holding ponds, because of the short three month season. Natural degradation over the remaining nine months of the year gets the COD level down to the point where some of it can be discharged. Ponds need to be emptied every year to dredge the settled soil, which has to be trucked away. Other sugar industries require the solids to be settled out and water treatment for the surplus that is discharged. This is an additional cost requiring extra supervision.

1.2.3 Dry cleaning

There are significant advantages to processing clean cane, in particular enhancing mill capacity and efficiency and reducing mill costs. Dry cleaning of cane prior to processing appears attractive relative to wet cleaning, because the losses of sugar are lower. In addition, water usage and amount of total mill effluent are reduced. For these reasons, dry cleaning is being used to an increasingly greater extent in Brazil and the Central American countries.

Systems in use are designed to remove some or all of the following: cane leaves and tops, roots and stubble, sand or field soil, clay mud balls, rocks and stones. The most cost-effective approach is probably to provide incentives to the grower or harvester operator to deliver clean cane. If this is not in the realm of the possible, dry cleaning of cane could bring the following advantages:

- Cost savings in terms of reduced wear and maintenance.
- Increased factory capacity due to reduced quantities of extraneous matter.
- Reduced energy consumption.
- Higher calorific value of the bagasse.
- Lower losses of sugar in filter cake, bagasse and molasses.
- Improved sugar quality.

There are some disadvantages as well:

- Additional equipment has to be installed, with associated capital, maintenance and operational costs.
- A small quantity of cane may be lost in cleaning.
- Provision needs to be made to dispose of the waste material removed.
- There may be implications for the particular cane payment system.
1.2.4 Removal of tops and leaves

Given the constraints on the performance of harvester cleaning systems, a strong argument can be made for additional secondary cleaning at the mill. Such an approach allows the harvesting operation to be optimized to minimize the cane loss, while ensuring that clean cane is supplied to the extraction plant. In a holistic analysis, the increased transport costs associated with the mass of the leaves and tops and reductions in load density are small compared with the gains in mill performance, sugar quality and total cane recovery.

It has been shown that most of the leaves and tops can be relatively easily removed from billeted cane at the mill by blowing the leaves and tops out of the cane as it drops from one conveyor onto another (Rein 2005). Roughly 80% of the leaves and tops were removed by blowing air at a velocity of about 30 m/s through a curtain of falling cane. The interesting feature is that the separation was achieved with virtually no loss of billets, but the problem of disposing of the enormous bulk of extraneous matter that rapidly built up at the mill could not be resolved and the separation was discontinued. A similar system is in use at the Providencia mill in Colombia, where the leaves and tops are blown out onto a large concrete slab and managed with the use of a front-end loader. Trash is reduced from 6% to 1% with whole stalk cane and from 10% to 3% with billeted cane (Ridge 2001).

Pneumatic cleaning of cane in Australia has also shown that removal of tops and leaves from chopper harvested cane with a low level of billet loss is possible (Schembri et al. 2002). The system was specifically designed to process cane with no trash removal in the field. Tests showed that, in order to reduce the leaf particle sizes to approximate bagasse, a relatively high power requirement for shredding of 12 kWh/t leaf material was required. However, recent installations of biomass cogeneration plants in New South Wales have proved to be uneconomical and are up for sale. The reasons for this situation are the drop in prices of renewable energy certificates (REC’s) and the unexpectedly high cost of removing leaves and tops from the cane at the mill prior to processing. The mills are reverting to cane burning instead of unburnt whole-of-cane harvesting (Anon 2009).

Other systems for mechanically stripping leaves off cane are described by Bernhardt (1994). Where leaves and tops are removed before crushing, the only viable option is to burn the material in the boilers. This is becoming attractive in a number of mills where surplus electric power generated is sold to the public grid. It is economically feasible to remove leaves and tops before crushing and send these materials to a shredder, mixed with bagasse and sent to the boiler station as additional fuel.

1.2.5 Removal of rocks and soil

Efforts to reduce the extent of soil and rocks in cane delivered to the mill are most worthwhile. In some cases growers need to be incentivized in this respect. As an example, in Guatemala, where cane is mechanically loaded in the fields, a sled is pushed under the cane to be loaded before it is grabbed, to reduce soil pick up with the cane. Soil and trash content of the cane are sometimes measured, but sampling and analyses are manually intensive and so expensive in some places. However, the act of measuring and reporting usually helps to improve average levels substantially.

If the cane is dry, a high proportion of the soil in cane will separate fairly easily. The use of perforated plate on a steel deck, particularly where the cane tumbles onto the deck, allows sand to fall through to be collected under the carrier. Other approaches with whole stalk cane include the use of carrier systems with gaps or open slats that permit sand and small stones to fall through the gaps while cane passes over them.
Installations in Thailand and Guatemala have proved successful in removing sand. These devices are usually a set of revolving intermeshing drums or discs, which convey the cane and through which the sand falls. Cane pieces may be as high as 25% of the reject stream, which have to be handpicked from the conveyor and returned to the mill conveyor.

In countries where rocks are a problem, particularly Hawaii, Mauritius and to a lesser extent South Africa, various systems have been tried. McElhoe and Lewis (1974) describe a dry cleaning plant installed in Hawaii, aimed primarily at removing rocks, but also removing cane trash. The plant claimed to remove 96% of all rocks over a two-year period and 38% of the trash.

A successful system for removing rocks and sand continuously has been described by du Plooy (1994). An 11 m wide feed table feeds cane at a steady rate onto an inclined plate. The cane stalks meet a revolving tyned drum, which lifts the cane up and over the drum. Sand and rocks fall down between the drum and the curved wiper plate between the tynes, and are removed at the bottom. Large rocks > 350 mm are combed to the sides of the sloping plate by the tynes. Divergent openings are incorporated to prevent jamming, with the diameter of the rotating drum larger in the center than the sides. The wiper plates can be moved away from the drum by hydraulic cylinders if any jamming below the rotating drum occurs. This system has worked successfully in a few mills in South Africa, but can only be used with whole stalk cane. However, there is still some loss of cane with the sand and rocks. The amount is small but significant, and has had to be recovered manually from the conveyor belt and returned to the mill conveyor.

1.2.6 Summary and good practice recommendations

<table>
<thead>
<tr>
<th>Box 1.2 Cleaning of cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cane should be delivered to the mill with a low content of field soil and extraneous matter.</td>
</tr>
<tr>
<td>• If sand and extraneous matter in cane can be measured, a penalty/bonus system should be considered, to incentivize cane suppliers to send clean cane to the mill.</td>
</tr>
<tr>
<td>• If the miller is responsible for cane harvesting and transport, measurement of soil and extraneous matter is still worthwhile to ensure that the operation is run optimally.</td>
</tr>
<tr>
<td>• Removal of extraneous matter from cane leads to an increase in effective capacity of the mill and reduced losses in bagasse, filter cake and molasses.</td>
</tr>
<tr>
<td>• Washing of cane is to be avoided unless absolutely essential, because of the additional losses of sugar and the high water requirement.</td>
</tr>
<tr>
<td>• If cleaning of cane is necessary, a dry cleaning system should be considered in preference. Various forms of pneumatic separation are available, and the system needs to incorporate the preparation and incorporation of the trash removed into the mill’s bagasse system.</td>
</tr>
<tr>
<td>• If field soil is a serious problem, measures to remove this at the mill should be considered.</td>
</tr>
</tbody>
</table>
1.3 Water use and recycling

1.3.1 Factory water balance

Since cane consists of about 70% water, a cane sugar mill processes more water than sugar. All the water entering a mill must also leave it in one form or another. In theory, there is a surplus of water produced in a sugar mill, which must inevitably find its way out of the mill in an effluent stream. Apart from water entering the mill in the cane, there may also be some additional water in the form of service or raw water added.

Water leaves the factory in a number of different ways, as shown in Figure 1.1.

![Figure 1.1. Flow diagram showing streams containing water entering and leaving a sugar mill complex (Rein 2007).](image)

If ethanol is produced, a large amount of water leaves the factory in the form of spent wash, or vinasse. If ethanol only is produced, the amount of vinasse produced is roughly 1 m$^3$/t cane. With improvements in fermentation and new distillation schemes, the amount of stillage generated has been reduced to less than 0.9 m$^3$/t cane. However for a mill producing sugar only, it should be possible to operate without any water addition to the plant through recycling and the re-use of condensate.

Cane washing complicates the situation considerably, because of the high water rates involved in cane washing plants. Water circulates at a rate between 1 to 10 m$^3$/t cane processed and, usually in the middle of this range, i.e. a water rate much larger than any of the streams shown in Fig. 1.1. A further complication is the fact that a significant amount of the wash water is entrained with the cane and enters the extraction plant. The entrained water is of the order of 0.1 m$^3$/t cane.

The water use benchmark in Brazil was historically in the region of 15 to 22 m$^3$/t cane, obtained from rivers. This is inflated by the use of cane washing, but has been drastically reduced to 2 m$^3$/t cane in 2005 on average, and is projected by CTC to go to 0.5 m$^3$/t cane. This assumes the production of
ethanol at the mill. The average intake in South African factories producing sugar and no ethanol is 0.6 m$^3$/t cane (Palazzo 2004). Factories in India consume 0.9-1.0 m$^3$/t cane and produce effluents in the range of 0.3-0.4 m$^3$/t cane (Sapkal et al. 2001).

In some mills close to a large river, once-through water is used in all condensers. This simplifies the factory system, eliminating the need for a cooling system, and is acceptable providing the water returned to the river meets effluent return standards. It does, however, change the water balance quite substantially. In some cases the water is subsequently used for irrigation, which inflates the water flow into the mill but has no net effect on the total water used in factory and fields combined. Methods by which the quantity of effluent may be reduced can be summarized as:

- Reduce the amount of fresh water into the factory; every tonne of water brought into the factory from an external source (all water other than that in cane) increases the effluent by the same amount.
- Segregation and storage of the major wastewater streams to facilitate their re-use.
- Close all cooling tower systems and stop once-through cooling.
- Use surplus condensate or cooling tower overflow for cleaning/wash down.
- Catch spillage in drains and return to the process.
- If practiced, reduce cane wash to the absolute minimum.
- Use clean condensate as makeup in small service cooling towers.
- Use surplus condensate and cooling tower blowdown in the boiler gas scrubbers to make up for evaporation.
- Make the factory less steam efficient (not always an option), losing water through evaporation in cooling towers or spray ponds.

In terms of minimizing water intake, the measures available include the following (Palazzo 2004):

- Monitoring of the major use areas.
- Use of pressurized general washing.
- Mechanical clean-ups (avoid wet clean-up operations).
- Substituting fresh water with excess hot condensate.
- Installing self-closing nozzles.
- Providing training on savings.
- Conducting regular cleaning of cooling towers (tower fill and sumps).
- Collection for re-use of initial tank and pipe washings.
- Closing cooling circuits.
- Use of air-contact coolers.
- Automated clean-in-place of vessels.

Efforts have been described by both Wright and Miller (1999) and Jensen and Schumann (2001) to reduce the quantity of effluent to a minimum. Jensen and Schumann describe work to get to a ‘zero effluent’ situation, not to be confused with zero surplus. Their approach involves recycling sugar-containing or contaminated streams within a factory in such a way that the water surplus to the factory site is ‘clean’ condensate and not effluent. However the condensate COD may still be quite substantial due to the presence of ethanol in the condensate.

Typical problems with attaining a zero discharge include (Wright and Miller 1999):

- Increased maintenance of water circuits.
- Reduced plant reliability.
- Accumulation of trace chemicals in the internal water circuits (particularly Ca salts).
- Increased likelihood of exceeding the allowable maximum concentrations for that wastewater which is discharged.
- Lost water rights.

1.3.2 Condensate and process water usage

Steam and vapor condensed in pans and evaporators is re-used in the factory. Fig. 1.2 shows how the condensate is usually recycled for re-use.

![Figure 1.2. Major water flows in a sugar mill (Rein 2007).](image)

The best quality condensate, usually exhaust steam condensate, is returned to the boilers as boiler feed water. The quantities of water used in these various stages are given elsewhere (Rein 2007).

If ethanol is produced, additional water is required, to make up for the loss in the vinasse stream. This can be reduced if the vinasse is evaporated to Condensed Molasses Solubles (CMS) at roughly 50 g solids/100 g vinasse, and the condensate from evaporation recycled, even though it is somewhat acidic. In future the net use of water even when making ethanol may be reduced by new technology, which recovers water using membrane technology in dehydrating rectified spirit and in concentrating vinasse.

1.3.3 Factory cooling water systems

The major cooling duty is that related to water used in direct condensation of water evaporated in evaporators and pans. Traditionally, the cooling was achieved by spraying hot cooling water into an open cooling pond, but most new projects make use of cooling towers. The choice of cooling towers or spray ponds depends on the particular circumstances. The issues to be considered include the following:
- Spray pond systems are cheaper to construct, consisting only of a set of pipes and sprays spraying water into the air.
- Cooling towers are more compact, taking up less space. Spray ponds require a large area to achieve the cooling required.
- Operating costs for a spray pond system are lower, because there are no fans to maintain, and because the large volume of water held up in the spray pond system generally does not require any chemical dosing (perhaps a low lime dosing to maintain the pH between 7.0 and 8.0).
- Chemical treatment costs are higher in a cooling tower and control of corrosion and microbial growth is necessary.
- If a low approach to wet bulb temperature is required for energy economy reasons, a cooling tower may be more cost-effective.
- A higher energy usage by cooling tower fans. This may be minimized by variable speed motors whose speed is adjusted by the temperature of the water leaving the tower's basin.
- The drift loss is larger with a spray pond system and can be a nuisance in windy conditions.
- There is a greater chance that the water will be contaminated with wind-borne debris (and sometimes local wildlife!) in a spray pond.

Because the vapors are condensed directly into the cooling water, the quantity of water in the system increases. An amount of water equal to over 80% of the vapor condensed is evaporated in the system to provide the cooling effect. Nonetheless, the net effect is a surplus of water which overflows and has to be dealt with by recycling or treating as an effluent. In an average mill, the overflow stream will be about 4 t/100 t cane processed. This overflow stream is reduced as the thermal economy of a mill is improved.

Cooling water is required for turbine bearings and oil coolers. Once-through good quality water is sometimes used for this, but a better solution makes use of a small dedicated cooling tower system. It should not be combined with other cooling systems which may be contaminated with sugar, because these cooling systems are vitally important for trouble-free operation and must be free from the potential growth or buildup of biomass in the system.

Separate cooling systems may also be used for crystallizer cooling and/or vacuum pump water for similar reasons – fouling and particularly corrosion caused by degrading sugars in the system are highly undesirable. Although the quantity of cooling water used is significant, a closed system for these duties has a negligible effect on the water balance because the heat load is not high.

### 1.3.4 Boiler ash scrubber systems

Wet scrubbers on boilers are becoming more common because they are efficient and low cost. However, they require a system to circulate water. The solid materials collected in the scrubber have to be settled out from the scrubber water in some form of settler/clarifier, with the clear water recirculated to the scrubbers. The underflow from the settler/clarifier is removed and preferably filtered before being disposed of, to reduce the amount of liquid lost with the solids.

### 1.3.5 Segregation of streams

As can be seen from Fig. 1.2 water is recycled and re-used, to minimize the need for outside sources. The best quality water is the condensate, particularly the exhaust steam condensate. The best quality condensate is returned to the boilers and other condensate is used as process water where required. The use of condensate minimizes effluent quantity and is preferable to adding external water sources, since it minimizes additional impurities added to the process.
Lower quality streams such as cooling tower underflow, boiler blow-down and floor washings constitute the effluent stream. Some of this may be used in the boiler scrubber water system, to reduce the amount going to effluent treatment.

1.3.6 Summary and good practice recommendations

Box 1.3 Water use and recycling
- Cane contains roughly 70% water and so a mill producing sugar only should theoretically have surplus water available.
- Minimize effluent quantities by recycling and re-using both water and condensate.
- Ensure that the best quality condensate is returned to the boilers as feed water.
- Use only condensate for process water requirements, i.e. imbibition, filter wash water, centrifugal spray water, dilution water and chemical make-up water.
- Use lower quality reject streams such as cooling tower overflow and boiler blow-down in the boiler scrubber circuit.
  - Minimize wash down in the mill.
  - Collect and re-use water where appropriate.

1.4 Technology choices

Good practice involves choosing the most appropriate technology for the particular circumstances. Although sugar and ethanol production are part of a mature industry, there are still a number of decisions to be made on the type of plant and equipment to be installed

1.4.1 Extraction

Larger milling units up to 2.75 m wide to cope with higher crushing rates are now available. A trend to variable frequency AC electric or hydraulic mill drives is evident, particularly when energy efficiency is sought. However diffusion is gradually overtaking milling as the process of choice. Capital costs are roughly 2/3 of those for an equivalent milling tandem, while operating and maintenance costs are considerably lower. Kumar and Rao (2000) report these to be 44 % of the cost of running a 4 mill tandem, while Caillier (personal communication 2006) reports comparative annual costs from Louisiana for milling as $9.12/t cane and $3.17/t cane for diffusion. A recent development announced by Bosch Projects enables the chain and headshaft, both expensive components, to be dispensed with (Voigt 2010). This should reduce the cost of a diffuser relative to mills even further.

A comprehensive comparison of milling and diffusion is given elsewhere (Rein 2007). Diffusers do not require more imbibition water than mills, do not necessarily require more steam and require only half the power input of a conventional mill (Rein 1999). Where significant power generation for export is planned, diffusion is the correct choice.

Over the last 10 years, most of the Southern African mills have started returning clarifier muds directly to the diffuser. This is now an established practice, and extraction and percolation conditions are not affected adversely. A number of significant advantages have been identified:
- The operational and maintenance costs associated with running a filter station are eliminated.
- Loss of sugar in cake is eliminated.
- Chemical and microbiological losses associated with filter station operation are eliminated.
- The cost of disposing of the cake is saved.
• Water washing of the cake is obviated, reducing evaporation requirements.
• Equipment for bagacillo and cake conveying is not required
• The bagasse supply to the boilers is increased.

However, the amount of ash in bagasse is increased by about 10%. This could have implications for increased boiler tube wear, depending on the boiler design. If gas velocities through the boiler tube banks are kept below 10 m/s, tube wear is minimal.

1.4.2 Clarification

Factories producing only sugar should choose low residence time clarifiers, to minimize losses of sucrose due to inversion. In general, holdup of liquids in the factory should be minimized, because losses and color formation are promoted by temperature and are proportional to time. Inversion is not as serious an issue for factories producing ethanol. New designs are available with improved performance (Steindl et al. 2005, Gaudet and Kochergin 2011).

Factories producing PWS (plantation white sugar) will need to incorporate sulfitation as part of their clarification process, to achieve the required color reduction. The process is simple and well-established. Rotary sulfur furnaces have replaced the tray type and a newer film-type burner is being used successfully in India.

1.4.3 Evaporation

Evaporation is the heart of a sugar factory, and its configuration largely determines the steam economy of the factory. The use of multiple effects and vapor bleeding to other process uses should be chosen to arrive at the required steam economy. The process steam/cane ratio is dependent on the evaporator arrangement; where no ethanol or power export is involved, the steam requirement is likely to be around 550 to 600 kg/tonne cane, whereas when energy efficiency is paramount, this ratio should be < 400 kg/tonne cane.

Robert evaporators are simple, cost-effective and easy to operate. They are still the evaporator system of choice, particularly in ethanol factories where residence time and inversion of sugar are not an issue. However in the very large sizes, long tube evaporators have a capital cost advantage.

Long tube evaporators have lower residence times, which minimize inversion losses and color formation, and so are particularly appropriate in the first few effects where temperatures are highest. Climbing film Kestner evaporators are used successfully on first and second effect duty. Falling film evaporators are a satisfactory option, but are more complicated to operate and control, and are usually more costly. Their use is particularly indicated where 5 or more evaporator effects is are required (for steam economy reasons). They normally require chemical cleaning, and so are not favored in developing countries where labor costs are low.

1.4.4 Syrup clarification

This is a simple and cost effective process, used particularly where a better sugar quality is required. It will reduce suspended solids content of the product sugar and lead to a color reduction in the sugar of around 15%. Details of the process and equipment are fully detailed elsewhere (Rein 2007).

Additional sulfitation is sometimes used at this stage, to gain further color reductions, to produce PWS. However it invariably results in the product sugar exceeding the SO₂ content of the product. Syrup clarification in conjunction with phosphatation has been used with success to replace syrup sulfitation in factories producing plantation white sugar (Steindl and Doherty 2005). It produces a
lower color sugar and also has the benefit of significantly reducing the residual SO₂ content of the sugar. Reductions in sugar color of between 21 % and 39 % were reported in factory trials.

1.4.5 Pan boiling

There has been a widespread move to continuous pans on all massecuite grades. They generally result in cost-effective installations, require less supervision and can give better quality sugar. They are particularly advantageous where high factory thermal efficiency is required, since they can operate on much lower quality vapor, either vapor 2 or vapor 3. Most designs of continuous pan are well-proven in practice. Some batch pans capacity is still required to produce the seed for the continuous pans.

1.4.6 Centrifugals

Batch centrifugals are still required for the production of good quality sugar. New designs may be more energy efficient than continuous machines and provide better massecuite exhaustion. Continuous centrifugals are preferred for low grade massecuites, because of their lower costs and easy operation.

1.4.7 Sugar drying

Sugar needs to be dried and cooled to improve handling and minimize loss and color formation in storage, enhanced by temperature and length of time in storage. Sugar should always go into storage at a temperature below 40 °C, and preferably lower, and so adequate cooling must be provided.

Color formation is lower in high pol than in low quality sugars. Even at 30 °C, raw sugar color has been observed in some instances to increase in color by 50 to 100 %. Apart from temperature, the most important parameter is the Safety Factor, SF:

\[ SF = 100 \times \frac{\text{moisture}}{100 - \text{pol}} \]  

where moisture is the % moisture in the sugar and pol represents the polarization in °Z. The SF should be < 0.25 to minimize deterioration in storage; thus at 98.5 pol, moisture must be less than 0.375%, and at 99.3 pol, moisture must be < 0.175%.

The type of drier may be rotary cascade, rotary louvre or fluidized bed. The latter is more often used as a cooler rather than a drier on raw sugar, as this type of drier does not easily handle occasional feed of wet sugar.

1.4.8 Fermentation

The fundamental choice to make is between batch and continuous fermentation. The trend to continuous fermentation in Brazil has reversed, and batch fermentation is again being favored. In theory the continuous system should lead to higher yields, but in practice better control of contamination in batch systems outweighs the advantages of continuous systems (Finguerut 2005). In particular, where the fermentation feedstock is of low purity, batch fermentation is indicated.

1.4.9 Distillation
Various distillation schemes are in use. Variations are mainly due to the degree of steam economy required. It is possible to substantially reduce the amount of steam required, but this usually comes at a cost. The initial capital outlay needs to be balanced against the ongoing energy operating cost.

Where anhydrous ethanol is required, the use of molecular sieves is now the process of choice (Moura and d’Avila 2005). The use of cyclohexane in an azeotropic distillation system is only rarely seen in new installations, when the initial capital cost is an important issue.

1.4.10 Energy efficiency

Choices relating to boilers and ways of improving energy efficiency are covered in section 1.7 of Part 2 of this manual. In selecting the type of boiler, the following should be considered:

- Boiler steam pressure has substantial implications for cost and operation. If no power is to be exported, a lower boiler pressure (< 32 bar) is appropriate, to provide the optimal steam/bagasse balance. If power is to be exported, the boiler pressure should be > 42 bar, with the optimal choice being decided on the best conditions of cost, revenue and operability.
- A pinhole grate is preferred unless coal is to be burnt as a supplementary fuel. A dump grate is cheaper than a continuous ash discharge stoker, but the latter may be necessary if very stringent air pollution requirements have to be met.
- Boilers with a single pass gas flow through the generating banks are recommended, particularly under conditions where there is a high proportion of sand in the bagasse.
- Economisers and/or air heaters may be chosen to provide the ideal boiler efficiency for the particular mill requirements.

1.4.11 Summary and good practice recommendations

Box 1.4 Technology choices

- The choice of the optimal plant and equipment depends on local circumstances and project requirements
- Energy efficiency and product quality, particularly color, will influence choices.
- Production of ethanol also influences optimal solutions
- Diffusion is likely to be a more appropriate choice than milling in most cases

1.5 Energy and chemical use in refining

Refineries may be classified in two categories:

1. stand-alone or autonomous refineries
2. white-end or back-end or attached refineries.

Refineries have traditionally been stand-alone refineries, usually located close to substantial sugar markets, and most refineries are of this type. However, there are some real advantages to back-end refineries in terms of cost of production.

1.5.1 Refined sugar – autonomous refineries

The cost of producing steam in a refinery is one of the largest cost items and so must be given detailed attention. The amount of steam used is often related to the quantity of sugar melted in the
form of a steam/melt ratio. A common target is a ratio of unity, i.e. mass of steam required equal to the mass of raw sugar processed.

Ideally, the specific energy used is a more appropriate measure than the specific steam usage. This takes account of the fact that the steam may be generated at different pressures; in the case of high pressure steam generation, the higher enthalpy gives a lower steam usage even at the same energy usage. Electrical energy used is often of the order of 230 MJ/t melt, and the use of one tonne steam at 200 kPa/t melt is equivalent to 2 700 MJ/t. In these terms a target of 2 900 MJ/t melt would therefore seem to be reasonable.

Al Khaleej refinery reports an energy usage of 2 250 MJ/t melt for a year, and a best month of 1 925 MJ/t (Al Ghurair and Singh 2000). This is extremely low and is achieved by substantial process integration and the melting of high pol raws.

One of the most efficient ways of reducing energy inputs is to source higher quality raws. Not only does this reduce the chemical inputs required, but it also substantially reduces the steam requirement in crystallization. The savings achieved in the refinery from processing high quality raw sugar are almost always more than the increase in the cost of the better quality feed.

Chemical usage depends on the clarification and decolorization processes used. For clarification, Table 1.2 provides a comparison of the two options used.

<table>
<thead>
<tr>
<th></th>
<th>Carbonatation</th>
<th>Phosphatation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>Capital intensive; larger filter area</td>
<td>Cheaper equipment</td>
</tr>
<tr>
<td></td>
<td>required</td>
<td></td>
</tr>
<tr>
<td>Operating cost</td>
<td>Low</td>
<td>High, due to cost of chemicals</td>
</tr>
<tr>
<td>Color removal</td>
<td>40-50 %; consistent</td>
<td>20-30 %; more dependent on sugar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>quality</td>
</tr>
<tr>
<td>Ash removal</td>
<td>Higher lime usage precipitates more calcium salts</td>
<td>Little ash removal</td>
</tr>
<tr>
<td>Waste produced</td>
<td>Large quantity of cake produced</td>
<td>Solid waste quantity small</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Higher energy costs</td>
<td>Very low</td>
</tr>
</tbody>
</table>

Decolorization processes in common use are ion exchange, granular activated carbon run in columns and regenerated, and powdered carbon used on a throw-away basis. A comparison of the three decolorization processes is given in Table 1.3.

<table>
<thead>
<tr>
<th></th>
<th>Granular carbon</th>
<th>Ion exchange</th>
<th>Powdered carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>High capital cost.</td>
<td>Medium to low capital investment.</td>
<td>Low investment as no regeneration possible and no columns – pre-coat on filter press.</td>
</tr>
<tr>
<td></td>
<td>Separate loading and regeneration.</td>
<td>Same vessel for loading and regeneration.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Requires a high temperature kiln.</td>
<td>More compact plant.</td>
<td></td>
</tr>
<tr>
<td>Chemical usage</td>
<td>No additional chemicals required.</td>
<td>Lower water requirement.</td>
<td>No additional chemicals required.</td>
</tr>
</tbody>
</table>

Table 1.2: Comparison of sustainability elements of carbonatation and phosphatation.

Table 1.3: Comparison of decolorizing processes.
<table>
<thead>
<tr>
<th>Needs regular make up of GAC.</th>
<th>Brine used as regenerant. Some caustic and HCl used. Low resin-make-up.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy usage</strong></td>
<td><strong>Energy used in regeneration of carbon. Regenerate at 900-1 000 °C.</strong></td>
</tr>
<tr>
<td><strong>Decolorization effectiveness</strong></td>
<td>High. No ash removal. 10x color capacity of bone char. Pore size important.</td>
</tr>
</tbody>
</table>

Ion exchange is favored in most circumstances, but requires adequate means of disposal of the brine regenerant. In back-end refineries it may be added into the molasses, but this is unlikely to be a sustainable practice in the long term. An ocean outfall may be permitted, but a more common solution is to install a membrane separation plant, which recovers about 80% of the brine and reduces the amount to be treated.

Australian law requires all contaminants from a refinery carbon regeneration plant to have an afterburner fitted, designed to hold the contaminants at 600 °C for 0.5 s.

### 1.5.2 Refined sugar – back-end refineries

The main advantage of a back-end refinery is the fact that fuel is essentially free, since use is made of the sugar mill boilers burning bagasse to provide the energy needs of the refinery. This requires the steam efficiency of the mill and refinery to be better than average if the use of supplementary fuels is to be avoided, but is relatively easy to achieve. Other benefits relate to shared utilities and overhead costs, and benefits in recovery through lower molasses purity and optimizing the raw sugar quality going to the refinery.

It is good practice and generally economically attractive to configure the raw sugar operation to be energy efficient, to reduce external energy requirements to negligible proportions. This is done by using evaporator vapors bled to the appropriate extent to achieve the steam economy required, and usually requires larger heating areas in evaporators, pans and heaters.

White-end refineries are usually smaller, using only the raw sugar produced at the mill and perhaps augmented by sugar from nearby mill(s). They are usually a good option if near to markets that will
absorb the white sugar. Autonomous refineries have to be much larger, using economies of scale to achieve a competitive cost of production.

Chemical inputs are usually lower in back-end refineries, which use less severe decolorization processes.

1.5.3 Plantation white sugar

It is possible to produce a direct consumption sugar in a raw sugar mill, with a color of the order of 100 to 200 IU (ICUMSA Units, a measure of sugar color). This is commonly referred to as ‘plantation white sugar’ and is made possible in factories with a below average juice color, the use of juice sulfitation and syrup clarification. Sulfitation requires the burning of sulfur to produce sulfur dioxide, which breaks down some of the colored material in the juice. Sulfur usage varies between 250 and 500 mg/kg cane, and emissions of SO₂ are usually negligible. Where there are limits on SO₂ content in the plantation white sugar (below 10 to 15 mg/kg) it is necessary to restrict usage to less than 250 mg sulfur/kg cane. The process requires the use of more lime, to neutralize the extra acidity associated with the process.

Some mills in Brazil and elsewhere are able to produce high quality sugar without sulfitation but need to use a phospho-flotation step between the evaporation and the crystallization phases of the process. Raw sugar is either categorized as VVHP, with 500 IU color and 99.5 pol, or VHP at 700 IU (range 600 to 1 000) and 99.3 to 99.5 pol. This quality of sugar attracts a premium from refineries, who can realize cost reductions with the better quality raws.

1.5.4 Summary and good practice recommendations

Box 1.5 Energy and chemical use in refining

- Autonomous refineries need to be energy efficient to keep costs of production down.
- Monitoring energy usage is very important, since energy costs are a large proportion of refining costs.
- Purchasing better quality raw sugar is a cost-effective way of reducing refining costs.
- Refining chemical usage depends on the refining processes chosen. Effluents are not large, but need to be considered in choosing the refining process.
- Back-end refineries are lower cost refiners and the best choice if market conditions are right.
- Plantation white sugar is an acceptable consumer quality sugar, but will not be of high enough quality for some large scale commercial users.

1.6 Process loss control and monitoring

Good factory control focuses on accurate estimation of losses of sucrose and/or ethanol. The losses that need to be quantified are as follows:

- Loss in bagasse
- Loss in filter cake
- Loss in molasses, or
- Loss in vinasse
- Undetermined loss (all other effects).
Sampling and analysis systems need to be set up for this purpose, to make information available to managers and supervisors in such a way that they can understand how well or badly the mill is running and so be able to identify any problem areas.

### 1.6.1 Measurement of recovery efficiency

Regular reports of all important operational variables are an essential prerequisite for good performance. Efficiency and loss reporting may be integrated into the mill’s management information system. The laboratories should be accredited to ISO 9000, indicating that the job of producing reliable data is taken seriously.

Operations manuals for both process and the laboratory are an important part of running an efficient operation. Issues relating to a sugars balance in a factory are available in some texts, e.g. Rein (2007).

In many operations targets are set for key performance areas for different employees. Regular publishing of comparisons of actual and target values of important parameters is often useful. Combined with incentives, this is a good way to motivate employees to better performance. A convenient way to communicate the more important process information is via a factory intranet, which may be made available to different levels of employees using passwords for stratifying purposes.

### 1.6.2 Physical losses

Losses may be due to inadequate entrainment prevention, foaming carry-over, spouting in vessels, tank overflows, leaks, liquidation losses. These can be reduced or minimized by good regular maintenance and correct operation of the plant and equipment.

Some of this lost sugar will be present in effluent before any effluent treatment. The effluent stream should be monitored continuously. Since sugar degrades quickly in effluents, a measurement of total sugars or Brix, rather than pol, should give an indication of the magnitude of any losses in this stream.

### 1.6.3 Chemical losses

The major loss is probably due to inversion, either at low pH or high temperature, but thermal decomposition and Maillard-type reactions also cause losses. The design of the processes used should take account of the fact that process conditions of high temperature, long retention times and pH values too high or too low are responsible for these losses. It is important to realize that pH measured at room temperature is higher than the pH at operating temperature.

### 1.6.4 Microbiological losses

These may occur in low Brix juices at ambient temperature, when the main products are dextran or ethanol (e.g. in the milling plant), or at elevated temperatures when the main product is lactic acid (e.g. in clarifiers and filters). Microbiological testing of process streams is necessary to keep these losses to a minimum. Measurements of lactic acid in fermentation are also useful in optimizing fermentation efficiency.
1.6.5 Summary and good practice recommendations

**Box 1.6 Process loss control and monitoring**
- Efforts to minimize losses of sugars are normally extremely beneficial economically.
- Good and reliable sampling and analysis of process streams is essential to monitor efficiencies and losses.
- Appropriate data reporting systems are necessary to ensure that the right people in the organization get the appropriate information for control and action.
- Laboratory personnel should be well-trained on methods of analysis as well as on appropriate reporting of results and events.

1.7 Environmental management systems

1.7.1 Procedures and monitoring systems

All industries are required to follow local environmental legislation, which is different in each country. Essentially, however, they focus on management of emissions into the air, water use, liquid effluents and solid wastes. Noise and odor are not usually legislated in sugarcane areas, but are expected to become more important issues in the future. A survey of environmental legislation affecting the sugar industry was published by the International Sugar Organization (2001). Examples of local legislation in Australia are given by Kealley and Milford (2010) and in South Africa by Padayachee (2010).

Many sugar operations are accredited to ISO 14001 Environment Management System, to guide them in operating in a way that is environmentally sustainable. This is considered to be good practice. In some cases external bodies are employed to monitor environmental performance while some rely on self-assessment.

Brazil has a wide range of federal and state laws regarding environmental protection, aimed at combining social and economic development with environmental preservation, with which the sugarcane business needs to comply (Amaral et al. 2008). In addition, voluntary adherence to environmental protocols is gaining increasing support. For example, the Agriculture and Environmental Protocol for the ethanol/sugar industry signed by UNICA and the Government of the State of São Paulo in June 2007, deals with issues such as: conservation of soil and water resources, protection of forests, recovery of riparian corridors and watersheds, reduction in greenhouse gas emissions and improved use of agrochemicals and fertilizers. A large proportion of the sugar mills have already signed the Protocol in São Paulo State, and a similar initiative is under way in the State of Minas Gerais.

1.7.2 Factory policies

All sugar and ethanol operations are expected to have formulated an environmental policy, which is communicated to all stakeholders. This is expected to contain the following elements:

- A commitment to sustainable operations
- Concern for the environment
- Policy promotion and communication
- Commitment to meeting or surpassing applicable regulations
- Efficient use of all resources
- Prevention of pollution
- Continuous improvement
• Ongoing review of policy and performance.

The key elements would frequently be guided by a Safety, Health and Environment Manual, aided by accreditation to ISO 14001. This needs to address issues such as the identification of environmental impacts, evaluating performance, major risks, and detailing of emergency planning and mitigation measures.

Even though not many milling companies have yet started to take carbon emissions into account in expansions/upgrading plant and equipment, where large scale expansion of cane production is taking place, care is being taken to ensure that this happens on previously farmed crop land, or pasture land – preferably not on virgin land. The soil carbon stock is reduced when most forms of land with natural vegetation is planted to new crops; this is particularly the case where forest land is used, but applies even to some forms of grassland.

1.7.3 Internal audits

Internal audits are essential to ensure that policies are adhered to. Record keeping is important and will normally be required by the local environmental authority.

1.7.4 External audits and reporting

Some mills are accredited to a number of different ISO standards, and are audited by external bodies. In most countries annual reporting of environmental issues relating to effluents, wastes and emissions is required by the local or national authorities.

Cost of compliance is usually quite considerable, including licensing fees, investments in measuring equipment, capital investments to improve performance, external auditing and accreditation, meetings with local communities, maintaining ISO 14001 or equivalent standards and keeping systems operational and updated. The cost was estimated to be US $200 000/y per factory in South Africa (International Sugar Organization 2001).

1.7.5 Bunding of storage areas

Liquid containment facilities that prevent leaks and spillage from tanks are required. One of the most common designs for large tanks is a Concrete or Masonry wall around the tank with a concrete floor. Bunding is used to prevent the liquid from causing damage in the event of leakage or a catastrophic failure. Almost all regulations require a holding capacity of 110 % of the maximum capacity of the biggest tank within the bund, or 25 % of the total capacity of all the tanks within the bund, whichever is the greatest.

Molasses and/or syrup storage tanks should be bunded, to prevent loss of material and prevent pollution. Chemicals used in cleaning or processing operations should also be bunded, particularly if they are aggressive, corrosive or could constitute a safety hazard. Fuel storage tanks and transformers at electricity sub-stations which are filled with oil for cooling and insulation purposes should also be bunded.
1.7.6 Summary and good practice recommendations

<table>
<thead>
<tr>
<th>Box 1.7 Environmental management systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• All mills should have an environmental policy accepted by all employees that complies with city, state and country legislation that covers this subject.</td>
</tr>
<tr>
<td>• All mills should have an environmental operations manual, which in many cases is combined with health and safety.</td>
</tr>
<tr>
<td>• Records should be kept of environmental performance, with regular reporting to local or national authorities.</td>
</tr>
<tr>
<td>• All mills should have a firefighting brigade and other specific crews trained to deal with hazards/accidents resulting from spillage or leakage of chemicals, liquid fuels and lubricants.</td>
</tr>
<tr>
<td>• There must be a plan to involve adjacent mills/industries on an emergency collective help basis when a problem occurs.</td>
</tr>
</tbody>
</table>

1.8 Management of energy

1.8.1 Energy generation from bagasse

Bagasse contains most of the fibrous material in the cane fed to the mill, from which a large proportion of the juice has been removed. It has a low bulk density and, being fibrous in nature, is difficult to handle as a solid. Although it is free flowing, it has the propensity to choke, bridge and pack tightly if not correctly handled. It also produces dust, which can represent a serious fire hazard and a health hazard under certain conditions. It is not corrosive but it contains sand that was delivered with the cane and so can be abrasive. It may also choke quite readily and any chutes used in transporting bagasse have to be diverging to ensure that choking does not occur.

As produced, bagasse has a moisture content of about 50 g water/100 g bagasse but, depending on conditions, that can vary between 46 and 55 g/100 g bagasse. The ash content of bagasse is very variable, being largely determined by the field soil or dirt in the cane processed (and to a lesser extent by cane variety). It is also affected by the extraction process. In milling Muller et al. (1982) have determined that on average 36 % of the dirt in cane is removed in the raw juice, a figure confirmed by experience in Louisiana. In diffusion, however, the proportion of ash in raw juice is much lower, with only about 10 % extracted. Typically, cane containing 1.5 g ash/100 g cane will lead to 2.5 and 3.3 g ash/100 g bagasse for milling and diffusion respectively (Lamusse 1984). Because of the dirt in the bagasse, handling of bagasse can lead to substantial wear on equipment due to its abrasive nature.

Bagasse is not a homogeneous material. It consists of a mixture of fiber and pith having very different particle shapes and aspect ratios. In handling, the pith tends to separate quite easily (and is the source of the dust problem). Classification in handling needs to be recognized in any sampling system; in sampling from a conveyor, a full-width hatch sample needs to be taken if a reliable and representative sample is to be obtained.

Quantity of bagasse

The quantity of bagasse is determined primarily by the fiber content of the cane being processed. Nearly all of it ends up in the bagasse, but some finds its way into the raw juice going to the factory, and some bagacillo is usually required for use on the rotary vacuum filters.

In practice a small proportion of the bagasse should be put aside in a bagasse store for recovery and use during start-up or shutdown, or for use during mill stops. This should be somewhere between
5 and 10% of the total amount of bagasse produced. This amount is dependent on the time efficiency of the mill.

Given all the issues which affect the amount of bagasse available for steam production on a continuous basis, the amount of bagasse available may be anywhere between 22 and 35 t/100 t cane, but is more usually in the range 25 to 30 t/100 t cane.

**Figure 1.3. Modern boiler with scrubber and electrostatic precipitator**

**Steam generated from bagasse**

The amount of steam generated from bagasse depends on the efficiency of the boiler, the pressure at which the steam is generated and the calorific value of the bagasse. Values of the ratio of steam to bagasse vary from about 2.4 t steam/t bagasse at low bagasse moisture content and low boiler pressure, to 1.9 t steam/t bagasse at high pressure with higher bagasse moisture content (Rein 2007). Typically a boiler operating at 30 bar g will generate 2.2 t steam/t bagasse.

The quality of the bagasse affects the calorific value of the bagasse. The gross calorific value, otherwise known as the higher heating value $H_0$ (in kJ/kg) can be calculated from a relationship developed in South Africa which has been widely used and is considered to be reliable (Don et al. 1977). The relationship is:

$$H_0 = 196.05 \cdot (100 - w_{W,B} - w_{A,B}) - 31.15 \cdot w_{RDS,B}$$  \hspace{1cm} (1.15)

The moisture content of the bagasse $w_{W,B}$ and the ash content $w_{A,B}$ (both in g/100 g) decrease the calorific value. The inclusion of the dissolved solids or Brix of the bagasse $w_{RDS,B}$ (g/100 g) in the equation accounts for the fact that the dissolved solids have a lower calorific value than the fiber.
Based on typical bagasse quantities of 27.5 t/100 t cane and 2.2 t steam/t bagasse, the amount of steam available from bagasse for continuous crushing is about 60.5 t/100 t cane. In a different form, the gross calorific value in the available bagasse represents about 2 500 MJ/t cane.

1.8.2 Bagasse balance and management of surplus/deficit

A sugar mill is fortunate in having bagasse available to serve as a fuel for supplying all its energy needs. The evaporator configuration (i.e. the number of effects and the extent of vapor bleeding) should be chosen to ensure that the steam required is not more than can be supplied by burning bagasse. Then no supplementary fuels should be necessary. Large mills are always more energy efficient than small mills, and find it easier to generate a bagasse surplus.

However, it is also important to ensure that all the bagasse is consumed at the sugar mill. If not, a surplus of bagasse can build up very rapidly and the mill then has a costly solid residue disposal problem. This may require that sufficient boiler furnace capacity is provided to burn all the bagasse. Various operational conditions alter the balance; this may be due to changes in fiber content of cane within a season, or periods of slow running, or other changes in factory loading. Some flexibility is available in the mill, involving the amount of imbibition water used in the mill, and some flexibility in using different evaporator vapors, to ensure that the amount of bagasse available matches the steam demand.

The situation is changed if there is a downstream user of bagasse for by-products, e.g. paper manufacture, or if the mill includes a back-end refinery, or if export of power or bagasse is practiced. In these cases, the mill strives to be as thermally efficient as possible, generating the maximum surplus possible.

1.8.3 Bagasse drying

The high water content of final bagasse both reduces its heating value and is the cause of the largest energy loss in the boilers, because the fuel moisture carries the latent heat of vaporization up the stack:

- The gross calorific value of bagasse decreases by 196 kJ/kg for every increase of 1 % in the moisture content.
- About 95 % of the losses from a bagasse fired boiler are stack losses and, for bagasse, the moisture loss is the most significant.
- The extent of the energy loss is proportional to the final gas temperature.

Drying the bagasse is therefore beneficial to boiler efficiency for several reasons: (a) the lower amount of water reduces the excess air required, at least down to a level of 40 % moisture, below which there is no reduction in excess air required (Magasiner et al. 2002); (b) it is possible to reach a higher adiabatic flame temperature; (c) a smaller flow of gases with less water vapor passes to the stack. Since the wet gas loss is the major loss in a boiler, the effect on boiler efficiency is greater than that achieved by just cooling the flue gases. Dixon et al. (1998) showed that reducing the moisture content of bagasse has a substantial effect on the capacity of the boiler. The benefit is reduced and so this becomes a less attractive option with high efficiency and high pressure boilers.

However, it never makes economic sense to pay for the energy required to dry bagasse. Drying only makes sense if waste heat in boiler flue gas is used. Driers, mainly rotary drum and flash types, have been installed in America, Brazil, Philippines, Australia, Argentina, Cuba and India, but consistent
results and conclusions have not always been obtained and the degree of success varies widely. Sosa-Arnao et al. (2006) provide a summary of all the bagasse drier installations.

The use of boiler exhaust gas to dry bagasse reduces the stack temperature and hence, from an efficiency point of view, is equivalent to adding more boiler heat recovery surface. An economizer does not give an efficiency gain as high as a drier, but has been usually the preferred option because of lower initial costs, better reliability and lower maintenance requirements. However, bagasse driers can reduce stack temperature to a lower figure than either an air heater or economizer. The use of an economizer enables a reliable and relatively cheap reduction in gas temperature to be obtained with simple heat exchange equipment with no additional fans, gas ducts or conveyors. With no moving parts, operational and maintenance costs are lower. The limit on outlet temperatures must be high enough to ensure that the corrosion will be unimportant unless very abnormal conditions occur (Magasiner 1996). Typically exit case temperature will vary from 220 to 160 °C, the latter in the most efficient boilers. If gas temperatures are brought down below 160 °C, a problem arises with acid condensation and corrosion in the backend of the boiler. Popular opinion in places like Brazil and South Africa suggests that air preheaters and economizers are preferred to a bagasse drier because of fewer problems, even though the efficiency is inferior. In particular, wear (erosion/corrosion) from high ash levels in cane can be a major problem for bagasse driers.

Leal (Brazil, 2010, personal communication) reported that CTC in Brazil developed some standard drier designs for different capacities which have been used to increase boiler efficiency in some mills. In one of them, the São Martinho mill, they installed four units and operated them for quite some time; after that they decided to remove them, due to excessive dust generation and some operational difficulties. It was possible to reduce the bagasse moisture to around 35 % – but the great problem was the recycle of solids, mainly sand. These solids promoted rapid wear of several parts of the boiler and excessive dust generation was also a problem. Belting and Semrau (2009) report results of a successful installation in Brazil which reduced the moisture content of the bagasse from 50 to 28 %.

A potential environmental advantage of bagasse driers in a well-designed system is the retention in the moist bagasse of small particles entrained with the flue gas, reducing the particulate emission through the stack (van der Poel et al. 1998). In India it is reported that the gas exiting the cyclones has a particulate loading of < 100 mg/m³ (Narendranath and Rao 2002). This also means a smaller quantity of sand in the gases, which together with lower velocities (because excess air is reduced) has resulted in a longer service life of exhaust fans and stacks (Maranhao 1986). Paz et al. (2001) showed that a substantial reduction in particulate matter (almost 96 %) in exhaust gases could be achieved with the installation of bagasse driers. As measured in the outlets of the drier multicyclones, a reduction from 4 500 mg/m³ to less than 300 mg/m³ was achieved.

1.8.4 Efficient management of boilers

The boiler efficiency is determined by the design of the boiler and the way it is operated. The most significant effect on efficiency is the degree of heat recovery from the boiler gases.

Older boilers were usually installed to generate steam at lower pressures, typically 21 bar. New installations are often at 64 bar; above this pressure the capital costs of boilers and turbo-alternators show substantial increases. Nonetheless, there are now many installations at 100 bar, and new designs from suppliers include boilers generating up to 120 bar, with outputs up to 400 t steam/h. Mono-drum designs are usually used for sizes above 275 t/h, for mechanical reasons.
If steam efficiency is a priority, regular measurements of boiler efficiencies should be carried out. Measuring losses and subtracting these from 100 is the easier and more accurate way of measuring efficiency. The only measurements needed are fuel moisture, ash and Brix, and excess air (O\text{2} or CO\text{2}) and gas temperature at the exit from the unit’s heat recovery section. These can all be measured relatively easily. Note that about 95% of the losses from a bagasse fired boiler are stack losses and are therefore related to the exhaust gas temperature. More detail is given by Magasiner (2007). Boilers must be well maintained and operated if good efficiencies are to be achieved.

1.8.5 Supplementary fuels

The bagasse and steam balance shows that under normal sugar mill conditions, there is sufficient bagasse available to provide all the steam necessary for the mill, and no supplementary fuels are necessary. However if there are substantial downstream operations (e.g. paper production, white-end refining), it is not unusual for supplementary fuels to be used.

Many mills were built many years ago when fuel prices were low. In more recent times, energy costs have risen substantially, and efforts have been made to improve steam economy and reduce the need for supplementary fuels. It is nowadays always cost-effective to design the steam usage of the mill to be independent of supplementary fuels, and all new installations should be designed on this basis.

Many mills like to have the security of the possibility of using supplementary fuels, in the event of major plant problems.

This often adds to the cost of a boiler, if for instance it is required to fire coal in the boiler. The most commonly used supplementary fuels are coal, natural gas and fuel oil. Costs vary considerably from one country to another. The choice of supplementary fuel is usually dictated by the availability of local sources. In Australia and southern Africa, coal is used, while in Louisiana and Florida, natural gas is used.

Wood chips are used in a number of countries to provide extra fuel for the additional steam demands. This is often insufficient to eliminate the need for supplementary fuels altogether. Wood chips are added to the bagasse supply at some mills in Brazil, and the use of other fuels available in the region is being investigated. These include crushed rubber tires and litter after separation of recyclables. The maximum proportion of these extra fuels is 20% when burnt with bagasse at the same time.

Natural gas is the cleanest burning fossil fuel available. It does not lead to particulate emissions and has a very low sulfur content, so SO\text{2} emissions are negligible. If coal or fuel oil is to be used, the fuel with the lowest sulfur content should be chosen. In Australia supplementary fuel is not to have a sulfur content of more than 3 g/100 g. When burning coal it is essential to equip the boiler with a travelling grate. Should the coal have a high sulfur content, particular attention needs to be given the outlet flue gas end of the boiler due to possible very aggressive corrosion.

In burning waste biomass, it is most important to consider the chemical analysis of the waste as a fuel. If the alkali metal content in particular is high, slagging and fouling of the boiler may occur. The highest concentration of alkali is typically found in the high growth portion of the plant, which would include the new growth and leaves (Briggs 1997). Thus tops and green leaves of cane contain much higher alkali than dry leaves. Likewise green wood is also unsuitable because of the high alkali metal content.
The boiler three drum bagasse feeder (Rein 2007) can handle wood chips provided the size does not exceed 25 mm all round, but the chips should be screened and the oversize reject recycled. Because wood chips and bagasse have very different bulk densities and because the feeders are volumetric feeding devices, it is difficult to get the controls to accommodate both fuels simultaneously. They can be calibrated to feed one or the other separately but not together when the proportions change continuously. Under these circumstances there are two solutions:

a. Use separate feeders for each fuel – preferred, or  
b. Install a density meter in the upper feed chutes which corrects for changes in density.

Sezela mill in South Africa developed a density meter for their boilers where they handle bagasse and furfural residue, which have very different densities, in combination (Field et al. 1992).

Cane tops and leaves are sometimes used, particularly in commercial cogeneration plants, as an additional source of biomass fuel. Tops and leaves should be crushed/shredded to a size similar to that of bagasse to be successfully burned in a boiler. Their ash contents usually include sufficient sodium and potassium to cause boiler fouling if they are burned on their own (Prabhakar et al. 2010). The problem can be minimized by thoroughly mixing them with bagasse so that the ratio of alkali metals to silica is low and preferably < 0.1 (Magasiner 2007).

1.8.6 Factory steam and energy balance

Although a mill with no downstream activities may generate over 600 kg steam/t cane, the amount used in processing may be almost halved by efficient use of steam and vapor in the mill. Minimum process steam usage using present technology is estimated variously to be 350 kg/t cane (Reid and Rein 1983), 330 kg/t cane (Broadfoot 2001) and 340 kg/t cane (Kong Win Chang et al. 2001). These values can only be achieved with extensive process integration, which has adverse implications for operability unless the plant is always run very steadily and has good centralized automation and process control.

In order to reduce the steam usage in the factory to a minimum, the following measures can be considered (Rein 2007):

- Do maximum evaporation in multiple effect in the evaporators, not the pans. This means the syrup Brix from the evaporators should be as high as possible.
- Increase the number of evaporator effects.
- Make good use of condensate flash.
- Use vapor 1, vapor 2 or even vapor 3 on the pan floor. This may require upgrading of pans to improve circulation with a lower pressure heating steam.
- Improve the exhaustions in the pan station, particularly in A massecuite boiling and centrifuging.
- Minimize the amount of water used in the pans and centrifugals. In order to do this, it is necessary to measure and control this amount of water.
- Use clarified juice instead of water for duties such as melting sugar and pan station water (for A massecuite boiling).
- Use a liquid/liquid heater to do the first stage of heating of raw juice with condensate. This also serves the purpose of cooling down condensate for use as imbibition on the mills. It is not an option with diffusion, where the raw juice is already at a temperature of 60 °C or higher.
- Use vapor 1 and vapor 2, vapor 3 and perhaps even vapor 4 for juice heating. This may require additional heater surface area.
- Reduce the amount of imbibition on the mills; this will affect extraction adversely.
• Reduce filter wash water; this will increase the loss of sugar in filter cake, or practice mud recycling.
• Increase the bleed vapor temperatures to gain more from bleeding vapor. This requires more evaporator heating surface.
• Ensure that any valves which can let down steam from exhaust to vapor 1 or vapor 2 are sealing completely. These letdowns should be used only on start-up or shutdown, and ideally should incorporate a double valve and bleed arrangement to eliminate the possibility of unwanted and unnoticed bypassing.
• Flash from condensed steam at any stage should be captured and used.

It is important to measure and control the whole energy system if it is to be optimized. On-line energy use statistics are available on modern plant-wide computer control systems, and can be most useful in minimizing energy usage. In cases where mills generate power for irrigation the cost and management of irrigation power are important issues.

Steam usage in the distillery has reduced substantially over the years. Various options for reducing steam usage are available, re-utilizing steam through running some columns under vacuum or pressure. The use of molecular sieves for dehydrating ethanol is now widespread, which brings some energy savings. In a few cases, the older azeotropic distillation route using cyclohexane is chosen, because of a lower capital cost. Brazilian distillation systems make use mainly of vapor 1 in the distillery, providing some steam economy efficiencies to be realized, while still running the columns under atmospheric pressure. This is in contrast to the Indian system, which uses a higher pressure steam, stripping column under vacuum and no recycling of yeast.

Figure 1.4. Molecular sieve ethanol dehydration
1.8.7 Batch vs. continuous processing

The general conditions favoring either batch or continuous systems are well summarized by Levenspiel (1962) in relation to chemical reactors:

"The batch reactor has the advantage of small instrumentation cost and flexibility of operation (may be shut down easily and quickly). It has the disadvantage of higher labor and handling cost, often considerable shut down time to empty, clean out, and refill, and poorer quality control of the product. Hence we may generalize to state that the batch reactor is well suited to produce small amounts of material or to produce many different products from one piece of equipment. On the other hand for the chemical treatment of materials in large amounts, the continuous process is nearly always found to be more economical."

As factories have become larger and have been looking to improve operating efficiencies, items of equipment have become larger, favoring continuous operation. Advantages include better energy efficiency. In the context of pan boiling, continuous pans can use a lower pressure calandria vapor than batch pans, while still relying on natural circulation. This allows steam economy to be significantly improved where this is of advantage. Continuous pans are operated in some mills with vapor 2 or even vapor 3, with significant steam economy benefits. A steady draw on the steam supply associated with continuous processing assists in reducing the overall steam usage. In addition, steamings from batch pans are eliminated, further reducing the overall evaporation load.

Almost all other operations are now continuous in operation. The exception is the use of batch sugar centrifugals, still used on high quality sugar product. The main reason is the better separation efficiency of the batch centrifugal, which has an indirect effect on steam economy. In addition, the newer models now make use of variable speed drives which recover a large proportion of the energy used in the process of regenerative braking, such that the energy usage per t massecuite processed is actually lower with batch centrifugals (Grimwood et al. 2002). Nonetheless, some continuous centrifugals are used on product raw sugar massecuites in Australia because of lower capital and operating costs. They are less efficient in terms of separation and produce a higher moisture content sugar.

Continuous fermentation in Brazil became popular, but the swing to this mode of operation has reversed. Fed batch fermentation is often preferred for control of contamination. This, however, has a much lesser impact on energy usage.

1.8.8 Generation of power for export

With export of power becoming more profitable and more widespread, there is a trend to use higher boiler pressures. In conventional mills, the choice of a boiler pressure in the 20 to 30 bar range was optimum. More recent boiler installations have been at a generating pressure of around 60 bar, going up as high as 100 bar. In Brazil, 65 bar is the preferred limit due to turbine construction. Above about 65 bar, the cost of generating equipment escalates dramatically, moving into the utility power station turbine range.

Export of power was first introduced on a large scale in island industries, particularly Hawaii, Reunion and more recently Mauritius, with no natural oil or coal resources. Increasing energy prices in general and encouragement of some countries because of environmental and political reasons, has seen the practice become more widespread. However, some countries with relatively cheap energy have not provided sufficient economic incentive for this to become an economic reality.
Cogeneration of power is mistakenly taken to mean the generation of power surplus to the mill’s needs, which is available for sale to third parties. Inkson and Misplon (2005) suggest that cogeneration couples a user of low grade heat, in this case the process house, to the power generation station. Surplus power may be exported during cogeneration when the mill is running, or burning stored bagasse when the mill is stopped.

The potential for cogeneration lies in utilizing whatever high pressure steam can be produced to maximize the generation of power in efficient turbo-alternators. Ideally, all steam letdown to exhaust is through generating turbines, and if a surplus relative to the factory’s needs is generated, use of a condensing turbine may be made to maximize power production. The control of exhaust pressure is achieved by controlling the flow to the generating turbines to keep the exhaust range pressure constant, or in the case of condensing turbines, controlling the pass-out to the exhaust range.

The most effective way of increasing the amount of power available is through the use of high pressure boilers. The amount of surplus that can be exported depends on a range of factors and typical values are shown in Table 1.4. A common choice of boiler conditions for power export is now 68 bar and 520 °C.

### Table 1.4. Typical alternatives for export of power (Linero et al. 2001).

<table>
<thead>
<tr>
<th>Process steam</th>
<th>Excess power</th>
</tr>
</thead>
<tbody>
<tr>
<td>t/100 t cane</td>
<td>kWh/t cane</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>22 bar/300 °C boiler, back-pressure turbine</td>
<td>50</td>
</tr>
<tr>
<td>45 bar/480 °C boiler, back-pressure turbine</td>
<td>50</td>
</tr>
<tr>
<td>82 bar/480 °C boiler, back-pressure turbine</td>
<td>50</td>
</tr>
<tr>
<td>82 bar/480 °C boiler, extracting/condensing turbine</td>
<td>34</td>
</tr>
</tbody>
</table>
If extraction/condensing turbines are used, then power available for export is also affected by the process steam usage. In the case of 80 bar boilers, process steam usage of below 40 t/100 t cane must be achieved.

Wright (2000) has shown that mechanical vapor recompression is not useful in increasing power available for sale, since the power required by the compressor is more than the additional power which can be generated thereby. Vapor recompression (thermal) may find a place in reducing process steam usage where any HP to LP steam let-down is put through an organ-type battery of thermo compressors.

In order to maximize export of power, energy efficient electric drives on cane preparation and milling equipment should be used. For a conventional 300 t cane/h factory, Rein and Hoekstra (1994) calculated that with 31 bar g boilers, a surplus of 1.9 MW would be available for sale from a mill and 6.4 MW from an equivalent diffuser mill. This illustrates the potential advantage which diffusion has in a cogeneration mill.

The use of cane leaves and tops as fuel is receiving widespread attention. It is policy to leave at least 30 % of this material on the fields, and up to 50 % in dry areas, for reasons of soil health and moisture retention. Baling machines are being developed to harvest this material, and in some instances dry cleaning systems are being installed to separate leaves and tops at the mill, but the capital cost is reported to be high. The optimum option depends on the transport arrangements.

It is reported in Brazil that a price of US $85/MWh is necessary to justify replacing 21 bar boilers with higher pressure boilers. Capital costs for cogeneration depend largely on the cost of boilers and turbo-alternators. In addition to these costs, there are also the costs of possible modifications to the bagasse handling system, grid interconnection, electrical control and protection equipment and drive electrification.

Hodgson and Hocking (2006) list the following criteria for successful cogeneration projects in Australia; they seem to be widely applicable:

- A group mill with access to bagasse from nearby mills.
- Site-specific operating factors, such as supplementary year-round energy sales to a co-located processing plant.
- Existing site specific plant configurations or underutilized plant, which can lead to significant capital cost reductions.
- Power purchase agreements (PPAs) that recognize avoided capital costs.
- Ability to offset cogeneration capital costs by other avoided capital, such as the need for steam capacity increase, the need to replace an aging boiler, or the need to improve stack particulate emissions from old boilers.

Other issues that could improve project viability include:

- Compensation from transmission and network bodies for the full benefits of an embedded sugar mill generator.
- Firm export and renewable energy certificate (REC) quantities in a PPA in return for premium payments.
- Multiple (or joint) projects where economies of scale can be achieved.
- Security of long term contracts for electricity sales.
Recent installations of biomass cogeneration plants in New South Wales have proved to be uneconomical and are up for sale. The reasons for this situation are the drop in prices of RECs and the unexpectedly high cost of removing leaves and tops from the cane at the mill prior to processing. The mills are reverting to cane burning instead of unburnt whole-of-cane harvesting. Bulk pile storage of bagasse becomes an important issue (see section 3.2.1).

There have been a number of installations where the export of power has been limited by the ability of the power transmission system to accept the additional power. This is frequently the result of vacillation on the part of the energy transmission company.

The success of cogeneration by sugarcane mills is fully dependent on the existing legal framework and the prevailing electricity market rules. In general a price of not less than about US $90/MWh is required for any substantial investment in export power to be economically viable.

1.8.9 Utilization of waste heat

The cane sugar is unlike the beet sugar industry in not having to rely on imported fuels. In cane sugar mills, the energy used is matched to the energy obtained from burning bagasse in the boilers. There is normally little incentive to use waste heat. In fact in large sugar mills that do not sell power, heat is sometimes purposefully wasted, to ensure that a surplus of bagasse is not generated, which would lead to a waste disposal problem.

In stand-alone sugar refining, energy efficiency is a concern. Waste heat is minimized by recovering energy from pan and evaporator vapors and from condensates.

1.8.10 Potential for biogas generation and use

The major opportunity for biogas generation is using vinasse from a distillery. Vinasse from 1 m$^3$ of ethanol treated anaerobically produces 115 m$^3$ of biogas, which in turn can generate 169 kWh of power, after deducting the power used in the process (BNDES 2008). Gupta quoted by Nguyen et al. (2010) indicates that 26 L biogas is produced per L vinasse, which is roughly equivalent to 312 m$^3$ from 1 m$^3$ ethanol. Moletta quoted by Nguyen et al. (2010) reports that 0.5 L biogas is produced/g COD removed. Meneses (2008) reports 0.53 Nm$^3$ of biogas is produced per kg COD destroyed, with 55 % methane content. Meneses (2008) reports that 90 % BOD and 67 % COD is removed.

Thus, the amount of biogas produced will depend on the COD of the incoming vinasse. Using a figure of 0.5 L gas/g COD removed and 67 % removal of COD, L biogas/L vinasse is 13.3 at 40 000 mg COD/kg and 26.6 at 80 000 mg COD/kg. With a vinasse/ethanol ratio of 12:1, this represents 161 and 322 L biogas/L ethanol respectively. Meneses (2008) reported that with an average vinasse COD of 97 900 mg/L, 417 m$^3$ biogas was generated/L ethanol and a heating value of 0.023 MJ/L biogas. Since the lower heating value of methane is 0.036 MJ/L, this implies that almost two thirds of the biogas is methane.

1.8.11 Energy-saving lighting, ventilation and other opportunities

Perhaps the major opportunity to conserve energy is to ensure comprehensive and adequate insulation of all steam and other high temperature items. Steam traps are often a source of losses and they should be maintained in good condition. The use of thermography to identify where heat losses are occurring can be very beneficial. Natural ventilation to keep work spaces for operators as cool as possible, particularly in the pan floor and boiler house, should be designed in. Energy efficient lighting is important only when it inflates imported energy or reduces exports of energy.

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Prepared by PGBI Sugar & Bio-Energy (Pty) Ltd.
Power factor correction on large drives is particularly useful in maximizing the amount of energy available for export.

1.8.12 Summary and good practice recommendations

<table>
<thead>
<tr>
<th>Box 1.8 Management of energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sugar mills are fortunate in having bagasse available as an energy source.</td>
</tr>
<tr>
<td>• The mill is able to configure the thermal economy of the operation to be independent of other fuel sources under most conditions.</td>
</tr>
<tr>
<td>• The thermal economy of the factory should be designed so that the mill does not need supplementary fuels or create a bagasse surplus.</td>
</tr>
<tr>
<td>• If waste biomass is to be used as a supplementary fuel, its suitability for use should be assessed from its chemical analysis, to ensure freedom from boiler fouling and slagging problems.</td>
</tr>
<tr>
<td>• If the mill can profitably export bagasse to a downstream use (e.g. for by-products), the thermal economy of the mill is most important.</td>
</tr>
<tr>
<td>• Likewise if the mill intends to export power, the factory should be set up to be energy efficient, and/or the distillery should employ a steam saving configuration, to maximize export revenue.</td>
</tr>
<tr>
<td>• Good energy efficiency is achieved by using high efficiency electric drives instead of turbines on plant and equipment and minimizing process steam usage.</td>
</tr>
<tr>
<td>• High pressure boilers are necessary if substantial export of power is envisaged.</td>
</tr>
<tr>
<td>• Good boiler efficiencies are achieved by incorporating air heaters and economizers, and through good maintenance and operation.</td>
</tr>
<tr>
<td>• Bagasse driers can deliver efficiency benefits, but the correct design and integration of the plant is vital if the benefits are to outweigh the additional operating costs.</td>
</tr>
<tr>
<td>• The existing legal framework and the prevailing electricity market rules can have a huge influence on an energy export project and should be thoroughly investigated before investing.</td>
</tr>
<tr>
<td>• The generation of biogas from vinasse when available can profitably contribute to energy production.</td>
</tr>
</tbody>
</table>

1.9 Sustainability and management of carbon emissions

1.9.1 Sustainability

There is increasingly wide acceptance of the fact that all agricultural and industrial enterprises need to operate in a manner in which not just the economic but also the social and environmental factors are promoted. At the same time energy use, production efficiency, elimination of wastage, a range of social and labor issues and the effect on global climate change need to be more carefully monitored.

The pressure for a system to certify that sustainable practices are being adhered to has come largely from the market place. A number of large industrial consumers of sugar want to be able to certify that sugar and other ingredients in their products are produced by means of sustainable practices. This initiative has been given additional momentum with biofuels export, where for instance the import of biofuels into Europe requires that these fuels are produced following sustainable practices. The discussion on sugarcane ethanol has largely centered on conditions in Brazil (Macedo et al. 2008; Wang et al. 2008). Several initiatives are being developed in Europe and the United States relating to certification for sustainable production of biofuels. A multi-stakeholder initiative, the Roundtable on
Sustainable Biofuels, is well advanced in producing guidelines for sustainable biofuel production. Issues relating to sustainability in the cane sugar industry have been highlighted by Rein (2009).

In the sugarcane industry, Brazil has been the most active in embracing and reporting sustainability performance. This is largely due to the need to meet sustainable standards in producing biofuels for export to first world countries. In the absence of agreed standards for sugarcane, a number of mills are reporting their results based on the Sustainability Reporting Guidelines proposed by the Global Reporting Initiative (GRI 2008).

Most mills in Brazil are very conscious of environmental issues. Intensive reforestation with indigenous trees is evident at a number of mills. Nurseries are maintained by the milling companies in Brazil and many other countries, and thousands of trees are planted each year, restoring degraded and riparian areas. The São Martinho group mills have Environment Education Centers, with impressive displays, to educate the general public as well as focus on their environmental standards.

Brazilian legislation requires 20% of the land to be natural vegetation, as well as riparian areas. This is a harsh requirement for existing sugar estates and is currently under review.

Industry environmental leaders have also been accredited to ISO 14001 for environmental management, including some mills in Brazil and Thailand. The ISO 14001 standard requires facilities to set up objectives and targets, and to establish, implement and maintain programmes to achieve these objectives and targets. The following issues should be considered in the process:

- Legal requirements
- Significant environmental aspects
- Technological options
- Financial, operational and business requirements
- Views of interested parties.

1.9.2 Estimation/measurement of carbon footprint

Climate change is rapidly becoming a serious issue and one which will increasingly demand the attention of sugar and ethanol producers. Estimation of the greenhouse gas emissions in production, otherwise known as the carbon footprint, is an essential part of any sustainability study. A method of estimating net energy usage and greenhouse gas emissions has been developed, based initially on work done on biofuels (Rein 2010). The calculation routine was developed for use in the Better Sugarcane Initiative standards, which focus on the sustainability of the sugarcane industry.

A number of studies have been undertaken to estimate the net energy ratios and carbon emissions associated with bioethanol production. Different estimates of GHG emission savings relative to fossil fuels are obtained if different assumptions are made in the calculation procedure. Wang et al. (2008) estimate a reduction of 78% relative to gasoline for ethanol transported to the US from Brazil; they estimate this will increase by up to 9 percentage points if cane burning is phased out (the CO₂ is not regarded as a GHG emission since it is derived from plant material, but emissions of CH₄ and N₂O are). Data produced in Brazil indicates that bioethanol produced and used in Brazil shows GHG emissions savings of 89% (BNDES 2008).

The EU has compiled a Renewable Energy Directive (RED) which sets out how the emissions should be calculated for the production of a biofuel from any particular feedstock. In addition some GHG emission saving default values, assuming no land use change, are given to be used in the absence of primary data required for its calculation. Ethanol produced from sugarcane has the best default
value of 71% emission saving relative to gasoline; emission savings using corn, wheat or sugar beet are significantly lower, varying between 16 and 52%, depending on the feedstock and the process used.

The EU RED also focuses on land use change. Any land use change after 1 January 2008 needs to take into account the change in land carbon stock as a result of any expansion of cane growing areas. Depending on the status of the new land before conversion, the change in carbon stock can make a huge impact on the carbon footprint, particularly if any natural forest is involved. Estimates are given elsewhere (Rein 2010).

The carbon footprint of sugar has received considerably less attention than that of bioethanol. PAS 2050:2008 is a Publicly Available Specification, developed in the UK in conjunction with the Carbon Trust (BSI 2008). Both British Sugar Corporation and Tate & Lyle have used this carbon footprint and labeling initiative to evaluate the carbon footprint of sugar, using a life cycle analysis approach. Renouf and Wegener (2007) have calculated the carbon footprint for raw sugar production under three different Queensland scenarios.

The main issues to be considered in estimating the carbon footprint are as follows (Rein 2010):

- **System boundary.** It is essential to describe accurately the boundary of the system being examined, indicating clearly what is included and excluded.
- **Direct and indirect effects.** Direct inputs are mainly fuel and power inputs, expressed in terms of the primary energy value (taking into account, for example, the efficiency of conversion of fuel to power, and the energy in producing gasoline and diesel). Indirect inputs include, in addition, the energy required for the production of chemicals, fertilizers and other materials used. In some cases the indirect inputs also include the additional energy necessary for the manufacture and construction of farm, transport and industrial equipment and buildings.
- **Direct land use change.** The effect on the carbon stock of planting cane compared to its previous status needs to be accounted for.
- **Indirect land use change.** This concerns secondary effects induced by large scale expansion. This displaces existing crops, leading to expansion of cropland elsewhere, either in the same country or in other parts of the world. The effects of these changes are very difficult to estimate, and have therefore been neglected in any analyses, largely because of the uncertainty in modeling the effects.
- **Handling of co-products and multiple products.** The method of allocating emissions to products can affect the estimates.
- **Default and secondary data.** It is always necessary to make some assumptions in the absence of direct measurements. The value and source of the data used can have a substantial effect on computed emissions.

Carbon dioxide (CO$_2$) from sugarcane emitted in combustion and in ethanol fermentation is considered zero CO$_2$ emission to the air, because this is the carbon taken in from the air during sugarcane growth. Carbon monoxide and volatile organic compounds (VOCs) emitted in combustion are assumed to be converted to CO$_2$ fairly rapidly, but methane (CH$_4$) and nitrous oxide (N$_2$O) from burning bagasse must be accounted for in GHG emissions. CO$_2$ emissions arising from biogenic carbon sources are excluded from the calculation of GHG emissions from the life cycle of products, except where the CO$_2$ arises from direct land use change. Methane and N$_2$O have global warming potentials 25 and 298 times that of CO$_2$ respectively (IPCC, 2007). The carbon equivalent value is calculated by multiplying the mass of one of these gases by its global warming potential. This is added to the CO$_2$ evolved and expressed as CO$_2$ equivalent (CO$_2$eq). Therefore even small amounts of CH$_4$ and N$_2$O need to be considered in arriving at GHG emission estimates.
Methane produced in anaerobic digesters that is used as fuel in boilers is not considered to produce GHG emissions. Methane produced by anaerobic processes from wastes but not captured has to be taken into account in calculating emissions. Where methane is combusted without the generation of useful energy (i.e. flaring), no GHG emissions shall be incurred where the methane being combusted is derived from the biogenic component of the waste.

The carbon footprints of sugar and ethanol are very small when compared with other foods and fuels. Rein (2010) has shown that particular improvements can be achieved by focusing on the following, in roughly the following order of importance:

- Cogenerate and export power to the maximum extent possible
- Maximize cane yield and factory recovery
- Reduce the amount of fertilizer and chemical inputs, particularly N fertilizer
- Reduce the extent of cane burning
- Reduce the quantities of any supplementary fuels purchased
- Minimize irrigation power input
- Reduce cane transport distances
- Recycle water to reduce water intake.

A critical issue is the effect of land use change. A cut-off date of January 2008 is adopted by the EU and the Better Sugarcane Initiative, so that land use change before that date is not considered. However changing land from most forms of natural vegetation to cane imposes a substantial increase in calculated emissions. For this reason, it is reported that all expansion of cane land in Guatemala has been on land previously used for agriculture. This is the common approach also in Brazil where the major expansion occurs in degraded pasturelands.

Any new project should look at the implications of land use change very seriously.

1.9.3 Finance opportunities for emission reductions

Carbon financing as a carbon emissions reduction strategy may include the host government-endorsed Clean Development Mechanism (CDM) or Joint Implementation of the United Nations Framework Convention on Climate Change.

The CDM allows emission reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO₂. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol.

A brief description of the CDM project activity cycle is as follows:

- Project participants submit information on their proposed CDM project activity using a project design document.
- A new baseline methodology is submitted by the applicant to the CDM Executive Board for review, prior to a validation and submission for registration of this project activity.
- Validation of the CDM project activity is the process of independent evaluation of a project activity against the requirements of the CDM on the basis of the project design document.
- Registration of the CDM project activity is the formal acceptance by the Executive Board of a validated project as a CDM project activity. Registration is the prerequisite for the verification, certification and issuance of CERs related to that project activity.
Verification is the periodic independent review and determination of the monitored reductions in anthropogenic emissions that have occurred as a result of the CDM project activity during the verification period. Certification is the written assurance that, during a specified time period, the project activity achieved the reductions in anthropogenic emissions by sources of greenhouse gases.

The process is tedious and requires investment ahead of reward. Some countries have developed or are developing national carbon trading systems. In the case of the sugar industry an added complication is the apportionment of CDM benefits between growers and millers to avoid double claiming.

1.9.4 Use of sustainability metrics

Various approaches to assessing sustainability have been taken, although none of the systems currently have wide acceptance. The São Martinho group in Brazil has been certified by Greenergy according to the UK Road Transport Fuel Obligation (RTFO) meta-standard, meeting all the requirements for export into the UK. In addition, other systems proposed by various consultants have been used in South America.

The system for certifying sustainability most likely to be widely accepted is the standard proposed by the Better Sugar Cane Initiative, now known as Bonsucro. Because it is crop specific, it can be made simpler and more appropriate. It proposes to use a system of metrics, based on impacts and outcomes, rather than prescribing ‘best’ practices, and it is expected to be released for commercial use during 2011. It is anticipated that any surplus revenue arising from the sale of certified product will be returned to the producers.

Coca Cola and other major users of sugar and ethanol regularly audit their supplying mills and their products according to their specific requirements. In some countries, including Australia, certification systems are primarily targeted at food safety and quality.

1.9.5 Summary and good practice recommendations

**Box 1.9 Sustainability and management of carbon emissions**

- All mills should adopt a sustainable operation policy, and consider being certified to ISO 14001.
- Any new project or expansion must take into account the sustainability of the project, encompassing not just economic but also social and environmental factors.
- Exporters of ethanol to developed countries need to get certified sustainability for their products.
- Sugar mills can produce products with a small carbon footprint because of the availability of bagasse as a fuel source.
- The effect on GHG emissions should be thoroughly considered in arriving at a final project design.
- New projects involving expansion onto virgin land should not be undertaken without a comprehensive study of the effect on land carbon stocks.
- The CDM process provides an opportunity for sugarcane projects to benefit from carbon credits, even though the process involved can be drawn out.
- Sustainability certification through the Better Sugarcane Initiative (Bonsucro) provides the most promising avenue to have sustainable production certified.
1.10 Safety training and safety management

1.10.1 Policy and management

Occupational Health and Safety requirements of persons involved in sugar and co-product industries should be covered by legislative requirements for each respective country and/or state. Safety policy and management should integrate with the respective laws and regulations (both at local and national government level). Good practice for sugar millers is to actively embrace these laws and seek to mitigate all risks for all persons in the workplace.

It is essential for a mill to have a well developed health and safety policy in place. Ideally, this needs to be implemented in such a way that it changes mindsets, which intuitively result in safe behavior. A number of mills are accredited to OSHAS 18000, an ISO standard, with external and internal audits for compliance. In some countries the mills subscribe to national safety bodies, which set standards and undertake regular reviews. One of these two approaches is essential.

The mill or distillery needs to have a procedure for reporting all occupational, health and safety incidents and accidents as well, and a system with registry controls and record keeping. Performance assessment relative to agreed standards needs to be widely available to stakeholders. Environmental, health and safety performance results are all available on the São Martinho intranet, for employees and company officials to see.

1.10.2 Hazards in the workplace

The most common risks for accidents in sugar mills are trips and falls caused by slippery floors, stairs, and elevated platforms (e.g. due to water and molasses), the incorrect use of equipment (e.g. packaging and transport equipment), contact with sharp edges on process equipment, burns due to steam/hot process fluids, accidents involving conveyor belts, and explosions (e.g. white sugar drying and storing, gas/fuels storage, and boilers).

Some particular issues relevant in a sugar mill and distilleries are as follows:

- A lock-out system is necessary on electrical equipment, to enable safe maintenance on conveyors and plant equipment.
- A lock-out system is necessary on steam and vapors valves, to enable safe cleaning and maintenance on internal parts of evaporators and vacuum pans.
- Hot work permits should be required in areas where bagasse dust and sugar dust are present.
- In ethanol plants, there need to be controls in place to ensure that no fire/explosion incidents occur.
- The installation of a facility to steam out massecuite cut-over lines needs to be engineered to eliminate the possibility of explosions due to the explosive decomposition of sugar products in contained spaces (Getaz et al. 2006).
- Checks for accumulated carbon dioxide (from fermentation or decomposing sugar) before entering tanks.
- Working at heights above 2 m and working in confined spaces should require special permits.

Good housekeeping is an essential part of reducing risks in the work place.

Chemical hazards are not usually severe in sugar mills, unless chemical cleaning of evaporators is required. Due care is necessary if chemical cleaning of plant and equipment is required, and biocides, if used, should be handled responsibly. Workers may be exposed to bagasse dust and sugar dust
during the sugar drying and packing processes. There is a potential health hazard associated with the storage and handling of bagasse, namely bagassosis, an allergic reaction of lung tissue to the presence of *Thermoactinomyces sacchari* spores. These develop only in stored bagasse and are not usually present in sufficient quantity to cause problems in a normal mill environment. Further details are given by Dawson *et al.* (1995).

Normal precautions for protection from noise in some parts of a sugar mill are necessary.

### 1.10.3 Risk assessment and mitigation

Sugar mill, distilleries and by-product factories are potentially hazardous places. There are many hazards that have the potential to harm people in the work place. Measures should be introduced to assess the risks and measures introduced to mitigate or minimize risks.

Preventive and protective measures should be introduced according to the following order of priority:

- **Eliminating the hazard** by removing the activity from the work process. Examples include substitution with less hazardous chemicals, using different manufacturing processes, etc.
- **Controlling the hazard** at its source through the use of engineering controls. Examples include local exhaust ventilation, isolation rooms, machine guarding, acoustic insulating, etc.
- **Minimizing the hazard** through design of safe work systems and administrative or institutional control measures. Examples include job rotation, training safe work procedures, lock-out and tag-out, workplace monitoring, limiting exposure or work duration, etc.
- **Providing appropriate personal protective equipment (PPE)** in conjunction with training, use, and maintenance of the PPE.

Plant design and installation standards are also vitally important in ensuring safety standards. Mechanical and electrical installations designed according to approved codes are essential. In the sugar mill context, steam and power generation and reticulation are an important focus. Appropriate operation and fire alarm systems need also to be in place.

### 1.10.4 Training

Training and retraining of all employees on health and safety issues on a regular basis should be common practice, and are usually addressed in most sugar producing areas.

Provisions should be made to provide OHS orientation training to all new employees to ensure they are apprised of the basic rules of work on the site and of personal protection. Regular updating training should be provided for all employees on a routine basis. The training should cover:

- Knowledge of materials, equipment, and tools
- Known hazards in the operations and how they are controlled
- Potential risks to health
- Precautions to prevent exposure
- Hygiene and health requirements
- Wearing and use of protective equipment and clothing
- Correct use and care of personal protective equipment
- How to identify and use safety signs
- Appropriate response to operation extremes, incidents and accidents
- Knowledge of safe routes to escape in case of an accident.
Workers and contractors, prior to commencement of new assignments, should have received adequate training and information enabling them to understand work hazards and to protect their health from hazardous ambient factors that may be present. A basic occupational training program and specialty courses should be provided, as needed, to ensure that workers are oriented to the specific hazards of individual work assignments. Training should be provided to management, supervisors, workers, and occasional visitors to areas of risks and hazards. Workers with rescue and first aid duties should receive dedicated training.

1.10.5 Safety equipment

Personal Protective Equipment (PPE) provides additional protection to workers exposed to workplace hazards in conjunction with other facility controls and safety systems. PPE is considered to be a last resort that is above and beyond the other facility controls, and provides the worker with an extra level of personal protection. Recommended measures for use of PPE in the workplace include:

- Active use of PPE if alternative technologies, work plans or procedures cannot eliminate, or sufficiently reduce, a hazard or exposure.
- Identification and provision of appropriate PPE that offers adequate protection to the workers and occasional visitors, without incurring unnecessary inconvenience to the individual.
- Proper maintenance of PPE, including cleaning when dirty, and replacement when damaged or worn out. Proper use and care of PPE should be part of the recurrent training programs for employees.

1.10.6 Measurement of lost time due to safety incidents

It should be a routine procedure to report the Lost Time Injury Frequency Rate (LTIFR), i.e. the number of lost time incidents per million man hours worked. A lost time accident is defined as one which results in a worker missing his next day or next shift due to the accident. The LTIFR should be below 15 in a sugar mill, and preferably below 10. Some mills report not only accident frequency rate, but also accident severity, based on the lost time associated with each incident. This is to be encouraged. In addition any safety incidents or ‘near misses’ should be formally reported, recorded and acted upon to eliminate recurrences.

Attempts should be made to reduce the number of accidents among workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. The systems and the employer should further enable and encourage workers to report to management all:

- Occupational injuries and near misses
- Suspected cases of occupational disease
- Dangerous occurrences and incidents
- Potential risk areas.

Occupational health and safety monitoring programs should verify the effectiveness of prevention and control strategies. The OHS monitoring program should include:

- Safety inspection, testing and calibration: This should include regular inspection and testing of all safety features and hazard control measures focusing on engineering and personal protective features, work procedures, places of work, installations, equipment and tools used. The
inspection should verify that issued PPE continues to provide adequate protection and is being worn as required.

- **Legal requirements**: Safety testing associated with boilers, rigging equipment, etc. are often prescribed by law. These must be undertaken at the required frequency.
- **Training**: Training activities for employees and visitors should be adequately monitored and documented (curriculum, duration, and participants). Emergency exercises, including fire drills, should be documented adequately. Service providers and contractors should be contractually required to submit to the employer adequate training documentation before the start of their assignment.
- **Security audit**: Checking services standards and safety procedures, reporting non-conformities and always looking for improvements.

### 1.10.7 Summary and good practice recommendations

<table>
<thead>
<tr>
<th>Box 1.10 Safety training and safety management</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A mill must have a well developed health and safety policy.</td>
</tr>
<tr>
<td>• External audits of safety performance by recognized authorities are essential.</td>
</tr>
<tr>
<td>• Internal audits should be conducted by a multidisciplinary team.</td>
</tr>
<tr>
<td>• A procedure for reporting all occupational, health and safety incidents, and a system of record keeping should be operational.</td>
</tr>
<tr>
<td>• Regular training and retraining of employees is necessary.</td>
</tr>
<tr>
<td>• Proper use of PPE is essential.</td>
</tr>
<tr>
<td>• Risk management should consider all potential hazards and where possible take action to mitigate them.</td>
</tr>
<tr>
<td>• Good housekeeping is important and contributes to achieving higher safety standards.</td>
</tr>
<tr>
<td>• Commitment and participation of managers and leaders in matters of health and safety.</td>
</tr>
<tr>
<td>• Health and safety company procedures constantly disclosed and properly deployed to all employees.</td>
</tr>
</tbody>
</table>
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CHAPTER 2 MANAGEMENT OF WASTES AND EFFLUENTS

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2. MANAGEMENT OF WASTES AND EFFLUENTS

2.1 Identification/characterization and disposal of solid wastes

2.1.1 Roadside cane spillage

Cane spilt on roads may become a traffic hazard and may block drainage channels. On public roads there may be a legal requirement to remove such spillage. This necessitates the setting up of road cleaning teams with provision for emergency response when large spills take place. The spilt cane is generally damaged and stale and is therefore not recovered for commercial use but is returned to cane fields. Attention to loading procedures is important for minimizing the amount of cane spilt on roads. Depending on transport systems, much of the spilt cane may arise from cane left in the transport vehicle after off-loading. This is particularly problematic with whole-stick cane and may necessitate manual removal of residual sticks after off-loading. One option for addressing the problem is to fit netting or canvas to ‘spiller-type’ trailers so as to prevent road spillage and ensure complete off-loading. Trials and economic assessment of one such system (Bezuidenhout 1993) demonstrated appreciable labor savings and improved vehicle utilization due to quicker turn-around. This illustrates the opportunity to manage the problem through attention to vehicle design.

Billeted cane transported in basket-type trailers generally does not present spillage problems if the trailers are not overloaded.

2.1.2 Cane washing mud

Cane washing is practiced in areas where soil and harvesting conditions result in significant amounts of mud being delivered to the factory with the cane. The mud is washed from the cane and settled in ponds. This settled mud is returned to cane fields periodically.

2.1.3 Filter cake from juice clarification

Filter cake produced during juice clarification consists of soil washed from the cane, precipitates formed by liming and heating the juice, and bagacillo added as filter aid. Diffusers produce significantly less cake than milling tandems because suspended matter is removed from the juice as it passes through the bed of bagasse prior to clarification. Average cake production from diffusers in South Africa was reported as 2.4 % (as filter cake) on cane, while milling tandems produced 5.6 % (Koster 1995).

Subsequent to this comparison some diffuser factories ceased the production of filter cake by pumping the clarifier underflow to the diffuser for sugar recovery and eventual incineration in the boiler (Meadows et al. 1998; Jensen and Govender 2000). This elimination of filter cake production offers the following advantages:

- Significant cost savings due to elimination of the filter station and all ancillary equipment, including bagacillo and filter cake handling equipment.
- Elimination of sucrose loss via filter cake and via microbial action in the filter station.
- Fuel savings due to availability of bagacillo, and reduced evaporation requirements due to elimination of filter wash water.
- No need for transport and in-field distribution of filter cake.

This option is recommended for most diffuser factories. Exceptions might include circumstances where there is profitable use of filter cake, especially where it is co-composted with vinasse. The
return of mud to the diffuser requires careful management of the factory mass balance due to recycling past the raw juice scale.

The composition of filter cake is influenced by various factors including soil type, harvesting conditions, extraction method (milling or diffusion) and by additions of other materials such as fly ash and refinery filter cake. An indication of composition is given in Table 2.1.

<table>
<thead>
<tr>
<th>Constituent (%) of dry cake</th>
<th>Source of cake (and reference)</th>
<th>Indian mill (Thangamuthu 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude wax and fat</td>
<td>Cane diffuser (Anon 1999)</td>
<td>Mill tandem (Anon 1999)</td>
</tr>
<tr>
<td></td>
<td>5 – 14</td>
<td>5 – 14</td>
</tr>
<tr>
<td>Sugars</td>
<td>2 – 5</td>
<td>2 – 5</td>
</tr>
<tr>
<td>Ash</td>
<td>9 – 20</td>
<td>9 – 20</td>
</tr>
<tr>
<td>Fiber</td>
<td>15 – 30</td>
<td>15 – 30</td>
</tr>
<tr>
<td>N</td>
<td>1.0 – 2.0</td>
<td>1.3 – 1.8</td>
</tr>
<tr>
<td>P</td>
<td>1.5 – 2.5</td>
<td>0.5 – 1.0</td>
</tr>
<tr>
<td>K</td>
<td>0.2 – 0.3</td>
<td>0.2 – 0.3</td>
</tr>
<tr>
<td>S</td>
<td>0.1 – 0.2</td>
<td>0.1 – 0.2</td>
</tr>
<tr>
<td>Ca</td>
<td>3.0 – 5.0</td>
<td>1.0 – 2.0</td>
</tr>
<tr>
<td>Mg</td>
<td>0.5 – 1.0</td>
<td>0.2 – 0.5</td>
</tr>
<tr>
<td>Moisture (% wet cake)</td>
<td>65 – 75</td>
<td>65 – 75</td>
</tr>
</tbody>
</table>

From Table 2.1 it is evident that the nutrient value of filter cake is very variable, particularly with respect to nitrogen and phosphorous. If fly ash is added the nitrogen and phosphorous contents decrease appreciably.

**Direct use of filter cake for cane growth**

Numerous studies have shown that filter cake applied to cane fields has beneficial effects. Dee et al. (2002) reported that it increases the organic carbon content of the soil, has a liming effect leading to an increased soil pH, increases the microbial activity in the soil and reduces aluminum toxicity. It adds basic cations plus C, N, S and P in organic forms. It is common practice to dispose of the cake by returning it to fields, but the nutrient value does not always justify the transport and spreading costs, so farmers will not necessarily remove the cake. The nutrient composition of the cake and the nutrient requirements of the receiving soil need to be determined before a decision on the economics of using filter cake can be made. In some soils the slow release of N from the cake has resulted in delayed ripening of cane. Adjustment of fertilizer nitrogen application is therefore necessary but is complicated by the fact that nitrogen availability from filter cake varies according to soil conditions – in well drained soils about 50 % of the nitrogen is available for early crop growth, but in wetter soils only about 30 % is available. If the cake has been well composted about 70 % of the nitrogen is readily available (Anon 1999).

Apart from nutrient benefits, filter cake has benefits in terms of improving soil conditions. When applied around newly planted cane setts at a rate of 30-40 t/ha it helps to retain moisture for use by the young plants.

Saline-sodic soils can be reclaimed by incorporating 350 t/ha of cake to a depth of 300 mm. At this depth the cake persists and provides a long term supply of calcium ions to displace sodium ions that can then be leached from the soil (Anon 1999).
The high water content of filter cake causes transport costs to be high. For this reason Steindl et al. (2010) investigated solid bowl centrifugation as a means of reducing the moisture content. Where mud fed to a conventional rotary vacuum filter gave cake of 75 % moisture the centrifuge could reduce this to 55 % but required the use of flocculants and bagacillo. The resulting cake was powdery but could be distributed by a normal cake-spreading truck.

**Composting of filter cake**

By composting filter cake its mass can be reduced and the carbon:nitrogen (C:N) ratio narrowed so that the nitrogen is more readily available (Alexander 1972). Composting requires a large area and a system for turning the compost regularly to promote the aerobic composting process. Bernhardt and Notcutt (1993) showed that composting is complete in six weeks, with a reduction in mass of more than 50 % due to loss of moisture and some organic carbon. Temperature during composting was found to increase to a value between 50 and 60 °C and temperature is assumed to be a useful indicator of activity. The material needs to be turned approximately every four to seven days and no water needs to be added. The quality of compost was assessed to be most suitable as a soil amendment, leading to substantial additional value.

![Figure 2.1 Composting operation at Sao Martinho](image)

Composting of filter cake in conjunction with vinasse produces a product with higher nutrient value and provides a means of evaporating and disposal of vinasse (Senthil and Das 2004). More details are given in Section 3.4.1. Other wastes such as gypsum, calcium carbonate, fly ash, boiler ash and chicken manure may be successfully composted with filter cake, as is done at São Martinho in Brazil.

**Anaerobic digestion of filter cake**

Filter cake is amenable to anaerobic digestion leading to the production of useful biogas. About 200 small scale digesters in India include filter cake as feedstock (Thangamuthu 2010). The resulting biogas has high methane content (65-75 %) and is used as cooking fuel for some factory canteens. Each kg of cake gives 0.05-0.06 m$^3$ of biogas. The digested cake has value as compost.

**2.1.4 Press muds from refinery processes**

Refineries using the carbonatation process produce cake that is rich in calcium carbonate. If applied indiscriminately to crops, this cake can cause long term ‘iron chlorosis’ (yellow leaves with stunted
growth) due to low availability of iron in the presence of the excess calcium carbonate. Such chlorosis is evident in the vicinity of a raw sugar factory that used the carbonatation process in the 1920s and distributed the resulting large amount of cake to surrounding cane. The effects were still evident 40 years later, especially when herbicides were applied (Gosnell 1965).

Factories producing raw cane sugar no longer use carbonatation. The amount of cake produced in carbonatation refining of the raw sugar is only about 0.3 % on cane. This small amount can be disposed of by judicious application to cane (usually in conjunction with cake from the raw sugar process). It assists in counteracting soil acidification (Anon 1999).

2.1.5 Boiler ash (and fly ash)

The composition and quantity of boiler ash is influenced by the amount of soil in bagasse and the natural ash content of bagasse and any supplementary fuels. An example of the composition is given in Table 2.2. Fly ‘ash’ consists of particulate matter collected from the boiler flue gases. It contains appreciable amounts of partially burnt fuel particles.

Table 2.2. Some chemical properties of ash (Dee et al. 2002).

<table>
<thead>
<tr>
<th>Material</th>
<th>pH</th>
<th>N (%)</th>
<th>P (%)</th>
<th>K (%)</th>
<th>Ca (%)</th>
<th>Mg (%)</th>
<th>Si (%)</th>
<th>P (%)</th>
<th>Water soluble Si (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>7.69</td>
<td>0.01</td>
<td>0.71</td>
<td>0.42</td>
<td>2.3</td>
<td>0.73</td>
<td>8.4</td>
<td>0.49</td>
<td>375</td>
</tr>
<tr>
<td>Boiler ash</td>
<td>7.45</td>
<td>0.13</td>
<td>0.46</td>
<td>0.47</td>
<td>4.4</td>
<td>0.55</td>
<td>8.3</td>
<td>0.21</td>
<td>152</td>
</tr>
</tbody>
</table>

The high pH and high Ca content of the ash suggests that it is a useful additive to acid soils. This was confirmed by Dee et al. (2002) in pot experiments with two different soil types of low pH. When ash was incorporated into soils at rates equivalent to 10 and 20 t/ha the soil pH increased by between 1 and 1.5 units. The increase in soil pH was accompanied by a decrease in exchangeable aluminum, which would have reduced aluminum toxicity. Despite the low nutrient content the ash increased crop yield significantly on both of the acidic soils. Apart from soil pH benefits, ash is a source of soluble silicon which increases plant resistance to various pests, particularly stalk borers (Laing et al. 2006).

Ash disposal to cane fields

The disposal of ash to cane fields is an option with some potential benefits mentioned above. Caution is, however, necessary if coal has provided a significant portion of the boiler fuel because elements from the coal (e.g. B, Mo, S and Se) may accumulate (Dee et al. 2002). Standard acid leaching tests on coal-based ash from one sugar factory (unpublished data) indicated that manganese was the only element likely to leach out in unacceptable concentrations if the ash was disposed of together with domestic refuse (acid leachate). The manganese is only mobile under acid conditions. It is not advisable to add coal-based boiler ash to very acid, waterlogged soils because the acidity is likely to persist despite the neutralizing effect of the ash, and because anaerobic conditions in waterlogged soils increase the solubility of manganese. If there is filter cake to mix with the ash it ameliorates potential manganese solubility problems by raising the pH, but modern diffuser factories often do not produce filter cake.

Ash disposal to landfill

The expense of road transport and in-field distribution of ash may exceed the value of the agricultural benefits. A less expensive option for some circumstances is to hydraulically transport the ash to a landfill site close to the factory. Details of one such system are given by Munsamy (1989), who also gives details of an alternative system for handling fly ash from wet scrubbers. The landfill may also provide opportunity for anaerobic digestion of factory effluent (discussed in Section 2.2.3).
Concerns about possible methane contribution to greenhouse gases need to take into account the fact that in open dams methanogenic bacteria are concentrated in the lower layers while methanotrophs are active in the upper layers. The latter use methane as an energy source. Measurements in rice paddies (Le Mer and Roger 2001) show that up to 90% of the methane produced by the methanogens may be consumed by the methanotrophs living in the partially aerated zones. In an open anaerobic dam, or partially submerged ash in landfill, there will be considerable activity of methanotrophs. These bacteria are so active around leaks from natural gas (methane) pipes that they cause a significant increase in the soil organic matter. It is therefore evident that methane emissions from open dams and landfill may be considerably less than the methane produced from equivalent COD in a closed anaerobic reactor.

In South Africa there is an example of an ash landfill that now supports thriving vegetable gardens where the site was previously unproductive. In another case the ash is periodically removed for use at a nearby cement factory.

2.1.6 Sludge from effluent treatment plants

Surplus sludge from sugar factory effluent treatment plants can be pumped to anaerobic dams for digestion and recycling of nutrients. If no anaerobic facilities exist then the sludge can be dried and buried or returned to cane fields. Whereas sugar factories and associated villages generally produce non-hazardous sludge, it should be noted that sludge from municipal effluent treatment plants may contain pathogens and heavy metals. The heavy metals are generally only problematic in sludge from treatment plants that receive input from certain types of industries (e.g. metal plating industries). Municipal sludge should not be accepted for disposal to cane fields if it does not meet local specifications or World Health Organization specifications (World Health Organization 2006).

2.1.7 Laboratory filter papers with lead acetate precipitates

Lead acetate used for clarification of sugar samples before analysis has caused concerns with disposal of the lead. Alternatives to the use of lead acetate have therefore been sought and many sugar industries have recently been able to reduce or eliminate the use of lead acetate. Adoption of such lead-free techniques (e.g. near infra-red spectrometer methods (Simpson and Naidoo 2010) and clarification of sugar samples with alumina cream) is recommended, but some use of lead may still be necessary for calibration. Where lead acetate is still used, the filter papers that trap most of the precipitated lead need careful disposal. This may require the services of specialist companies that either recover the lead or dispose of it to special sites.
2.1.8 Summary and good practice recommendations

Box 2.1 - Identification/characterization and disposal of solid wastes

- Solid wastes that require management include:
  - Roadside cane spillage
  - Cane wash mud
  - Filter cake
  - Boiler ash
  - Fly ash
  - Lead-containing laboratory precipitates.

- With the exception of the last item, these wastes are non-hazardous and can be returned to cane fields. Boiler ash derived from coal may contain heavy metals that need additional care. Manganese from such ash will dissolve if the ash is deposited on acid, waterlogged soils.

- Disposal challenges relate mainly to the low value of the wastes causing farmers to be reluctant to bear the costs of transport. In such cases, subsidization of transport costs by the mill may be necessary.

- New factory designs often eliminate filter mud by pumping it to diffusers where it is trapped in the bagasse bed and then burnt with the bagasse.

- Alternatively the filter cake can be increased in value and decreased in mass by composting, making it attractive as an organic fertilizer. It is particularly attractive if vinasse can be co-composted with the filter cake.

- As an alternative to trucking boiler ash back to fields it can be hydraulically transferred to landfill. Such landfill can accommodate microorganisms that anaerobically digest factory liquid effluent included in the ash water circuit (see Section 2.2.3).

2.2 Management of waste water and other liquid effluents

The logical first step in management of waste water is to minimize the quantity. Successes in this direction for a cane-based ethanol factory are summarized by Oliverio et al. (2010) with examples that include the substitution of cane washing by dry cleaning, and the efficient concentration of stillage such that volumes can be reduced from 13 L/L ethanol to 0.8 L/L. The long-term vision is of a ‘zero-wastewater, zero-residues, zero-odors and minimum emissions mill’. In addition, the futuristic mill could be self-sufficient in water, using only the water in the incoming cane, with the potential to export some of this water for other uses. This will involve novel cooling systems and efficient recovery of vapors. It is already technically possible for mills producing sugar only.

Initiatives to minimize effluent treatment may be aimed at reducing the polluting load without necessarily reducing the water flow. Jensen and Schumann (2001) presented a practical example of this in which the philosophy was to capture and re-use water in different roles (e.g. vessel wash-water for lime preparation) whilst discharging only condensate. Practical problems may include increased ash in molasses causing decreased recovery, and unacceptably high Chemical Oxygen Demand (COD) in discharged condensates due to ethanol from stale cane.

Wright and Miller (1999) provided comprehensive details of water requirements and potentials for effluent reduction in Australian sugar factories. Depending on the arrangement of water circuits and water re-use, the amount of high COD effluent produced by Australian factories ranges from 5-60 % on cane. South African factories are comparable, with an effluent flow of 25-30% on cane. These factories have no cane washing and no ethanol production. They recycle the water used for cooling and flue-gas scrubbing.
2.1.1 Sources of liquid effluents

Factory floor water
This includes spills, leaks and the hose water used to wash vessels or flush away spills and leaks. Where leaks or spills involve high Brix materials (e.g. leaking massecuite pumps) the load of COD can be considerable. The COD of massecuite is approximately 800 000 mg/kg, which means that a leak of 10 kg/h will cause the COD of final effluent to rise by 160 mg/L (i.e. well above acceptable concentration) if the final effluent flow is 50 t/h.

The impact of management on sugar loss in floor water is illustrated by Purchase et al. (1984) who monitored sucrose in this water with a continuous sampler. When the lost sucrose steadily rose to an alarming 28 t/week, all hoses were removed and replaced with flat shovels for recovering spills. This reduced the losses but could not control leaks of low Brix juices. The drains were then fitted with a sump from which spills could be recovered and returned to process. This reduced losses to less than 4 t/week (Fig. 2.1).

![Figure 2.2. Sucrose lost in floor water as affected by management actions.](image)

Although it is now common practice to operate recovery sumps, the primary management action should seek to minimize leaks and spills, because returns from sumps introduce microbes and enzymes to the process. It is obviously important to clean sumps regularly and to minimize the retention time of captured juices.

The need for constant vigilance is illustrated by Fig. 2.1, where early season checks would have indicated low losses, but subsequent high losses were probably caused by increasing leakage from seals.

Cooling water overflow
The major flow of water in a sugar factory is that associated with condensation of vapors from the evaporators and vacuum pans. This water is usually itself cooled in a spray pond or cooling tower before being recirculated. If the water is not recirculated but used on a once-through basis, then it represents a major flow to effluent.
The water always picks up some sugar through entrainment in the condensed vapors. With recycled water, this sugar inevitably causes the COD to exceed the standards required for discharge to public water. Even with once-through water the tighter standards (e.g. 75 mg/L COD) may be exceeded. With recycled water there is inevitably a surplus that overflows to effluent and represents a large portion of effluent discharge.

Entrainment separators in pans and evaporators must be well designed and maintained to prevent high COD in the cooling water. Contaminated cooling water presents an expensive effluent treatment problem if its large volume is to be discharged to public water.

If condensers are not working efficiently more water is required per unit of heat removed. It is therefore important that the condensers be carefully designed and that performance is monitored by measuring approach temperatures (i.e. the difference between input vapor temperature and the temperature of the outlet water after contact with vapor). If this temperature is more than 5 °C the system cannot be considered efficient. On a once-through system it will generate more water than is necessary.

Some water is used for cooling of bearings but the quantity is small compared to that used for condensers, and the water is usually in a closed circuit with its own cooling tower.

**Evaporator cleaning**

Evaporator cleaning may be by mechanical or chemical means. The former involves rotating cutters that remove the scale when pushed through the tubes; the latter involves boiling a chemical in the tubes to dissolve the scale. The chemical is usually mainly caustic soda, which may be augmented with the use of an acidic agent. A combination of mild chemical cleaning followed by mechanical cleaning is also possible, and may involve high-pressure water jets for the mechanical cleaning.

The high sodium content of evaporator cleaning solutions dictates that the disposal of the used solutions be carefully considered. Disposal via irrigation water can cause serious damage to soils. Attempts have therefore been made to micro-filter the used solutions to remove the dissolved sludge so that the caustic can be re-used (Chetty et al. 2002) thereby reducing the disposal problem. Use of the caustic for pH control in cooling circuits and effluent plants should be done with caution as it will inevitably produce a final effluent of unacceptable sodium content. In South Africa, one means of disposal is to tanker the used caustic to a paper factory where it is used in the paper making process before being disposed of to an ocean outfall.

Where mechanical cleaning is practiced it results in temporary high flow of rinse water. Ideally, this needs a buffering dam to smooth the hydraulic load if it is fed to an effluent plant.

**Scrubber water, ash sluicing and boiler blow-down**

When wet scrubbing is used to remove particulate matter (smuts or fly-ash) from flue gases, the resulting water is generally clarified and recirculated. Clarification may be via large settling ponds (which may also receive boiler ash) or it may be via special clarifiers from which the underflow is dewatered using filters. Modern scrubber designs minimize the use of water, using as little as 0.5 m³/t of steam produced, where older designs used about 2 m³/t steam. Despite the use of less water the efficiency of particulate removal is increased.

It is important that suspended solids from the scrubber water do not mix with the stream of effluent that passes to biological treatment because such solids displace bacteria responsible for the treatment and they affect the suspended solids content of the final effluent. Any piles of smut must be managed carefully to prevent rain from washing solids into the effluent system.
When coal constitutes a significant portion of the boiler fuel the blow-down from scrubber water will contain sulfur, which may have some adverse effects on anaerobic digestion of effluent. The microbes involved can, however, adapt to some sulfur from this source.

Boiler blow-down is usually added to scrubbing and sluicing water. Some boiler treatment chemicals contain high levels of phosphate which may create a problem if discharged to sensitive catchments. For example, the South African Special Standard for discharge to such catchments requires less than 1 mg/L of P. This requires management of the selection of boiler treatment chemicals.

Laboratory washings
The use of lead acetate for clarification of juices before pol analysis may impose an unacceptable lead load on the effluent. For this reason the filter papers that trap lead precipitates should not be rinsed to effluent but should be collected for appropriate disposal. Analytical procedures that exclude lead have become available (Simpson and Naidoo 2010) and should be adopted where possible.

Runoff from cane yards
The initial runoff of rainwater from cane yards is generally regarded as effluent and must be treated accordingly. A sump-and-weir system is needed to capture the first runnings for treatment but to divert subsequent heavy flow to a natural watercourse. The sump is sized according to the area of cane yard and depth of runnings that needs to be captured.

Similar considerations apply to rain-exposed areas that may be contaminated with co-products such as filter cake, smuts or molasses, but it is important to ensure that inert suspended matter from these sources is not diverted to an effluent plant. Bunding of smuts handling areas may be necessary to prevent the smuts from being washed to the effluent plant.

Vinasse
Vinasse is the residue remaining after ethanol has been distilled from a fermented broth. The amount produced varies according to the fermentation system but is usually about 12 L/L of ethanol produced, although this may average below 9 L/L at many Brazilian distilleries. The COD generally exceeds 30 000 mg/L and the inorganic content is high, particularly potassium (see Table 3.1 for details). The high nutrient value of vinasse makes it a valuable co-product rather than an effluent. Its distribution must however be managed carefully to avoid serious environmental effects. When added to soil the COD load is small compared to the COD in trash and roots already in the soil. Aerobic soil conditions facilitate rapid oxidation of the soluble COD from the vinasse – but if the vinasse contaminates a water body then its high COD causes depletion of oxygen.

Vinasse may be evaporated to reduce its quantity and recover water, covered in Section 3.3.2. Conventional effluent treatment technology in the form of anaerobic digestion can be applied to vinasse for recovery of energy in the form of methane. A trend towards this technology is being encouraged by opportunities to sell energy, and by recent availability of ‘off-the-shelf’ methane-based technologies. Recovery of methane does not diminish the nutrient value of the vinasse, which remains available for distribution. More details are given in Section 3.3.6.
2.2.2 Legal requirements and reporting

An example of legal requirements relating to a sugar industry is given by Kealley and Milford (2010), who list 32 items of legislation or regulation relating to the Australian industry. Much of the legislation is aimed at controlling the quality of river water that ultimately affects the Great Barrier Reef. Although the legislation is aimed mainly at agricultural activities it is clearly incumbent on sugar factories to ensure that rivers are not polluted.

Legislation in different countries is influenced by the sensitivity of surrounding ecosystems such as the Great Barrier Reef, the Everglades in Florida and the Pantanal region in Brazil. Legislation relevant to these sensitive areas may not be appropriate for countries where a small amount of plant nutrient released to rivers may have a beneficial effect (e.g. in nutrient deficient areas of Africa).

In some countries (e.g. South Africa, India and Brazil) the legislation requires minimum standards of training for operators of waste treatment plants. This improves career paths for qualified people, and has led to improved compliance with effluent discharge specifications.

Penalties for non-compliance can involve factory closure or fines. The fines are sometimes set to match the cost of proper effluent treatment, thus reducing the temptation to pay fines rather than invest in effluent treatment.

Discharge to public water

Most countries have legislation specifying the minimum standards applicable to wastewater that is discharged to public water. As an example, the most challenging standards applicable to sugar factory effluents in South Africa are given in Table 2.3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>&lt; 75 mg/L</td>
</tr>
<tr>
<td>Oxygen absorbed (OA)</td>
<td>&lt; 10 mg/L</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>&lt; 25 mg/L</td>
</tr>
<tr>
<td>Lead</td>
<td>&lt; 0.1 mg/L</td>
</tr>
<tr>
<td>Sodium</td>
<td>&lt; 90 mg/L increase over intake water</td>
</tr>
</tbody>
</table>

The biggest challenge in meeting such standards is the removal of dissolved sugar that appears as COD. In accordance with the equation below, the oxidation of 342 g of sucrose requires 384 g of oxygen.

$$C_{12}H_{22}O_{11} + 12 \text{ O}_2 = 12 \text{ CO}_2 + 11 \text{ H}_2\text{O}$$  \hspace{1cm} (2.1)

Being in solution, the sugar is readily available to bacteria, thereby creating a rapid oxygen demand that depletes dissolved oxygen in a receiving river. The release of untreated effluent to a river is, therefore, likely to cause death of aquatic organisms through oxygen starvation.

Chemical Oxygen Demand is measured by exposing the effluent to strong chemical oxidation in a reaction requiring about 2 h for complete oxidation of all organic matter. In nature, the oxidation is mediated by biological organisms and is much slower, particularly for insoluble materials such as bagasse. The COD measurement gives a good indication of total organic load but it does not reflect the rate at which oxygen will be depleted by biological oxidation in a river – i.e. COD does not
accurately reflect the immediate impact of adding the effluent to a river. For this reason some countries (Table 2.4) prefer to specify standards in terms of biological oxygen demand (BOD), which is measured by incubating the effluent with bacteria for five days and measuring the oxygen demand (expressed as BOD5 if the incubation period is five days).

For sugar the BOD5 is almost equal to COD, but for bagasse the BOD5 is a small fraction of COD because the bagasse is not readily digested by bacteria in five days. In fresh factory effluent the BOD5:COD ratio is generally about 1:2 but this ratio increases to about 1:5 as the readily digestible components are oxidized. A disadvantage of using BOD for specification purposes is that the measurement takes too long to be of real value for control purposes. Oxygen absorbed (OA) is a quick (4 h) measurement that uses weak chemical oxidation to assess the content of readily oxidizable material in the effluent. The result is generally closer to BOD than COD but is not a reliable substitute for BOD.

Although the COD and BOD standards are the most challenging for sugar factories the other standards cannot be ignored. For example, the use of lead acetate in laboratories may cause the lead standard to be exceeded, and sodium hydroxide used for evaporator cleaning may require special disposal to meet sodium standards.

A comparison of specifications for different countries is presented in Table 2.4. Most countries initiated their effluent discharge standards between 1970 and 1990 and have made changes as circumstances change, so Table 2.4 should be regarded as indicative rather than definitive. In addition, some countries (e.g. South Africa) have different standards for different catchment areas.

Table 2.4. Standards for effluent discharged to public water (Purchase 1995 updated).

<table>
<thead>
<tr>
<th>Country</th>
<th>COD</th>
<th>BOD</th>
<th>Solids</th>
<th>P</th>
<th>Soap &amp; oil</th>
<th>Pb</th>
<th>Na</th>
<th>pH</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>20</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.5-8.0</td>
<td>1*</td>
</tr>
<tr>
<td>Colombia</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.0-9.0</td>
<td>40</td>
</tr>
<tr>
<td>India</td>
<td>100</td>
<td>100</td>
<td>5</td>
<td>10</td>
<td>0.1</td>
<td></td>
<td></td>
<td>5.5-9.0</td>
<td>5*</td>
</tr>
<tr>
<td>Indonesia</td>
<td>200</td>
<td>30</td>
<td>175</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td></td>
<td>6.5-8.5</td>
<td></td>
</tr>
<tr>
<td>Jamaica</td>
<td>100</td>
<td>30</td>
<td>50</td>
<td>5</td>
<td>10</td>
<td>0.1</td>
<td>100</td>
<td>6.5-8.5</td>
<td>37</td>
</tr>
<tr>
<td>Mauritius</td>
<td>100</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.0-9.0</td>
<td>40</td>
</tr>
<tr>
<td>Philippines</td>
<td>100</td>
<td>50</td>
<td>70</td>
<td>0.4</td>
<td>5</td>
<td>0.5</td>
<td></td>
<td>6.5-8.5</td>
<td>3*</td>
</tr>
<tr>
<td>Reunion Island</td>
<td>125</td>
<td>30</td>
<td>35</td>
<td>10</td>
<td>10</td>
<td>0.5</td>
<td></td>
<td>5.5-8.5</td>
<td>30</td>
</tr>
<tr>
<td>South Africa</td>
<td>75</td>
<td>25</td>
<td>1**</td>
<td>2.5</td>
<td>0.1</td>
<td>90*</td>
<td></td>
<td>5.5-9.5</td>
<td>35</td>
</tr>
<tr>
<td>Thailand</td>
<td>60</td>
<td>30</td>
<td></td>
<td></td>
<td>5</td>
<td>0.2</td>
<td></td>
<td>5.0-9.0</td>
<td>40</td>
</tr>
</tbody>
</table>

*** Standards apply to UNFILTERED samples  ** Special Standard applicable to sensitive catchments  *

*Maximum rise above intake concentration or temperature

The monitoring of compliance varies according to local regulations and agreements but there is generally a requirement for routine analyses to be performed, with results being periodically submitted to the authority responsible for enforcing compliance. Where discharge is to public water the COD should be analyzed daily. As evidence of good management there is a trend towards voluntary periodic independent professional auditing of treatment systems, with samples being analyzed by independent accredited laboratories.
Although there is no absolute measurement for odor it is the parameter most likely to cause complaints from affected communities. Most regulations have a general requirement that the discharged effluent does not cause offensive odor.

**Irrigation-related legislation**

When effluent is used for irrigation the COD is not a problem for soils but care is necessary to ensure that untreated effluent does not run off to public water, and that there are no offensive odors. This runoff is a particular problem during rainy periods or during break-down of the irrigation system. There is, therefore, often a requirement for a holding dam to retain the effluent during such periods. In South Africa the dam must be sized to hold approximately ten days of effluent flow.

If the effluent contains some treated sewage there may be a disease threat to agricultural workers and to people consuming the irrigated products. This is controlled by imposing a standard on fecal coliform levels and by guidelines (e.g. World Health Organization 2006) relating to use of such effluents on different crops. Sugarcane is one of the least sensitive crops because it is processed before consumption.

**2.2.3 Treatment technologies**

**Irrigation**

If suitable land is available the best option for disposal of sugar factory effluent is irrigation. Legal requirements mentioned above need to be complied with and it is recommended that water and soil samples be taken to monitor any detrimental accumulation of salts. In most circumstances disposal of sugar factory water by irrigation has a beneficial effect on the receiving cane. Putrefied effluent may however contain sufficient organic acids to ‘burn’ sensitive crops.

To avoid offensive odors and crop damage the effluent should be irrigated whilst still fresh (assuming that it is not too hot for the receiving vegetation). It is sometimes assumed that holding the effluent for a few days prior to irrigation ensures that it is partly treated before irrigation. In practice, with sugar factory effluents, any such retention causes anaerobic conditions with resulting accumulation of odoriferous organic acids (mainly acetic, butyric and valeric) which are volatile at low pH and are particularly odoriferous if distributed via overhead irrigation. An example of acid build-up in a holding dam is provided by Purchase and Perrow (1983), who monitored a holding dam for six months and found that the inlet organic acid content averaged about 100 mg/L while the outlet averaged above 750 mg/L. This dam, with its associated overhead irrigation, caused considerable complaints relating to odor. In another instance (unpublished) odor from an irrigation system was controlled by building a small dam within the main dam and then operating with the main dam empty. Effluent pumped to the small dam was pumped to irrigation within hours instead of days.

**Biological treatment**

Biological treatment is used for the treatment of domestic effluents and many industrial effluents, including those from sugar factories. The historical development of this technology has related mainly to domestic effluents. In general, the design criteria for domestic effluents can be applied to sugar factory effluents, but there are three important differences:

1. Domestic effluents contain an excess of nitrogen and phosphorous, which must be removed by incorporating special nutrient removal stages in the effluent plants. By contrast, sugar factory effluents contain too little nitrogen and phosphorous to support adequate growth of the biological organisms (sludge) that digest the effluent. It is therefore essential to add nitrogen and phosphorous to these effluents.
2. The COD in sugar factory effluents is soluble, whereas a large portion of the COD in domestic effluents is in solid form. The scarcity of solid matter in sugar factory effluents has the consequence that the growing sludge is not attached to solid particles and is therefore inclined to form ‘bulking sludge’ which escapes from the system because it does not settle in the clarifiers. Bulking sludge is the major operational problem faced by many industrial effluent plants.

3. The COD of sugar factory effluent is 2-4 times that of domestic sewage (after simple settling). Biological treatment falls into two major categories – anaerobic and aerobic. Both options are applicable to sugar factory effluents and are usually used in combination. The advantages and disadvantages of these options are compared in Table 2.5.

<table>
<thead>
<tr>
<th>Table 2.5. Comparison of anaerobic and aerobic digestion.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anaerobic</strong></td>
</tr>
<tr>
<td>Does not require mechanical aeration, thereby saving capital and running costs.</td>
</tr>
<tr>
<td>At COD concentrations below about 2000 mg/L the volumetric activity is so low that enclosed reactors cannot be justified. Open dams with very low volumetric activity are used. May produce offensive odors. Not economical for reducing COD below about 200 mg/L and therefore requires a subsequent aerobic stage if a low COD is required. Produces relatively little sludge per unit of COD removal thereby saving on sludge disposal costs. Requires relatively little N and P for sludge growth; this being particularly advantageous for sugar factory effluents because of the deficit of N and P. A two-stage process with the second stage being mediated by specialized, slow growing and delicate bacteria that cause slow start-up and high sensitivity to toxins and operating disturbances. If the two stages are not in balance the acids produced by the first stage inhibit the second-stage bacteria. Produces methane which has value as a fuel. Well suited to very high COD concentrations. With high COD concentrations the COD removal per unit volume is higher and less costly than that with aerobic digestion.</td>
</tr>
</tbody>
</table>

**Anaerobic digestion**
From Table 2.5 it is evident that anaerobic digestion is not well suited to the low concentration (1 500 - 2 500 mg/L COD) produced by most raw sugar factories. It is, however, commonly used because storage dams are needed to buffer the erratic flow from the factories. Despite the fact that these dams are open they are anaerobic through most of their depth because the effluent contains sufficient sugar to ‘stoke the microbial furnaces’ and thereby deplete dissolved oxygen. The existence of these anaerobic conditions makes it logical to optimize conditions for anaerobic
digestion. As mentioned previously (Section 2.1.5) some of the methane produced in open dams is consumed in the aerobic surface layers by methanotrophs, so methane emissions from open dams are lower than from equivalent COD in closed reactors.

**Design of open anaerobic dams.** Distinction should be made between dams intended to hold effluent prior to aerobic treatment and those holding effluent prior to irrigation. As mentioned earlier, the latter should be maintained in a near empty state so as to ensure minimum residence time and maximum spare capacity for temporary storage when irrigation is not operating. Where the dams precede an effluent treatment plant they should incorporate the following design features:

- Silt trap to minimize long term volume reduction due to silting. The traps usually consist of two small dams that are used alternately, with one being desludged while the other is in operation.
- Valve-controlled outlet (not simple overflow) with a screen. This enables the dams to be routinely run at below full capacity so that they can smooth out erratic flows due to evaporator draining and cleaning, for example. The screen is necessary to prevent debris (e.g. leaves and plastic bags) from entering the downstream reactors.
- Sized for loading of no more than 0.08 kg COD/m³/d. This loading may seem extremely low in comparison with the 20 kg COD/m³/d that is possible with sophisticated, enclosed reactors handling concentrated effluents, but it is a figure confirmed in a variety of circumstances (e.g. Cox and Hemens 1970). Exceeding this loading inevitably results in poor COD removal, high lime consumption and odor.
- Maximum mixing rather than plug flow. Plug flow effectively creates overloading at the inlet which results in acidified effluent passing through the system and preventing active growth of methanogens. For this reason a single large pond (or ponds in parallel) is better than ponds in series. To encourage mixing, the incoming effluent (warm) should be released at the base of the pond and from a number of inlets, each of which is large enough to prevent blockage by foreign objects (e.g. plastic bags). If it is released to the top there is a danger of thermal layering and short-circuiting.

If these design features (Figure 2.2) are applied it is normally possible to remove 50-60 % of the COD from the effluent but with overloaded, poorly designed dams the removal is less than 10 %.
Ash-filled anaerobic dams. Vermeulen and Vawda (1989) reported a situation where effluent was combined with boiler ash and smuts that were hydraulically transported to a landfill dam. The dam was designed such that water for recycling had to pass through the ash deposit before it returned to the factory. The return water had sufficiently low COD to meet the standard (75 mg/L) for discharge to public water. On further investigation, involving cores of ash incubated in a laboratory with added sugar, it was concluded that the ash dam was effectively a packed anaerobic reactor exhibiting a COD removal rate of approximately 0.6 kg/m³/d. The active microbes were located mainly on the carbonaceous smuts rather than the inorganic ash.

The success of this system depends on having a sufficiently large ash deposit through which the effluent must flow. This takes a few years to accumulate. Simply adding ash to an anaerobic dam will not meet the flow-through requirement and will reduce the effective volume of the dam. The successful system is more stable and of lower volume than conventional anaerobic dams and it may offer a complete treatment system without the requirement for aerobic finishing. Govender (2001) reported on the long term performance of one such system, noting that success depended on use of corrosion-resistant piping, addition of nutrients and some inflow of rainwater to dilute dissolved salts. Note that this effluent treatment system is suitable only for dilute effluents, not vinasse. Methane emissions are ameliorated by methanotrophic organisms that live in the aerated zones and consume methane.

High-rate enclosed anaerobic reactors. Where ethanol is produced the distillery effluent (vinasse) has a COD concentration high enough to justify capital expenditure on sophisticated, enclosed reactors. Some details of this technology are given in Section 3.3.6.

Aerobic digestion
Aerobic systems fall into the following categories:

- High rate
  - Activated sludge plants
- High rate trickling filters.
- Extended aeration
  - Aeration ditches (e.g., Pasveer ditches)
  - Low rate trickling filters in polishing mode
  - Aeration ponds.

**Activated sludge.** This involves a tank and a clarifier. High rate aeration takes place in the tank thereby enabling sludge to grow actively. Treated liquor and sludge from the tank is settled in the clarifier. Most of the settled sludge is then returned to the aeration tank but some sludge is disposed of so as to diminish the average age of the sludge and thereby ensure high activity. The sludge disposal may involve drying the sludge over a bed of sand in drying beds but if an anaerobic dam is available the sludge is pumped to the dam where it is digested and the nutrients recycled.

When treating sugar factory effluents a common problem with activated sludge plants is that the sludge develops so-called ‘bulking sludge’ characteristics and will not settle properly. The sludge escapes from the system, causing significant reduction in treatment capacity. The causes of bulking sludge are not well understood, and it is particularly a problem with soluble effluents such as those from sugar factories. It usually involves a change in the composition of the microbial flora. Control of bulking sludge has sometimes involved the drastic action of chlorination to kill the sludge. The problem can often be controlled by turning off the aeration system for an hour each day. The resulting anaerobic conditions inhibit the bulking organisms. The addition of flocculants may help to settle some types of bulking sludge.

A design feature that assists in the control of bulking sludge is to have two aeration tanks in series with the first tank never receiving return sludge. This may reduce the maximum capacity of the system but it generally improves the long term average capacity in cases where bulking sludge would otherwise be a problem. The design loading for activated sludge plants is based on volume but during operation the major factor controlling tolerable load is the sludge concentration. This means that the loading in terms of COD/mixed liquor suspended solids (MLSS) is the critical loading parameter. It highlights the adverse effect of bulking sludge and the benefit of having some control over the loading released from upstream anaerobic dams.

The sizing of clarifiers should be generous to minimize the escape of bulking sludge.

**High rate trickling filters.** These consist of tanks filled with packing material, usually crushed rock. The wall and base of the tank have an air inlet and distribution system (driven by natural convection). Rotating radial arms distribute effluent onto the packing and it trickles through the packing against a counter-current of rising air. The advantage of such a system is that the sludge is attached to the packing material so there are no problems of bulking sludge, but the packing is inclined to choke, especially if effluent is contaminated with smuts. Furthermore, if a trickling filter is preceded by an overloaded anaerobic dam into which lime is added for pH control, then the trickling filter is presented with calcium salts of organic acids. Carbon dioxide generated in the trickling filter causes precipitation of calcium carbonate, which contributes to choking of the system.

When used in the high rate mode, trickling filters grow sludge rapidly and this can contribute to choking. Packing material with a high void space is therefore necessary and there is a requirement for a minimum hydraulic loading to flush out solids, including the sludge (called humus) that peels off the packing (Bruijn 1975). Part of the runoff from the filter is recirculated to ensure adequate flow. Filters showing signs of choking can sometimes be cured by restraining the rotating distributor so that it deposits to a fixed area and flushes that area.
The choice of packing material and its sizing is obviously important in minimizing the propensity for choking. Hollow plastic fill is very effective but expensive. Crushed stone of 75-150 mm is the most common fill for high rate filters but it has a void space of only 53 % compared with 94 % for the hollow plastic material, and it has a relatively low surface area (40 m$^2$/m$^3$ vs. 200 m$^2$/m$^3$) (Bruijn 1975). Microbial activity in the filter is strongly correlated with surface area of packing material. This should be taken into account when pricing fill because fill that is expensive per unit volume will require less volume to achieve equivalent activity.

Although trickling filters are not commonly used for sugar factory effluents they do offer some advantages (discussed later). Proper design and operation is critical.

_Aeration ditches_. These consist of a racetrack-shaped ditch around which the effluent is circulated while being aerated. The aeration is less vigorous than with activated sludge and the retention time is longer (2-3 days). The aerators have the dual function of dissolving air in the effluent and moving the effluent round the ditch with sufficient velocity (30 cm/sec) to keep the sludge in suspension. The ditch is usually about 2 m deep and has internal clarifiers created by dividing a length of the ditch with a central wall. Gates on each side of the wall close alternately so that the effluent flows through the open gate while settling in the area in front of the closed gate. After a period of settling, automated valves allow release of clarified effluent from near the top of the clarifier. Settled sludge is resuspended when the gate opens.

The extended retention time enables dead sludge to digest within the plant, making it unnecessary to have sludge drying and disposal facilities. Sludge is pumped out during off-crop to prevent long term accumulation of inorganic sludge (grit).

Various types of aeration devices are used. Older devices tended to waste energy on excessive movement of the effluent. Some such devices have rows of fingers attached to a horizontal shaft situated slightly above the effluent. As each row hits the surface it imposes a shock on the gearbox resulting in short gearbox life. Modern devices involve perforated discs revolving on the shaft. The discs have small lugs on them designed to move the effluent at no more than the required speed. The associated gearboxes operate smoothly with minimum wear.

_Low rate trickling filters_. When operating as polishing filters, trickling filters have to be operated with relatively low loads and therefore at low rates. The lower rates mean that less sludge is produced and smaller packaging material can be used without being choked by sludge growth. Sometimes trickling filters are operated in series, with the first being high rate and the second low rate.

_Aeration ponds and artificial wetlands_. Aeration ponds are shallow ponds where the effluent can ‘mature’ before final release. They inevitably support vegetation that helps to remove nutrients and to add oxygen. The COD loading must be sufficiently low to prevent development of overall anaerobic conditions.

Artificial wetlands are constructed such that applied effluent is caused to percolate through a permeable matrix (e.g. sand) that supports plant growth. A combination of filtration and microbial digestion removes COD from the effluent, under aerobic conditions. Attempts to treat sugar factory effluent in artificial wetlands were reported by Schumann (1991), who found that COD removal was good but the surface of the wetland tended to choke and limit the flow capacity to sub-economic levels. The COD input concentrations were usually of the order of 1 400 mg/L, which is well above the concentration (< 3 00 mg/L) which might be used in maturation systems.
Settling ponds for cane wash-water. The purpose of these ponds is to settle out soil washed from cane so that the water can be re-used. The ponds may be partly anaerobic.

Case studies on the integration of anaerobic and aerobic systems
Huang et al. (1995) conducted laboratory and full scale tests on a baffled reactor in which the first four stages were anaerobic and the last four stages were well aerated. Their detailed analyses of each stage showed the accumulation of organic acids in the first four (anaerobic) stages with an accompanying decline in pH to below 5, emission of odor and only 24% removal of COD. During passage through the subsequent aerobic stages the pH rose to 7, odor disappeared and the total COD removal reached 97%. This study illustrates the limited value of anaerobic digestion under overloaded conditions.

Govender (1992) reported on an effluent plant involving an open anaerobic dam feeding into an aeration ditch. The anaerobic dam was loaded at 0.08 kg COD/m$^3$/d and performed well with 50-60% COD removal, no excessive odor and no need for liming. Apart from periodic problems with bulking sludge in the aeration ditch, the plant performed well until the factory capacity was increased and the load to the effluent system increased accordingly, such that the anaerobic dam was overloaded. The dam became acid and odoriferous with less than 10% removal of COD. The aeration ditch was unable to reduce the COD to the required standard. The situation was remedied by installing a high-rate trickling filter between the dam and the aeration ditch but with part of the outlet from the filter being returned to the anaerobic dam. The purpose of this return was to ‘detoxify’ the dam by using aerobic digestion (in the filter) to remove organic acids, which otherwise accumulated to inhibitory levels. The removal of acids raised the pH of the effluent by one unit across the filter and eliminated odor from the anaerobic dam. Expensive liming of the dam was no longer necessary and the plant consistently achieved the 75 mg COD/L target. An additional advantage of the filter was that humus that washed off the packing provided solid material to the aeration ditch thereby improving the settling characteristics of the sludge.

Operating parameters and guidelines for biological treatment systems
The fundamental requirements are to:

- Grow sludge
- Retain adequate sludge in the system and keep it in good condition
- Ensure adequate dissolved oxygen in the aerobic stages
- Avoid over-feeding the sludge, especially at the anaerobic stage.

Definitions and abbreviations for various useful measurements are summarized in Table 2.6.
Table 2.6. Parameters and target values for managing various types of sugar factory effluent plants.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition and use</th>
<th>Target values*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Plant type</td>
</tr>
<tr>
<td>MLSS</td>
<td>Mixed liquor suspended solids (g dry sludge/L of mixed liquor). An important indicator of sludge availability.</td>
<td>2 000</td>
</tr>
<tr>
<td>MLVSS</td>
<td>Mixed liquor volatile suspended solids, i.e. MLSS after subtracting the ash content (g dry/L of mixed liquor).</td>
<td>1 600</td>
</tr>
<tr>
<td>MLVSS/MLSS</td>
<td>A ratio reflecting the extent of sludge contamination with inorganic matter.</td>
<td>&gt; 0.8</td>
</tr>
<tr>
<td>SVI</td>
<td>Sludge volume index (mL occupied by 1 g of sludge (dry basis) after settling for 30 min). The measurement can be a valuable indicator of impending sludge bulking.</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>COD:N:P</td>
<td>The ratio of COD to nitrogen (N) to phosphorous (P). A valuable measurement during the start-up of a plant for deciding how much N and P to add for growing the sludge. Anaerobic organisms produce less sludge than aerobic organisms per unit of COD consumed, so the ratio is different for anaerobic and aerobic stages. Recommended ratios are 100:1:0.2 for anaerobic and 100:2:0.4 for aerobic. After start-up much of the nutrient is recycled, meaning that nutrient addition should not be based on COD addition but can be much less than the above ratios, depending on sludge wasting and whether the sludge is wasted to the anaerobic stage.</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>Sludge production (kg/kg COD consumed).</td>
<td>0.2</td>
</tr>
<tr>
<td>F:M ratio</td>
<td>Food: microorganism ratio (kg COD/kg MLSS (dry)/d).</td>
<td>0.2</td>
</tr>
<tr>
<td>Volumetric consumption</td>
<td>COD consumed/unit volume/d (kg/m³/d). Useful as a loading guide/check. It depends on MLSS and F:M ratio.</td>
<td>0.4</td>
</tr>
<tr>
<td>Aeration energy</td>
<td>Energy required for aeration equipment (kWh/kg COD load). Varies widely depending on COD concentration and MLSS but 0.8 is a general guide.</td>
<td></td>
</tr>
</tbody>
</table>

* These target values are derived from various sources and observations and do not necessarily match figures derived from domestic effluent, which are often in terms of BOD rather than COD used here.
** Fast = high rate trickling filter. Slow = slow rate (polishing) trickling filter.

Separation of oil
When the prime movers in sugar factories were steam engines, the oil in untreated effluent regularly exceeded discharge specifications. A simple oil removal method was to pass the effluent through a channel containing floating bagasse which absorbed the oil. More sophisticated methods include oil skimmers used in conjunction with stilling wells that collect washings from oil prone areas, e.g. milling tandems.

Effluent from modern sugar factories is less likely to require special oil removal techniques because modern oil seals are more efficient. It is also claimed (Perfetti and Alonso 2010) that modern
lubricants for mill brasses are less prone to leakage and are biodegradable. Conventional effluent treatment removes some of the biodegradable lubricants, although lubricant loss rates measured by Perfetti and Alonso suggest that the oil content of fresh, untreated effluent will exceed the specifications applicable in some countries. The bearing cooling water circuit, therefore, often includes an oil trap (Wright and Miller 1999).

The increasing use of hydraulic mill drives and hydraulic screen movers in diffusers requires care in the management of hydraulic oils.

**Odor**

Odor is the least measurable but most noticeable of problems associated with effluent treatment. The major sources of odor are overloaded anaerobic dams and irrigation systems that distribute effluent that has been held for a few days. Management of the problem involves proper sizing of anaerobic dams, liming of overloaded dams to convert volatile (odoriferous) organic acids into non-volatile salts, adding floating aerators to overloaded dams to oxidize the organic acids, and irrigating with fresh effluent rather than stored effluent.

### 2.2.4 Summary and good practice recommendations

**Box 2.1 Management of waste water and other liquid effluents**

- The primary management action for liquid wastes is to reduce the quantities by paying close attention to water management.
- Major sources of liquid effluents are:
  - Condenser water
  - Floor water, consisting of floor and equipment washings and spills
  - Scrubber water (if using wet scrubbers)
  - Boiler blow-down
  - Contaminated first runoff of rain from cane yards.
- Most countries have strict legislation defining standards that treated effluent must attain before discharge to public water.
- Dissolved sugar is the main problem component. It is measured in terms of its oxygen demand because it is this demand that causes oxygen depletion in receiving waters.
- Effluent treatment is focused on the removal of oxygen-demanding components from the effluent. This is achieved by biological means, usually involving a combination of anaerobic and aerobic systems. Details of design and operating parameters for such systems provided here.

### 2.3 Management of dust/particulate emissions

Dust may be generated in a number of areas in a sugar mill. Unloading and handling of cane can sometimes lead to dust if the cane is dry and dirty, but such dust generation is intermittent and represents no serious workplace problem. Dust may also be generated from unpaved roads, which is often mitigated by spreading of molasses or vinasse on the unpaved roads.

The most common problem in a sugar mill is the generation of dust from handling bagasse, if the handling system is not designed properly. Fall-out of soot/unburnt bagasse from boiler stacks is less common than in the past, with most countries imposing adequate standards for boiler emissions. Finally sugar dust may be a problem, particularly in refineries, where the sugar is dry and solid handling systems are substantial in packing and loading stations. None of these represent any threat to the environment, but may have unpleasant consequences for factory personnel.
2.3.1 Boiler emissions regulations

Regulations governing stack emissions vary significantly from country to country and even from state to state within a country. They are likely to become more stringent over time. Only particulate emissions are regulated in most sugar growing regions. In countries such as the USA and France, regulations are in force governing CO, NO\textsubscript{x}, SO\textsubscript{x}, volatile organic compounds and heavy metals emissions as well.

Particulates in sugar mill boiler gas consist almost entirely of carbon and so are not as hazardous to health as some other process industry emissions.

Stack emission concentrations are defined in three ways; either in terms of volume or mass per unit volume of flue gas or as a mass per unit energy input to the boiler. The third has the advantage that it is an absolute measurement. For the first two to be of value, they must be referred to a standard excess air concentration. Unfortunately different standards are in use in different parts of the world making it difficult to compare numbers. The problem is further compounded by the fact that some concentrations are referred to the wet gas analysis and some to the dry gas analysis. Typical emission standards in various countries are given in Table 2.7.

Table 2.7. Examples of particulate emission standards for bagasse boilers.

<table>
<thead>
<tr>
<th>Standard (mg/Nm\textsuperscript{3})*</th>
<th></th>
</tr>
</thead>
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<tr>
<td>Australia, license limit for dry collectors (2005)\textsuperscript{1}</td>
<td>700</td>
</tr>
<tr>
<td>Australia, license limit for wet scrubbers (2005)\textsuperscript{1}</td>
<td>250</td>
</tr>
<tr>
<td>Australia, for new boilers, after 1990 (2005)\textsuperscript{1}</td>
<td>250</td>
</tr>
<tr>
<td>South Africa (2001)\textsuperscript{2}</td>
<td>200</td>
</tr>
<tr>
<td>Brazil, old boilers (2010)\textsuperscript{6}</td>
<td>350</td>
</tr>
<tr>
<td>Brazil, new boilers &lt; 75 MW (2010)\textsuperscript{6}</td>
<td>230</td>
</tr>
<tr>
<td>Brazil, new boilers &gt; 75 MW (2010)\textsuperscript{6}</td>
<td>200</td>
</tr>
<tr>
<td>India, step grate boilers (2010)\textsuperscript{4}</td>
<td>250</td>
</tr>
<tr>
<td>India, horse shoe/pulsating grate boilers (2010)\textsuperscript{4}</td>
<td>500</td>
</tr>
<tr>
<td>India, spreader-stoker boilers (2010)\textsuperscript{4}</td>
<td>800</td>
</tr>
<tr>
<td>Thailand (2007)</td>
<td>320</td>
</tr>
<tr>
<td>Mauritius (1999)\textsuperscript{5}</td>
<td>400</td>
</tr>
<tr>
<td>Malaysia (1999)\textsuperscript{3}</td>
<td>400</td>
</tr>
<tr>
<td>World Bank, for project funding (2010)\textsuperscript{5}</td>
<td>50 – 150</td>
</tr>
</tbody>
</table>

* Usually corrected to 12 % by volume CO\textsubscript{2}. Brazil based on dry gas at 8 % excess air.

\textsuperscript{1} Heron and Traicos (2005); \textsuperscript{2} Wienese (2001); \textsuperscript{3} Lora and Jativa (1999); \textsuperscript{4} Srinivasan, personal communication 2010; \textsuperscript{5} the upper limit only if justified by environmental assessment; \textsuperscript{6} Marino, personal communication 2010.

2.3.2 Removal of particulates from boiler flue gas

Whilst the particulate emission concentration leaving a bagasse fired boiler normally varies from about 4 000 to 12 000 mg/Nm\textsuperscript{3}, figures as high as 24 000 mg/Nm\textsuperscript{3} have been recorded. The emission rate is a function of:

- Fuel ash content
- Fuel moisture content
- Fuel size grading
- The type and rating of the grate
• The type and design of the furnace
• Boiler load.

Particles vary in size from pieces of charred bagasse measuring around 1.5 mm diameter x 6 mm long, to dust particles as fine as less than one hundredth of the thickness of a human hair in diameter.

Three different ways of removing particulates from flue gases in sugar mill boilers are used. These are:

• Cyclone collectors
• Wet scrubbers
• Electrostatic precipitators (ESPs).

Different types of dust collectors and operating results have been reported by Moor (2007) and Lora and Jativa (1999). Table 2.8 schedules the approximate collecting efficiencies of the types of particulate collectors with their approximate power consumptions (Magasiner 2007).

<table>
<thead>
<tr>
<th>Type of collector</th>
<th>Comment</th>
<th>Approx. ΔP (Pa)</th>
<th>Power absorbed per m³/s hot gas</th>
<th>Efficiency (%)</th>
<th>Outlet burden (mg/Nm³ at 12 % CO₂ dry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal multi-cell cyclones</td>
<td>300 mm diameter cells</td>
<td>350 to 650</td>
<td>~ 0.8 kW (fan)</td>
<td>80 to 85</td>
<td>500 to 2 000</td>
</tr>
<tr>
<td>Vertical multi-cell cyclones</td>
<td>250 mm diameter cells</td>
<td>650 to 800</td>
<td>~ 1.5 kW (fan)</td>
<td>90 to 94</td>
<td>400 to 800</td>
</tr>
<tr>
<td>Wet gas scrubber</td>
<td>Saturated gas at about 70 °C at outlet</td>
<td>750 to 1 800</td>
<td>~ 3.0 kW (fan and pump)</td>
<td>98 to 99</td>
<td>60 to 150</td>
</tr>
<tr>
<td>ESP with primary collector</td>
<td>Primary collector horizontal multi-cell or non-saturating gas scrubber</td>
<td>650 to 1 100</td>
<td>~ 2.5 kW (fan and fields)</td>
<td>99 to 99.95</td>
<td>20 to 100</td>
</tr>
</tbody>
</table>

**Cyclone collectors**

Because the efficiency of a cyclone collector is inversely proportional to its cell diameter (i.e. the smaller the diameter the higher the efficiency) best performance is obtained by arranging small diameter cells (250 to 300 mm) in banks called multi-cyclone collectors. Vertically mounted cells are generally more efficient than horizontal ones but tend to be larger and more expensive.

The efficiency of a cyclone collector is proportional to the pressure drop across it. However, because the pressure drop is a function of $u^2$ ($u$ is the gas velocity) and wear is a function of $u^{3.5}$, it follows that there is a very definite limit to the efficiency that can be achieved without incurring excessive wear. The problem is further complicated by the fact that larger char particles break down into smaller ones when passing through cyclone collectors, making them even more difficult to collect.
High efficiency cyclones will usually not get the dust concentration much below 700 mg/Nm\(^3\) (Moor 2007), although this is achieved in some Australian mills. For cyclone collectors to work effectively their dust discharges must be properly sealed against air ingress and must be well-maintained to ensure no gas leaks. Larger diameter cyclones arranged in banks must discharge into independently sealed systems to prevent gas recirculating from one cell to another.

Possible techniques to minimize boiler stack emissions from boilers fitted with dry dust collectors include (Lloyd et al. 2009):

- Maintaining the boiler plant to ensure the dry dust collector systems operate as per design specifications.
- Ensuring the dust collector system matches current boiler operational load rather than design MCR.
- Tuning the boiler plant to minimize the dust collector inlet particulate levels. This will in turn reduce the outlet particulate levels.
- Retrofitting a hopper evacuation system to increase the collection efficiency of the dry dust collector system.

However, each boiler at each site has its own particular design and operational idiosyncrasies and must therefore be considered individually when determining the preferred approach to minimize dust collector emissions.

**Wet gas scrubbers**

There are several types of wet gas scrubbers available. The most common are:

- Impingement (‘bath’ type) scrubbers
- Venturi scrubbers
- Fixed vane scrubbers
- Perforated (sieve) plate scrubbers
- Constant Δ\(p\) or ‘variable throat’ cyclonic scrubbers.

There are a number of investigations into the performance of wet scrubbers that indicate that they are capable of consistently reducing particulates content to < 100 mg/Nm\(^3\), and in some cases considerably less. Wet scrubbers on the high pressure boilers in Guatemala result in boiler gas with particulates content between 50 and 70 mg/Nm\(^3\).

The fixed vane scrubber, perforated sieve plate scrubber and the variable throat scrubber are widely used in the sugar industry. The fixed vane scrubber has a limited turndown range. Pennington (1999) reports that turndown of a single unit is limited to 75 % of MCR. Two or more units must therefore be installed if emission limits are to be maintained over a reasonable operating range. The sieve plate unit is the least expensive and, although Magasiner (2007) suggest its turndown is also limited to about 75 % of MCR, Moor (2007) claims good turndown for these units. Magasiner (2007) reports that the variable throat scrubber is able to accommodate larger load swings, capable of operating efficiently down to about 30 % MCR. Its nozzles, which are about 15 to 20 mm in diameter, are prone to choking if there is a high percentage of suspended solids in the water supply. Sieve plate and fixed vane scrubbers have larger nozzles.

To minimize mist carry-over, efflux velocity must be less than 2.5 to 3.0 m/s at MCR, or additional internals are required to eliminate entrainment.
The temperature of the gas leaving a scrubber will vary from about 68 to 72 °C, depending on the moisture in the bagasse, the gas temperature, the quantity of water used per unit volume of hot gas entering the scrubber, and the temperature of the water entering and leaving the scrubber. Between 0.7 and 0.9 L of water is used per m³ of hot gas entering a scrubber. The amount of water evaporated is also a function of these parameters. As a rule of thumb, if the difference between the inlet and outlet scrubber water temperature is 20 °C, the scrubber evaporation rate will vary from about 2.0 % of boiler MCR for the higher flow rate, to 3.3 % for the lower flow rate. If the temperature difference is zero, the evaporation rate will be about 7.5 % of MCR.

Electrostatic precipitators
Electrostatic precipitators (ESPs) are very bulky and costly pieces of equipment. There are only a limited number of them presently operating in the cane sugar industry. They are installed in areas where very stringent emission limits are in place. Frequently these installations are subject to continuous emissions monitoring by state authorities. ESPs use two sets of electrodes that are insulated from each other to collect dust. The collecting electrodes are grounded. The discharge electrodes operate at a high DC voltage (60 to 120 kV). Plate type collecting electrodes and tube type discharge electrodes are commonly used. The performance of an ESP is sensitive to gas velocity, particle resistivity (the higher the resistivity the lower the efficiency), gas humidity and gas temperature. Efficiency increases with increasing humidity and decreases with increasing gas velocity and gas temperature. When burning bagasse, the low resistivity of the carbon dust causes current to flow to ground before it can charge the particles. To avoid emission spikes caused by the sudden release from electrodes of collected carbon particles, either a cyclone collector or a nonsaturating gas scrubber must be installed in series with an ESP to remove the larger carbon and char particles.

As a rule of thumb, the efficiency, $\eta$, per field of an ESP is about 85 %. For a two-field machine, therefore the efficiency can be calculated as follows:

$$[(100 - 85) - (85/100 \cdot 15)] = 2.25 \% \text{ and hence } \eta = 97.75 \% \quad (2.2)$$

For a three-field machine the efficiency is calculated as follows:

$$[(100 - 97.75) - (85/100 \cdot 2.25)] = 0.34 \% \text{ and hence } \eta = 99.7 \% \quad (2.3)$$

ESPs have a pressure drop of between 150 to 250 Pa. The pressure drop across the inlet and outlet gas distribution devices accounts for most of this.

Choice of collector and collector location
Dry collectors should be installed after the induced draft (ID) fan so that they operate under positive pressure to avoid ingress of air (oxygen) and so catching alight. This means the ID fan is subject to high erosion.

Wet gas scrubbers will be the ‘collector of choice’ for most mills where fairly stringent particulate emission control becomes necessary, below 120 mg/Nm³. Whether the ID fan should be placed before or after the scrubber, however, is not so clear. If bagasse is the only fuel to be burned, placing the fan after the scrubber has many advantages, the most important of which are:

- A ‘wet’ fan has to handle only 75 to 80 % of the volume that a ‘dry’ fan has to handle.
- There is no need to protect the ID fan from erosion by installing a cyclone collector upstream of it, as would be the case with a dry fan.

A dry fan will, therefore, absorb about 25 to 35% more power than a wet fan.

The main disadvantage is that a wet fan must be epoxy lined to minimize corrosion, and present day epoxies can only withstand a maximum operating temperature of about 120 °C. If the scrubber water supply fails, the boiler must be shut down to prevent damaging the epoxy. Alternatively, a second emergency water supply must be available to take over immediately from the main supply.

2.3.3 Gaseous emissions

Sulfur dioxide emissions are very low if bagasse is burnt, as the sulfur content of bagasse is very low. Nitrogen oxides and carbon monoxide are the two most important noxious gas emissions.

In Australia, the proposed limit for NOx is a peak hourly-averaged ground level concentration of 320 µg/m³, not to be exceeded more than once in a month (Kroes and Dixon 1998). NOx emissions from bagasse-fired boilers at selected Australian sugar factories, measured in 1996, were well below the set limits. The results showed that, with the proposed statutory limit, NOx produced by bagasse-fired boilers is not a concern to the sugar industry. The limit in boiler gas in Brazil is 350 mg/Nm³ expressed as NO2. If it is necessary to reduce NOx emissions, details of the options available can be found in Magasiner (2007).

CO emissions are being more and more tightly controlled. Burning carbon to carbon monoxide rather than carbon dioxide is wasteful. Time, temperature (> 980 °C) and turbulence play a significant role in minimizing CO formation provided there is sufficient excess air available. Proper fuel feed and furnace designs are crucial elements in achieving the required results.

Strict emission controls required by the US EPA discourage the installation of new boiler plant. Electrostatic precipitators are often necessary and some mills choose instead to upgrade existing boilers and introduce steam economy measures to cope with higher crushing rates (Alvarez and Johnson 2006). The US Sugar Corporation recently commissioned a large bagasse fired boiler in Florida, which used CFD studies to predict particulate carry-over and NOx and CO emissions; emission levels better than requirements of 81, 363 and 111 mL/m³ dry gas for NO2, CO and volatile organic compounds respectively were achieved (Anon 2006). The selective non-catalytic reduction process involving the introduction of urea was used to achieve NOx targets.

Sulfur in the fuel oxidizes predominantly to sulfur dioxide in the furnace. Between 2 and 4% is converted to sulfur trioxide. The SOx concentration in the stack emission is a function of the amount of sulfur in the fuel and because there is little sulfur in bagasse, it does not present a problem. Problems occur when either heavy fuel oil or high sulfur coals are burned as auxiliary fuels. It ought to be possible to reduce SOx emissions in flue gas desulphurization plants designed for fossil fuels, but so far this has not been demonstrated nor has it been necessary.

2.3.4 Management of dust from bagasse systems

Fine bagacillo easily separates from a bagasse stream, as evidenced by the bagasse dust problem in most sugar mills. Unless conveying systems are designed carefully to eliminate this problem, it can be an uncomfortable problem to live with.
Most dust generation occurs at transfer points from one conveyor onto another. Careful design can minimize the problem. A bagacillo extraction system for the filters has been described by Sanders et al. (1995), by sucking air through a stream of bagasse at a conveyor transfer point. There is a fire risk with bagasse conveyors, and fire retardant belting should be used. It is also common to install deluge fire protection.

The potential health hazard associated with the storage and handling of bagasse, namely bagassosis, is not considered to cause problems in a normal mill environment (see Section 1.9.4).

2.3.5 Dust in the workplace

Sugar dust explosions are not an issue with raw sugar, but are a very important consideration when handling white sugar. Dust explosions are caused when a high concentration of sugar dust is ignited by a source such as discharge of static electricity, sparks, arcing from machinery or very hot surfaces such as overheated bearings. Dust should be sucked away from any area where it is generated, e.g. conveyor transfer points, and filtered in bag filters. However, suppression systems are necessary, particularly with bucket elevators, in which a very high concentration of dust may be contained in the elevator housing. Explosion vents on enclosures such as these may be used. Good control of crystal sizes during the crystallization phase also helps to minimize the sugar dust formation during sugar handling.

As this is an area requiring specialized technical knowledge, external consultants may be employed to ensure freedom from sugar dust explosions.

Simunye mill in Swaziland have an elaborate system to control dust from raw sugar handling, and recover the dust in wet scrubbers. This leads to good housekeeping and eliminates physical losses.

2.3.6 Summary and good practice recommendations

**Box 2.2 Management of dust/particulate emissions**

- Wet scrubbers should be incorporated on all new boilers, to meet emission standards below 120 mg/Nm$^3$.
- Boiler particulate emissions limits vary in different countries, but are tending to become stricter and wet scrubbers on all boilers should be the aim.
- In a few countries, it may be necessary to install electrostatic precipitators if more stringent standards are imposed.
- Gaseous emissions are not usually a problem because bagasse has a low sulfur content.
- If supplementary fuels high in sulfur are burnt, consideration must be given to monitoring SO$_x$ emissions.
- Bagasse dust in the workplace must be given adequate attention to obviate a workplace nuisance.
- Sugar dust explosion protection measures are needed in refineries where white sugar is handled and should be considered in factories producing VVHP sugars.
2.4 References


# CHAPTER 3 - CO-PRODUCT PRODUCTION

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3. CO-PRODUCT PRODUCTION

Most mills operate for only part of the year. Economics dictate that the milling season should be as long as possible, but this is usually limited by climatic conditions. Consequently, in order to supply the market or downstream uses of co-products throughout the year, mills should have sufficient storage capacity of molasses and bagasse during the off-crop season.

3.1 Management of molasses storage and handling

In most cases it is not necessary to have enough storage for rateable off-take throughout the year, but it is not unusual to see one or more storage tanks of about 10 000 t capacity each, particularly at larger mills. The tanks should have adequate venting to prevent a build-up of gas in the event of Maillard reactions occurring.

In some instances molasses is stored in a ‘dam’ in the ground, as a cheap means of providing large storage capacity. It requires careful ground preparation and an impermeable liner, usually plastic (e.g. high density polyethylene), to contain the molasses. A cover of a roof or a plastic membrane is also required to prevent rain dilution.

3.1.1 Losses in storage

In all storage systems, precautions are desirable to prevent condensation of water that drops onto the molasses. This dilutes the top layer of molasses, which can lead to localized fermentation. Otherwise the high dissolved solids content is such that microbiological losses are not significant in stored molasses.

Losses of fermentable sugars can take place over the period of a few months. Work done on degradation of A and B molasses in storage (Smith and Cazalet 1987) shows that some sucrose is inverted to monosaccharides, but that there is also a reduction in total sugar content. This can be minimized by storage temperatures in the range 35 to 45 °C. Their work also shows that the traditional Lane and Eynon method for measuring fermentable sugars underestimates the losses incurred; HPLC or GC measurements of sucrose and monosaccharides are necessary to measure losses accurately.

Olbrich (1963) reported that storage at temperatures above 45 °C leads to substantial losses, which can be minimized if temperatures are kept below 40 °C. Storage at 30 °C for six months led to an average loss of 1.2 % of total sugars. Honig (1965) reported that 10 % of the sugars in molasses are lost in ten months in storage.

3.1.2 Maillard reactions in molasses

Reports of molasses tank explosions appear regularly from different parts of the cane sugar world. Olbrich (1963) gives details of such events going back to 1922. Although the cause of these events is still debated today, it appears certain that the cause of the problems is the occurrence of Maillard-type reactions in the stored molasses and is not microbiological in origin.

Newell (1979) reported the results of a comprehensive investigation into the factors promoting the reactions. The most important factor is temperature, with a doubling of the rate of reaction for a 5 °C increase in temperature; this was confirmed by White et al. (1983). The reaction appeared to increase substantially above 65 °C, but was measurable at 50 °C. It was also found that high dissolved
solids content and low purity promote the reaction, so that high Brix final molasses is particularly susceptible to this reaction occurring.

Apart from the loss of sugars and glucose in particular, other changes occur. Carbon dioxide is evolved, evident in the initial stages as a volume increase (swelling of the molasses) and the formation of foam (Honig 1965). The pH also drops as a consequence, promoting inversion of sucrose. A considerable increase in viscosity is evident (White et al. 1983). The reaction is exothermic, so that when it occurs the temperature increases, further promoting the reaction. Thus, once it starts and gains momentum, it is difficult to stop and can rapidly lead to explosions in a closed vessel, or to solid charred material in the worst case in a tank at atmospheric pressure.

The best way to prevent this happening is to cool the molasses to below 40 °C before storage. If necessary, the Brix could also be controlled at not more than 80. Even so, it is good practice to pump molasses from one tank to another or recycle molasses within a tank periodically. Some molasses tanks are fitted with an air injection system that blows compressed air into the tanks a few centimeters above the tank floor. The amount of air need not be high, just sufficient to cause movement and circulation of molasses in the tank. The air has the ability to break up any foam which may have formed, but more importantly the circulation prevents the formation of hot spots in the tank, where Maillard-type reactions may be starting, and so disperse any heat generated.

The molasses tanks painted silver or a light color reduce the risk of temperature increase due to the incidence of the sunlight.

3.1.3 Summary and good practice recommendations

Box 3.1 Management of molasses storage and handling
- Losses of sugars in molasses can occur if attention is not given to adequate storage conditions.
- Under the worst conditions, Maillard-type reactions can lead to explosions.
- Molasses should be cooled to below 40 °C before being sent to storage.
- To minimize losses of sugars in molasses with long storage times, the molasses should be circulated by periodic pumping or by air induced circulation in the tanks.
- Molasses tanks must have a good venting system protected against the entrance of water, debris and insects.
- Moisture accumulation on the top of molasses in tanks should be minimized.

3.2 Large scale storage of bagasse

3.2.1 Dry bulk storage of bagasse

A number of factories attempt to store the maximum amount of surplus bagasse for off-crop use. Because of the low bulk density of bagasse, large areas are involved, which usually means storage in the open air. A system will possibly incorporate a long belt conveyor across a concrete slab, with the ability to tip bagasse from the belt at any point, or to a boom stacker moving on rails. In some cases bagasse is transported in large trailers to remote storage areas. Bulldozers or front end loaders are required to move the bagasse into large piles to store the maximum amount of bagasse on the hard surface storage area. The bulk handling vehicles travel up the piles and in so doing help to compact the bagasse. These vehicles are also essential in reclaiming bagasse fed back to the mill bagasse store. When the piles are completely formed and profiled, they may be covered or partially covered with large tarpaulins.
Figure 3.1. Vapor plume from boiler stack after wet scrubber, also showing surplus bagasse onto an outdoor storage area

Bagasse should be stored on specially constructed pads with a hard surface and preferably profiled. This is necessary to ensure that any rain water runoff or leachate is contained and treated or stored. The bagasse may be stored on a single storage area or on a number of separated storage pads. Separate piles enable them to be more easily covered, assists in first-in-first-out handling, and helps contain fires.

Apart from the large area required, the main problems associated with outside storage are rain wetting the bagasse and the dust nuisance, particularly when bagasse falls a long distance from the conveyor down to ground level. The net effect of average rainfall is not serious. The exterior surface of an uncovered pile forms a relatively impermeable skin up to 30 mm thick (Dixon 1988). A compact pile usually results in most rainfall running off rather than into the pile. Pile management becomes important in maintaining sloping piles and ensuring that no ‘dams’ form which can catch and hold water.

Spontaneous combustion is not common but can occur if the bagasse dries out with an accompanying temperature rise above 94 °C. Factors which cause the bagasse temperature to rise
from the quasi-steady level of 65 °C to the onset of dry bagasse combustion have not been established (Dixon 1988). Monitoring of pile temperatures can give advance warning of imminent spontaneous bagasse combustion.

Because of the potential dust nuisance problem, storage sites are sometimes chosen some distance away from the mill. The sites are chosen with regard to prevailing wind directions and the proximity of residential areas. A buffer area around the storage piles is maintained, preferably planted with trees to act as a screen. Large mesh screens surrounding storage areas have been tried with mixed success.

3.2.2 Storage for paper manufacture

Bagasse is also used for the manufacture of paper in some countries. Quantities of bagasse to be stored are large because of the large size necessary for a paper mill to be profitable – storage of fiber for a three month off-crop might require the storage of 60,000 t bagasse, and the low bulk density means that a very large storage area is necessary.

There are two different approaches to storing bagasse fiber to preserve the bagasse without degradation losses or deterioration in quality:

1. By drying the bagasse to a moisture content of < 20%.
2. By storing the bagasse wet and excluding oxygen.

This is normally the responsibility of the paper company, who may or may not be the owner of the sugar operation.

The Ritter system seems to be the most consistently successful and is a widely used method for storing fiber for pulp and paper. This involves wet storage of bagasse fiber in large piles on a concrete slab. Bagasse from the mill is slurried to 3% solids, pumped via an elevated flume and distributed on storage piles. Water is continuously circulated over the bagasse and recycled. The water, known as Ritter liquor, develops a flora of microorganisms, which produce acetic acid and butyric acid and drop the pH to a value between 4 and 5. The liquid keeps the bagasse pile anaerobic and minimizes degradation and consequent loss of fiber. Losses in storage are less than 5%, and it is reported that virtually no loss of usable fiber occurs (Morgan et al. 1974). It also has the effect of eliminating bagasse dust as a problem, but has the disadvantage of developing an off-odor characteristic of anaerobic systems. This is not normally too serious in the context of the range of odors commonly experienced at paper mill sites. Bagasse is reclaimed by fluming the bagasse to the paper mill.

3.2.3 Export of bagasse

Mills with a surplus of bagasse often find it profitable to sell surplus to other nearby mills that require the additional bagasse for by-product use or power generation for export. Bagasse is normally transported in road vehicles. It is important to design loading systems which contain the dust and ensure that the trucks are sealed before leaving the mill.

Bagasse is a light, fluffy material with a low bulk density, and so transport of large amounts may be costly. The density of depithed bagasse in a truck is 240 kg/m$^3$, or 130 kg dry fiber/m$^3$ (Rein 2007). Baling bagasse can lead roughly to a doubling of the bulk density, but then incurs the cost of baling and breaking down bales at the receiver’s location.
Large scale cogeneration at Pioneer mill in Australia requires the importation of bagasse from surrounding mills. An amount of 110 000 t/y of bagasse is trucked in to be stored at the mill for off-crop generation (Trayner 2008). Storage piles are covered by tarpaulins to minimize ingress from rain water, as a barrier to oxygen penetration, as protection from external ignition sources, to reduce dust nuisance and minimize odor and leachate runoff.

3.2.4 Summary and good practice recommendations

Box 3.2 Large scale storage of bagasse
- Large scale storage of bagasse is possible in outdoor storage areas.
- Bulk storage sites must be designed to catch any run-off rain water.
- Consideration should be given to screening around storage sites to minimize dust problems.
- Bagasse should be transported in sealed trucks.
- A firefighting system must be available around the bagasse storage yard.

3.3 Management of vinasse from a distillery

Vinasse is the residue from alcoholic fermentations after the alcohol has been distilled out. The quantities range from about 8 to 13 L/L of ethanol produced. Formerly regarded as a problematic effluent, this material is now accepted as a useful co-product. Nevertheless, it requires careful management because of its high concentrations of potassium and BOD.

The composition of vinasse from cane-based fermentations depends on whether the feedstock was molasses alone or juice; the latter being of higher sugar purity than the former. Table 3.1 shows the major components of vinasse from different feedstocks. Confusion may arise from the fact that some countries express the mineral content in terms of the mass of oxide (e.g. K₂O), while others use the mass of the element itself. The phosphorous content may exceed the range indicated in Table 3.1, particularly if the distillery feedstock has not been subjected to liming for clarification, or if supplementary phosphorous has been added for fermentation.

<table>
<thead>
<tr>
<th>Parameter (units)</th>
<th>Fermentation Feedstock</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Molasses</td>
<td>Juice</td>
</tr>
<tr>
<td>Total solids (g/100g)</td>
<td>8</td>
<td>2.5</td>
</tr>
<tr>
<td>Volatile solids (g/100g)</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>BOD (kg O₂/m³)</td>
<td>65</td>
<td>15 – 33</td>
</tr>
<tr>
<td>COD (kg O₂/m³)</td>
<td>80 – 120</td>
<td>22</td>
</tr>
<tr>
<td>K (kg K₂O/m³)</td>
<td>3.7 – 7.8</td>
<td>1.2 – 2.1</td>
</tr>
<tr>
<td>N (kg N/m³)</td>
<td>0.4 – 1.6</td>
<td>0.1 – 0.7</td>
</tr>
<tr>
<td>P (kg P₂O₅/m³)</td>
<td>0.1 – 0.3</td>
<td>0.01 – 0.2</td>
</tr>
<tr>
<td>Ca (kg CaO/m³)</td>
<td>0.4 – 0.5</td>
<td>0.13 – 0.15</td>
</tr>
<tr>
<td>S (kg SO₄/m³)</td>
<td>6.4</td>
<td>0.6 – 0.75</td>
</tr>
<tr>
<td>pH</td>
<td>4.2 – 5.0</td>
<td>3.7 – 4.6</td>
</tr>
</tbody>
</table>
3.3.1 Direct use of vinasse for irrigation

Irrigation (often called ‘fertigation’) is the most common method of disposal for distilleries based in agricultural areas. The vinasse must be distributed over most of the land from which it originated otherwise serious soil damage can result from the application of excessive potassium. This need for widespread distribution creates logistics challenges. Pipelines or lined channels may be used to move the vinasse to distant fields where it is then distributed by mobile pumps feeding overhead spraying equipment. Alternatively, tanker trucks are used to transport and spread the vinasse. Equipment used for handling the vinasse must withstand corrosion.

Judicious application of vinasse enables fertilizer costs to be reduced and leads to long term benefits to the soil. Optimum application depends on the vinasse composition and the soil characteristics. Some sensitive areas need to be avoided because of problems of odor or water pollution. One set of guidelines, developed in Brazil in 1986, prevents application in the following areas:

- Flooded areas or areas subject to floods
- Areas less than 200 m from rivers and streams
- Areas where the underground water table is within 2 m of the surface
- Areas less than 1,000 m from residential and business centers and less than 200 m from roads and railways.

Additional broad guidelines in Brazil suggest that maximum application rates per annum should be 450 m$^3$/ha for vinasse derived from juice, 300 m$^3$/ha for that derived from a mixture of juice and molasses and 150 m$^3$/ha for that derived from molasses. In São Paulo State in Brazil, the application of vinasse is controlled by the amount of K$_2$O applied instead of controlling the application based on volume. Other Brazilian states such as Goiás, Minas Gerais, Mato Grosso do Sul, Mato Grosso and Paraná are tending to adopt the same concept. In fact, by law, it is a requirement to measure K$_2$O in the soil before the application of vinasse. The required additional K$_2$O is calculated based on a maximum application rate of 160 kg of K$_2$O/ha. The appropriate quantity of vinasse is calculated based on its K$_2$O content. This quantity may be further adjusted according to the amount of K$_2$O that is contributed by tops and leaves after harvesting unburnt cane. This adjustment is approximately 60 kg of K$_2$O/ha.

A number of studies (e.g. Casagrande et al. 2007) show that the potassium requirements of cane can be supplied by appropriate application of vinasse (calculations of vinasse requirements need to account for the fact that a small portion of the potassium in vinasse is not immediately available to plants). An added benefit of vinasse is that it seems to provide an energy source for biological nitrogen fixation, thereby diminishing fertilizer nitrogen requirements (Resende et al. 2006).

More details of soil and agronomic considerations are given in the Fertilization and Soil Management sections of this manual.

Although direct use of vinasse for irrigation is the most used disposal method there are circumstances where it is impractical, usually due to the long transport distances involved in redistributing the vinasse to an acceptably large area. For this reason alternative methods, involving evaporation of the vinasse, have been applied.
3.3.2 Evaporation to Condensed Molasses Solubles (CMS)

In some circumstances the vinasse is evaporated to a concentration of between about 40 and 55% dissolved solids, referred to as CMS, prior to distribution (or sale as a fertilizer). This requires expensive, multiple effect, stainless steel evaporators and significant energy. The steam required for evaporation depends on how the evaporator system is integrated into the distillation plant, but generally this almost doubles the steam requirement for the distillery.

Scaling of the evaporators is a serious problem requiring frequent stoppages for cleaning. Provision for a chemical cleaning system using nitric acid is usually necessary. For distilleries located in agricultural areas the costs of evaporation generally exceed the resulting reduction in transport costs, but evaporation may be appropriate in some circumstances.

3.3.3 Spray drying

Vinasse from some distilleries is spray-dried to produce a marketable powder. The powder is used mainly in animal feeds but the market for such feeds is very small because the high potassium content limits the amount that can be ingested.

3.3.4 Incineration in boilers

Vinasse has some energy value that can be recovered in special boilers whilst retaining most of the fertilizer value in the ash. For ignition and continuous burning, the vinasse must first be evaporated to 60% solids and then be burnt in conjunction with a supplementary fuel. The burning process must be controlled carefully to prevent slagging. Simple addition of concentrated vinasse to bagasse fed to conventional boilers is not an option because it can lead to serious problems with deposits on boiler walls and tubes. Schopf and Erbino (2010) presented details of a swirl burner optimized for the burning of concentrated vinasse. Despite the technical feasibility of incineration it has not been applied on a large commercial scale. Some energy can be recovered from the vinasse but, because of the need for pre-evaporation and co-combustion with fossil fuel, the overall energy ratio (renewable energy out: fossil fuel in) of the production system is lowered (Rocha et al. 2007). This energy ratio effect is irrelevant if the aim is to recover energy.

3.3.5 Use in composting

Addition of vinasse to filter cake during composting has the benefits of adding nutrients to the compost and of evaporating the vinasse during the composting process. In effect this uses fuel from the vinasse and filter cake as a source of biological heating for evaporation; in turn leading to reduced transport costs for vinasse and filter cake. Details are given in Section 3.4.4.

3.3.6 Anaerobic digestion to produce biogas

The total energy contained in vinasse from a distillery is approximately 18% of the total contained in the ethanol produced in the distillery (Leal 2007). A large portion of this energy can be recovered by digesting the vinasse under anaerobic conditions to produce fuel in the form of methane. Table 3.2 indicates the quantities of biogas and energy available through methane production.

<p>| Table 3.2. Generalized figures for biogas production relative to average conditions in Brazilian ethanol plants (Leal 2007). |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas production</td>
<td>Nm³/m³ ethanol</td>
<td>175</td>
</tr>
<tr>
<td>Lower heat value (LHV)</td>
<td>MJ/Nm³</td>
<td>21.4</td>
</tr>
<tr>
<td>Biogas energy equiv.</td>
<td>MJ/L ethanol</td>
<td>3.74</td>
</tr>
<tr>
<td>Energy distribution</td>
<td>Total biogas % total ethanol</td>
<td>18</td>
</tr>
<tr>
<td>Electricity production potential</td>
<td>kWh/t cane</td>
<td>20</td>
</tr>
</tbody>
</table>

The concentration of COD in vinasse is sufficiently high to justify the use of sophisticated enclosed anaerobic reactors. Features of these reactors include:

- A settling zone to ensure retention of the active methanogens (in the form of sludge).
- A means of agitation, which may be the rising biogas but usually involving recirculating pumps or agitators.
- Facilities for heating (not necessary for hot vinasse) and temperature control.
- A means of collecting the biogas and burning it.

**Figure 3.2. Anaerobic digester with associated small clarifier**

During start-up or overloading of an anaerobic reactor the treated effluent may be odoriferous, but odor is not a problem with well treated effluent, which can be disposed of via irrigation in the same way as raw vinasse.

Details of the types and numbers of reactors installed in recent years are given by Kassam et al. (2003), who indicate that upflow anaerobic sludge blanket (UASB) reactors with internal circulation were the most popular choice in the year 2000. Table 3.3 gives major parameters applicable to methane technology.
Table 3.3. Parameters applicable to methane technology.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Mean</th>
<th>Min.</th>
<th>Max.</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total biogas production</td>
<td>Nm³/kg COD removed</td>
<td>0.5</td>
<td>0.2</td>
<td>1.0</td>
<td>Kassam et al. 2003</td>
</tr>
<tr>
<td>COD loading</td>
<td>kg COD/m³/d</td>
<td>10</td>
<td>5</td>
<td>20</td>
<td>Various</td>
</tr>
<tr>
<td>COD removal</td>
<td>%</td>
<td>65</td>
<td>50</td>
<td>90</td>
<td>Various</td>
</tr>
<tr>
<td>Methane % total biogas</td>
<td>%</td>
<td>60</td>
<td>50</td>
<td>80</td>
<td>Various</td>
</tr>
<tr>
<td>CO₂ % total biogas</td>
<td>%</td>
<td>38</td>
<td>35</td>
<td>40</td>
<td>Various</td>
</tr>
<tr>
<td>Methane solubility in water</td>
<td>ml/L at 20 °C</td>
<td>35</td>
<td></td>
<td></td>
<td>Various</td>
</tr>
<tr>
<td>Recoverable methane</td>
<td>Nm³/kg COD removed</td>
<td>0.31</td>
<td>0.28</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Methane density</td>
<td>g/L at 20 °C</td>
<td>0.717</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Use of biogas to fire boilers or for electricity generation
The biogas can be used as an additional fuel for boilers or it can be used in large stationary internal combustion engines for electricity generation. The latter are more efficient (40 % energy conversion to electricity) than boilers but the capital cost cannot always be justified. The carbon dioxide (approximately 38 %) is not removed from the biogas prior to burning in these stationary engines.

Use of biogas as vehicle fuel
Subsequent to the peak in crude oil prices in 2008, considerable developments took place in commercial equipment for using methane as a mobile vehicle fuel. This included equipment for removing carbon dioxide and hydrogen sulfide from biogas, compressing of methane, storage cylinders and a variety of internal combustion engines. Purified compressed biogas is equivalent to compressed natural gas which is now (2010) used by more than ten million vehicles worldwide. Most of the major suppliers of vehicle engines now offer a methane-fuelled option. The rapid development of this technology and associated ‘off-the-shelf’ equipment suggests that earlier pessimistic conclusions regarding its application in the sugar industry need to be reviewed. One assessment (Purchase 2008 unpublished) concluded that a sugarcane estate producing only ethanol could produce enough methane to replace the diesel requirements for all agricultural operations including cane transport.

3.3.7 Life cycle assessment of various options for vinasse usage
Rocha et al. (2010) presented a comparative life cycle assessment of the above options (excluding the last one) showing outlines of the processes together with the energy ratios and greenhouse gas emissions. In terms of surplus energy production, GHG emissions and effects on soil health, the best option appeared to be anaerobic digestion with subsequent irrigation via canals and pumps.
3.3.8 Summary and good practice recommendations

**Box 3.3 Management of vinasse from a distillery**

- Ethanol distilleries produce approximately 12 liters of vinasse per liter of ethanol.
- The vinasse has sufficient value to be regarded as a co-product rather than an effluent. The value relates mainly to the high potassium content that enables vinasse to partially replace mineral fertilizers.
- The chemical composition of vinasse is strongly influenced by the source of the fermentation feed (molasses or juice) used in the distillery.
- The high mineral content and high organic matter content of vinasse can lead to serious soil damage and water pollution if the vinasse distribution system is not well managed.
- The requirement to limit the amount of vinasse applied to any one field means that distribution has to be extensive, involving considerable transport. Such transport may be via long pipelines or lined channels but, where this is not possible, road transport may be necessary.
- Reduction of transport costs by evaporating the vinasse is possible but not always economical because of the high equipment and energy costs.
- Recovery of energy, in the form of methane, is possible by anaerobic digestion of the vinasse. This does not reduce the volume or the fertilizer value. Alternatively it is technically possible to recover energy by incineration of the vinasse but this requires prior concentration and burning with a supplementary fuel.
- Composting of vinasse in conjunction with filter cake is a practical means of reducing the amount of vinasse (and filter cake) for transport. The composting procedure requires special equipment and careful management. The quantity of filter cake available may not be sufficient to accommodate all the vinasse.
- Care must be taken to avoid conditions in channels and vinasse ponds that encourage breeding of flies and mosquitoes.

Most of the treated wastes from sugar factories have some value when returned to the suppliers of the cane but the value per unit mass is too low to justify widespread marketing. The primary aim is usually to dispose of the wastes at minimum cost rather than to hope for profitable residue sales.

Compost made from a combination of filter cake and vinasse has relatively high value per unit mass and finds a ready market among farmers in India. Raw filter cake and boiler ash have such low value per unit mass that disposal to fields is often paid for by the factory because farmers cannot justify transporting the material.

**3.4.1 Compost**

It is common practice in Brazil to produce compost from mill filter cake, boiler waste and vinasse. This is done on a large scale and requires a large area of land, but in the case of a very large mill it is generally not able to take care of all vinasse produced. The compost is turned every four to seven days with specially made machines and composting is normally complete within 50 days. The temperature in the piles is monitored, and not allowed to rise above 60 °C. At São Martinho, gypsum, lime and chicken litter are also added into the mix. In general they try to keep the C:N ratio below 18.

Distillers in India and Pakistan add stillage to filter cake on large concrete slabs. The heat generated by the composting process is sufficient to evaporate the water, and very good quality compost high in potash is produced in about 30 days. The disadvantages are the very large areas required for composting and the cost of transporting a bulky, relatively low value product to the market.
Composting in conjunction with vinasse and/or bagasse produces a superior and marketable product. Senthil and Das (2004) report on an ISO 9001 certified composting facility in India in which filter cake is delivered by truck and formed into rows 1.5 m high and 4 m wide at the base. After drying for a week, the cake is watered with vinasse over a period of 10 weeks such that the ultimate vinasse:cake ratio is between 2.5:1 and 3.5:1 (wet mass), and the moisture content is maintained between 50 and 60%. A microbial starter culture is mixed into the cake and a special compost turning machine mixes and aerates the compost at least five times a week. The temperature rises to about 70 °C. After ten weeks the material is allowed to dry before being bagged at about 35% moisture. The composition of the materials before and after composting is shown in Table 3.4. The heat developed during composting ensures that the final product is free of weed seeds, nematodes and plant pathogens. The low moisture content and high nutrient content makes it amenable to transport over fairly long distances.

Table 3.4. Changes occurring during composting of filter cake with vinasse (Senthil and Das 2004).

<table>
<thead>
<tr>
<th>Component and Parameter</th>
<th>Value before composting</th>
<th>Value after composting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vinasse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD</td>
<td>40 000 – 80 000 mg/L</td>
<td>Less than 100 mg/L (in 1 % leachate)</td>
</tr>
<tr>
<td>COD</td>
<td>80 000 – 200 000 mg/L</td>
<td>Less than 500 mg/L (in 1 % leachate)</td>
</tr>
<tr>
<td>pH</td>
<td>3.5 – 4.5</td>
<td>7.0 – 8.0</td>
</tr>
<tr>
<td>Odor</td>
<td>Strong, repulsive</td>
<td>Mild, pleasant</td>
</tr>
<tr>
<td>Color</td>
<td>Dark brown</td>
<td>Black</td>
</tr>
<tr>
<td><strong>Filter cake</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C:N ratio</td>
<td>35:1</td>
<td>Between 10:1 and 15:1</td>
</tr>
<tr>
<td>Wax</td>
<td>8 – 15 %</td>
<td>Below 1 %</td>
</tr>
<tr>
<td>Humic acids</td>
<td>Negligible</td>
<td>More than 4 %</td>
</tr>
<tr>
<td><strong>Final compost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>30 – 35 %</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1.7 – 2.5%</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>1.0 – 1.5%</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>3.0 – 4.0 %</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>2.0 – 4.0 %</td>
<td></td>
</tr>
</tbody>
</table>

Challenges involved in this composting operation include the need to provide an impervious base for the composting area and holding tanks for run-off caused by rain, the need to locate the composting operation away from residential areas and the fact that there is inevitably too little filter cake to absorb all the vinasse.

3.4.2 Filter cake

Because of the moisture content and some residual sugars, fresh filter cake ferments, forming acids and often creating unpleasant odors. It is often left to stand in a pile before spreading for this reason. This also leads to a drying out of the cake, which reduces transport costs.

Filter cake contains some wax originating from the cane stalk. About 40% of the cane wax is extracted into the raw juice (Paturau 1989) and at various times attempts have been made to recover this wax. The carnauba wax component of cane wax has properties which make it a desirable product. The wax consists of essentially two fractions, fatty lipids and waxy lipids. The latter is the
desirable product and the former has to be separated from it. Roughly half the crude wax is recovered as refined wax product, representing about 40 kg wax/100 t cane.

The process usually involves extraction with solvents in either one or two stages. The solvents are flammable, making it a potentially hazardous process. In most cases it does not appear to be an economic option and plants which ran commercially for a number of years have mostly closed down.

3.4.3 Boiler fly ash

Boiler ash, smuts and fly ash have little commercial value, and are usually trucked to the fields or a dump site at minimum cost. Alternatively, it may be added to the material used in making compost using vinasse. This material has sometimes been used as a filler in building bricks.

3.4.4 CMS and spray dried vinasse

Vinasse may be concentrated in specially designed multiple effect evaporators to reduce the volume to be handled. If more concentrated effluent can be produced, it may have use as a binder in animal feeds, or merely reduce the quantity of material and hence transport costs to outlying fields. However, the high capital cost of stainless steel evaporators, the need to clean with aggressive chemicals and the additional steam required sometimes makes this unattractive, but often is the only practical option. Integration of stillage evaporation with distillation can, however, reduce the steam usage significantly.

A system for combining CMS (at 50 g solids/100 g), filter cake, boiler ash and fly ash together with mineral fertilizers to produce a granular fertilizer called ‘Biofom’ is being marketed by Dedini and described by Oliverio et al. (2010). The product is spray dried/granulated to produce small, easy to handle pellets. It is envisaged that significant value is added. An analysis of the economics indicates a payback time for capital equipment of less than four years when the ‘income’ was considered to be (a) savings on fertilizer, (b) elimination of the need to transport a large volume of vinasse and (c) water savings equivalent to the condensate from the vinasse evaporators. However, the condensate from CMS evaporators is acidic and cannot be directly recycled.

A downstream business from Simunye in Swaziland takes the CMS and adds fertilizer nutrients to the 40 Brix CMS, based on soil or leaf analyses for particular fields. It is then applied for the grower by the supplying company. The mill is paid a price based on the K content. Fortification of vinasse with required fertilizer ingredients is also practiced in Brazil. In Australia, based on soil or leaf analyses, other fertilizer requirements are added into the vinasse to provide one application liquid fertilizer to surrounding farmers. The vinasse is produced at a higher concentration and in smaller volumes relative to conventional vinasse, because of the fermentation process used. The process reduces the cost of distributing the concentrated vinasse to the farmers and has resulted in a profitable venture arising from the disposal of the vinasse.

3.4.5 Bagasse pellets

It is possible for mills to produce a substantial amount of surplus bagasse, which may be sold as a fuel if the local economics do not favor the production and export of power from the bagasse surplus. Biomass is becoming an attractive source of alternative fuels in some places, and bagasse pellets have value in these cases. Where gasification of bagasse has been investigated, pellets appear to offer the best opportunities. Work at Campinas University has investigated combustion and properties of bagasse pellets. Dried bagasse in pellets 9 to 18 mm in diameter have a density around 1 000 kg/m³ for best results (Lora and Beaton Soler 1992).
However the pelleting presses may be expensive to operate, particularly if there is significant sand in the bagasse, which leads to rapid wear of expensive dies. In these cases some pre-classification of the bagasse to remove sand is advised.

Bagasse pellets have been sold in the past as animal feed. The bagasse provides roughage, and if mixed with molasses before pelleting, provides a valuable animal feed.

3.4.6 Yeast

Baker’s yeast is commonly produced from molasses by aerobic fermentation. One kg of yeast requires roughly 2 kg of fermentable sugars.

Recovery of yeast from ethanol distilleries in Brazil is becoming more widespread. Roughly 15 g dried yeast/L ethanol may be obtained in this way without affecting the ethanol yield. At São Martinho, 20 kg dry yeast is available as a co-product for every m³ ethanol produced. This can be a substantial amount at a large distillery. Most of it is used as a poultry or animal feed.

Various strains of Torula and Candida yeasts may also be produced as animal feeds. There are sufficient fermentable substances in ethanol stillage to permit a yeast fermentation to be feasible.

3.4.7 Summary and good practice recommendations

<table>
<thead>
<tr>
<th>Box 3.4 Marketability of treated residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Disposal of factory residues is often at a net cost to the processor.</td>
</tr>
<tr>
<td>• Particular circumstances where a mill is located may facilitate a revenue stream for a processor, depending mainly on the value of the residue in enhancing crop yields.</td>
</tr>
<tr>
<td>• Vinasse from a distillery can usually be processed in such a way as to represent a valuable co-product.</td>
</tr>
<tr>
<td>• Opportunities for extracting value from residues are otherwise fairly limited.</td>
</tr>
</tbody>
</table>
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1. INTRODUCTION

Technological advancement has driven significant change and improvement in the sugar industry through a wide variety of initiatives and developments from the improvement of cane varieties, soil management techniques, yields, irrigation techniques and machinery performance, to factory recoveries and efficiencies to mention but a few. Technology can even help businesses to reduce the risk of climatic conditions, but technological advancement can do little to mitigate against the risk of the ‘human factor’; an influencing factor that can have a major impact on business operations, management, profitability and sustainability. This influencing factor, if the resource is managed correctly can be extremely positive, but if not managed correctly, can bring down the most successful of businesses in an instant. A slight exaggeration perhaps, but the importance of developing appropriate human resource and social support systems cannot be overstated.

The stakeholders of the industry go beyond company shareholders and investors, extending to employees, neighboring communities, civil society, governments and consumers. The expectations, roles and responsibilities of each of these stakeholders differ significantly but have to be considered by the industry and incorporated into operations and management plans. Managing these stakeholders throughout the lifetime of a business is extremely challenging, enhanced by the advances in technology making it easier for the consumers to observe and react to the actions of a company. Guidelines and standards can be developed to aid companies to manage the challenges, but every scenario is different dependent on a multitude of factors including but not limited to; the country of operation, its economic, social and political environment, culture and traditions, other industries, the environment, education and capacity levels, financial resources, natural resources and climatic conditions. There is no single ‘Good Management Practice’ or even range of practices that can be developed to suit all scenarios; however this chapter attempts to introduce a number of recommendations and potential solutions to common industry situations that can be adapted to suit by the implementers.

2. REGULATORY FRAMEWORKS

2.1 Legal and industry regulation

The creation of an enabling environment for the development and continued success of the sugar industry in any country is of paramount importance to all direct and indirect stakeholders, and how this enabling environment is developed differs from country to country. The sugar industry is an extremely important sector of the world economy providing valuable foreign exchange, export opportunities, employment and income generating opportunities via a strong dynamic value chain to all economies regardless of their status in development terms.

As the industry develops through new investors in ethanol and sugar production, and diversifies into electricity production and the development of downstream products, the importance of a flexible and dynamic regulatory and monitoring framework increases. There are a number of reasons why an industry should begin to consider some form of regulatory framework but more recently, a significant influencing factor is the increased scrutiny of private sector industry by many national and international Government, non-government and consumer bodies. This direct interest leads to an increased need for transparency of operations, participatory representation of all stakeholders, good governance and accountability, which, if not governed by existing national frameworks or initiatives, can be aided by an industry regulatory framework.
Legal regulation in the sugar industry is implemented through a variety of different routes dependent on the policies of Government, the enforcement and monitoring capacity of its existing legal framework and the stage and capacity of the industry itself. Many countries use Sugar Authorities or Sugar Boards as governing regulating bodies, some of which are parastatal and others are more participatory with stakeholder representatives. Legal controls and regulations are generally prescribed through a Sugar Act and/or Sugar Industry Agreement, a legal document which details the conditions of operation within the country. The Act or Agreement is often very detailed and comprehensive and covers a number of issues, including:

The roles and responsibilities of industry stakeholders and supporting institutions:

- Sugar Boards or regulating bodies – how they are governed and the scope of activities and responsibilities.
- Sugar research institutions – how they are governed and operated, research areas, information dissemination and commercial activities.
- Training institutions – how they are governed and operated, who they cater for, thematic subject areas, funding and commercial activities.
- Industry funding institutions – how funds will be sourced, dispersed and managed.

Cultivation of sugarcane:

- Cultivar control – importation, breeding and penalties for the use of non-approved cultivars.
- Crop husbandry – regulations limiting the use of certain chemicals and providing guidelines and legal limitations for certain practices to improve performance.
- Pest and disease management – guidelines for controlling P&D, legal limitations to chemical use, restricted growing areas, penalties for non-compliance with control measures, and allocation of responsibilities for control.

Licensing and registration:

- Growers – the legal registration of cane suppliers incorporating details of growers and land areas.
- Processors and refiners – provision of licences to process sugarcane supplemented by processing guidelines and regulations.
- Traders – provision of import and export licences for sugar.

The administration and financial management of the industry bodies:

- Asset management – what physical assets the industry can own.
- Human resources – how the regulating bodies are managed and supported.
- Arbitration routes – how industry disputes are managed.

Whilst Sugar Acts are useful for establishing regulations and standards, and guiding industry development, they can also be cumbersome – being slow to change and react to industry development. If not cautious, the number of regulatory bodies that are established can become a burden to the efficient operation and development of an industry. Interestingly, the major growth in the Brazilian industry has occurred since deregulation, supported by industry self-regulation and strong national laws, yet in Africa, many countries not yet regulated are driving towards it. The need for industry regulation can depend heavily on the general legal environment of a company, e.g. if there exists a strong national environmental department and framework that is monitored and enforced effectively, there is less need for an industry specific regulation and guideline, as the rule
will be simply to meet national legal standards. However, where capacity is lacking in key areas of national government to enforce legal standards, there is more of a need to regulate in an industry specific manner. It is important that the framework adopted must be dynamic and support innovation, thus allowing industry to adapt efficiently to changes in innovation and market demand.

A regulatory framework can establish a ‘level playing field’ for all stakeholders within the industry, setting basic standards on which good management practices can be developed. Different stakeholders have different views on the value, roles and responsibilities of a regulatory framework, and these ideas differ according to the role of the stakeholder and the perceived power of the organization. Some stakeholders believe that regulating an industry is necessary to control income flows to the Government and to ensure that operations are undertaken within the legal requirements of the country. Others see a regulatory framework as a way to build harmony between the stakeholders, develop operating standards and strengthen business relationships, resulting in a more efficient industry beneficial to all stakeholder groups. It is important to understand that there is no single framework, Act, Bill or regulatory body for the sugar industry that suits all environments, and each is governed by the laws of the country in which the industry operates.

A regulatory framework should add value to an industry rather than confine and subdue development of commercial operations; the risk of a heavily regulated industry is not only the cost but the difficulty in decision making procedures, and also in changing the business focus to react to the fluid changes of the market and industry. Mauritius, for example, as a well established industry that has recently been forced to consolidate and streamline activities due to market changes, has an extremely complex and heavy regulatory framework that can cost 6-8% of gross revenue. With the changes taking place and the move away from sugar as the main product into a cane cluster approach, the industry is considering refining the regulatory framework and streamlining or merging a number of the organizations to reflect the dynamics of the industry. However, changing the regulatory framework is a lengthy process. The advantages and disadvantages of regulating an industry are presented briefly below.

The advantages can be listed as:

- Strengthening weaker industry stakeholders.
- Creating a level playing field on which to base operational standards.
- Developing and enforcing industry operating standards.
- Improving transparency and accountability.
- Improving representation, unity and communication within the industry and external stakeholders.

The potential disadvantages of regulating an industry can be listed as:

- The creation of an autonomous regulatory body is difficult and time consuming.
- Regulation in many countries is a lengthy process.
- Over-regulation can hamper necessary developments in the industry to meet market and technical demands.
- Cost of regulation and supporting the implementation is high.
- Industry self-regulation may lack enforcement mechanisms.
- Regulation may impose further pressure on low capacity stakeholders.
- Increased bureaucracy where stakeholders are already regulated through existing laws.
Although the development of a legal regulatory framework is an area that companies have little influence over, it is important that companies engage with other stakeholders to address the most suitable structure for the situation, and develop or manage a framework in a participatory and transparent manner that reflects the needs of all stakeholders.

2.2 Market driven regulation

Many least developed countries (LDCs) and emerging economies across the world have experienced a significant increase in interest and investments in the sugar industry over the past decade as European countries source sugar and ethanol to satisfy increasing market demand. Despite this positive growth in many countries, others are being forced to diversify from the sugarcane industry or streamline activities within the industry due to the removal of subsidy programs and increased competition. These changes in the dynamics of the industry have raised its public profile and consumers are increasingly aware and conscious of the plight of the smaller stakeholders and the sustainability of the industry. Consumers are beginning to demand that companies demonstrate improved social awareness and do more to support the development of the rural poor and conserve the environment. Consumer expectations have risen as awareness of the plight of many LDCs has increased through more interactive media and ease of communication. In response to the increased knowledge of conditions in rural areas and processing industries in developing countries, markets are beginning to set standards and demand equity throughout the value chain, and that human rights and social development be considered within the value chain.

With this raised profile of trade as a potential development tool has come an increase in the number of Non-Government Organizations (NGOs) acting as ‘consumer watchdogs’, promoting social and environmental awareness within industries. The sugar industry itself has a number of specific institutions monitoring its activities and engaging where necessary with stakeholders to improve the conditions of the more marginalized communities and stakeholders. One such organization is Ethical Sugar (2010), a non-profit civil society organization established to, “protect human rights and progress social and environmental standards in the global sugarcane industry.” The organization partners with a number of high profile organizations and acts as a communication and dialogue platform that brings together stakeholders to raise awareness of social issues within the sugar sector, and more recently also the biofuel sector. In addition to participatory communication initiatives it produces studies on social impacts of the industry in some of the major sugar producing countries, and provides recommendations on improving social and environmental welfare within these industries. The organization welcomes engagement with corporations, civil society organizations and standards organizations to improve the industry. Further information can be found at www.sucre-ethique.org.

Many other high profile NGOs and civil organizations are also engaged in the sugar industry at varying levels. The World Wildlife Foundation, in its mission to, “stop the degradation of our planet’s natural environment and build a future in which humans can live in harmony with nature” and to, “save bio-diversity and reduce humanity’s impact on natural habitat”, has engaged with a number of producer countries to improve sugarcane management practices to protect the environment. The organization focuses on the main environmental impacts of cane agriculture, and works with specific experts and stakeholders to address and mitigate against the impacts. Further information can be found at http://wwf.panda.org.

In addition to civil society actions and pressure groups a number of market driven sustainability initiatives have developed over the past two decades to provide further economic justification for the adoption of improved and sustainable management practices. Consumer demands for sustainable and equitably produced goods and products are increasing the focus on human resource
management. The global media has raised the profile of working conditions of direct and indirect employees and suppliers through exposés of numerous high profile companies and brands resulting in instant condemnation. The development of global supply chains has in many cases unwittingly exposed previously responsible companies to businesses that breach laws and standards in relation to workers’ rights. Thus it is becoming increasingly necessary and important for companies and industries to adopt a comprehensive corporate Code of Conduct to govern human resource management and supply chain relationships to minimize their own risk of adverse exposure.

Codes of Conduct are becoming more common with companies and industries due to many large buyers designing and implementing their own codes and standards to govern their supply chain. Although there are significant positive impacts to setting and monitoring standards to improve conditions and sustainability, the negative impact of these multiple initiatives is the number of codes that a supplier or processing company may need to adhere to and manage. These multiple initiatives can result in significant strain on business resources, as companies have to implement and audit the necessary standards. In addition, whereas there are a number of codes of conduct and standards that companies are required to adhere and report to, it is difficult for stakeholders and consumers to assess the effectiveness and professionalism of the interventions. There are organizations that set the ‘standards for standards’ and will certify approved initiatives to enable stakeholders to be comfortable that the initiatives are implemented appropriately, the most common being ISEAL Alliance (www.isealalliance.org). The ISEAL Alliance audits and certifies many major standards and codes of conduct such as Fair Trade (FT), the Forestry Stewardship Council (FSC), the Marine Stewardship Council (MSC), and the International Organic Accreditation Service (IOAS), and is known as an organization to ensure credible standards. In addition, for labor standards the predominant assessment organization is Social Accountability International (SAI); a non-governmental, multi-stakeholder organization whose mission is to advance the human rights of workers around the world. SAI developed the Social Accountability 8000 standard; an auditable standard establishing voluntary requirements for employers globally to meet in the workplace to improve workers’ rights and conditions. Further information about SAI and the SA 8000 standard can be accessed at www.saintl.org.

Given the constraint of multiple codes of conduct and the pressures that they place on companies, many industries have moved towards the development of industry codes of conduct supported by consumers and buyers. This industry wide approach will streamline initiatives and interventions to enhance sustainability and good practice certification. Within the sugar industry the main two market driven industry sustainability initiatives are the ‘Bonsucro: Better Sugarcane Initiative’ and Fair Trade. In addition to these, niche markets also demand organically produced and certified sugar.

### 2.2.1 Bonsucro

Bonsucro is a multi-stakeholder action established to reduce the environmental and social impacts of sugarcane through the development of principles and criteria leading to certification to be adopted by member organizations to promote sustainability. Some of the world’s largest sugar buyers have signed up to the initiative and are increasingly demanding that their suppliers demonstrate sustainability and responsibility in their business functions. Bonsucro “aims to improve the social, environmental and economic sustainability of sugarcane by promoting the use of a global metric standard, with the aim of continuously improving sugarcane production and downstream processing in order to contribute to a more sustainable future” (Bonsucro 2011). Bonsucro has designed a working Standard and certification process based on indicators measuring outcomes and not management practices. Metric indicators encourage and provide a means of measuring continuous improvement by producers. Bonsucro will work on the market to increase demand for sustainably certified products by promoting the standard and its intent to further drive the industry
uptake and therefore improve the industry. Bonsucro also provides an industry platform to promote open discussion on sustainability and continuous improvement with a goal of, “transforming the industry” (Bonsucro 2011).

The Standard incorporates a set of ‘Principles, Criteria, Indicators and Verifiers’ which will be used to guide and certify producers and processors in compliance, and aid sugar and ethanol feedstock procurement processes in obtaining sustainable goods and investors looking for opportunities in the industry. The Standard will cover operations from field to market, incorporating all links in the value chain, and is intended to create a document which will be checked by certified auditors. The Standard has been recently amended to suit the requirements for ethanol production for the EU market. Bonsucro has begun an accreditation process for the auditing of corporations looking for certification.

Companies are encouraged to join Bonsucro and, in doing so, members undertake to conform to the five guiding principles listed below.

**Box 2.1 Summary of Bonsucro’s five guiding principles**

**PRINCIPLE 1.** Obey the law.

1.1 Comply with relevant applicable laws.

1.2 Demonstrate clear title to land in accordance with national practice and law.

**PRINCIPLE 2.** Respect human rights and labor standards.

2.1 Comply with ILO labor conventions governing child labor, forced labor, discrimination and freedom of association and the right to collective bargaining.

2.2 Apply Bonsucro human rights and labor standards to suppliers and contractors.

2.3 Provide a safe and healthy working environment in workplace operations.

2.4 Provide employees and workers (including migrant, seasonal and other contract labor) with at least minimum national wage.

2.5 Provide clear, equitable and comprehensive contracts.

**PRINCIPLE 3.** Manage input, production and processing efficiencies to enhance sustainability.

3.1 Monitor production and process efficiency; to measure the impacts of production and processing so that improvements are made over time.

3.2 Monitor global warming emissions with a view to minimizing climate change impacts.

**PRINCIPLE 4.** Actively manage biodiversity and ecosystem services.

4.1 Assess impacts of sugarcane enterprises on biodiversity and ecosystems services.

4.2 Implement measures to mitigate adverse impacts where identified.

**PRINCIPLE 5.** Continuously improve key areas of the business

5.1 Train employees and other workers in all areas of their work and develop their general skills.

5.2 Continuously improve the status of soil and water resources.

5.3 Continuously improve the quality of sugarcane and products from the mill.

5.4 Promote energy efficiency.

5.5 Reduce emissions and effluents. Promote recycling of waste streams where practical.

5.6 Foster effective and focused research, development and extension expertise.

5.7 For Greenfield expansion or sugarcane projects, to ensure transparent, consultative and participatory processes that address cumulative and induced effects via an environmental and social impact assessment.
5.8 Ensure active engagement and transparent, consultative and participatory processes with all relevant stakeholders.
5.9 Promote economic sustainability.

www.bonsucro.com

The Production Standard was developed through three working groups: social and labor; processing and milling; and agriculture. The Standard also lists specific criteria and conditions for special markets and provides detailed guidelines for each criterion to facilitate progress by members. The system incorporates a Chain of Custody standard to ensure traceability of all products and materials throughout the supply line. It has not yet been established whether a market premium is available for certified sugar; however, a number of NGOs have sourced funds from the market place to work with outgrower to develop standards and procedures which will enable them to become certified.

The ultimate aim of Bonsucro is that, as the profile of sustainability increases, the market will demand that sugarcane products are sustainably certified and that the Bonsucro Standard will provide the necessary security to meet the demand. Those parties interested in joining Bonsucro and becoming certified can download further information, an application pack and guidance notes from www.bonsucro.com.

2.2.2 Fair Trade International

Box 2.2 Main role of Fair Trade International

Fair Trade International, formerly known as the Fair Trade Labelling Organization (FLO), offers an opportunity for consumers to choose products that they can be certain have been produced in a fair and equitable way through its Fair Trade (FT) standards and branding.

“Fair Trade is a trading partnership, based on dialogue, transparency and respect, that seeks greater equity in international trade. It contributes to sustainable development by offering better trading conditions to, and securing the rights of, marginalized producers and workers – especially in the South. Fair Trade organizations (backed by consumers) are engaged actively in supporting producers, awareness raising and in campaigning for changes in the rules and practice of conventional international trade. Fair Trade's strategic intent is:

- deliberately to work with marginalized producers and workers in order to help them move from a position of vulnerability to security and economic self-sufficiency
- to empower producers and workers as stakeholders in their own organizations
- to actively play a wider role in the global arena to achieve greater equity in international trade.”

www.fairtrade.net

The FT logo has become internationally recognized and its reach into markets and producer groups has spread significantly since its conception in the 1950s as a partnership between importers and development charities to alleviate poverty through improved market prices and the reduction of power of the ‘middleman’ or ‘intermediary’. The market for FT goods has grown considerably and rapidly over the past two decades as the consumer social conscience has developed and consumers become more aware of where their food and products come from. FT enables the producers to directly access the northern markets and be paid a premium price for their goods. Over the years FT has developed a range of brands for commodities and unique market access points, and incorporates a wide range of raw and processed products including sugar, tea, coffee, cocoa, fruit and fruit products, cotton, flowers, honey, nuts, rice, herbs and spices, wine, sports equipment and gold.
The initiative operates by selling a product at a premium (usually in markets in the northern hemisphere, although FT is becoming popular in emerging markets) which is passed back to the FT committee. The FT premium is an additional sum of money that is used by producers to improve conditions.

The FT standard is aimed at two specific groups, (i) ‘small producers’, so in the sugar industry it would specifically engage with small scale outgrowers, and (ii) ‘hired labor’ for companies wishing to improve the livelihoods of their employed labor. The certification standards are ISO 65 certified and certification services are available in more than 70 countries. Applicants will be required to operate as an association or cooperative which they govern democratically. This association will need to establish a FT committee comprising the producers and/or labor to manage the process, payments and investments. Investments can be made in social, environmental and business development. The producers are expected to conform to a number of standards, including environmental standards that restrict the use of agrochemicals. The organizations will be able to access pre-harvest credit to support operations. There are initial application fees and ongoing annual fees and strict guidelines and conditions for the certification standards. FT provides significant capacity building of the producers and labor to facilitate management; however, in the sugar industry, it may be advantageous for the miller to aid initial contact and development. There is a requirement for the mill to become certified as a processor, and there are a number of standards to which the mill must conform.

There is an on-line inquiry system where organizations can check whether or not there is an applicable FT standard and to ascertain suitability (www.flo-cert.net).

**Box 2.3 Fair Trade for small scale sugarcane outgrower producers**

The Kasinthula Sugarcane Growers Scheme in Malawi is FT certified with a committee made up of farmers and hired labor. The scheme produces approximately 8 000 tonnes of sugar which is exported to Europe for the FT market. The FT committee receives a premium of $60 per tonne of sugar equating to approximately $480 000 per annum. The committee has implemented a number of social and community improvement projects over the years including, but not limited to, the building of an under fives clinic and funding of staff to support the clinic, the building of accommodation for the clinic staff to attract qualified persons to the rural area, improvements to school buildings and equipment, rural electrification and housing infrastructure improvement, provision of safe water supplies to surrounding villages, and financial support to supplement an EU grant to expand the scheme to incorporate more farmers.

**2.2.3 Organically certified sugar**

Organic farming is founded on a holistic management approach which promotes the improvement of the health of the soil and ecosystem to improve crop development and yields. Organic farming looks at long term sustainable management practices which address the cause of problems rather than applying immediate solutions. Organic farming improves the health of the agro-ecosystem related to biodiversity, nutrient bio-cycles, soil microbial and bio-chemical activities (Kshirsagar, 2006). Organic farming emphasizes management practices involving substantial use of organic manures, green manuring and management of pests and diseases through the use of non-synthetic pesticides and practices (Kshirsagar, 2006).

Although there is significant market demand for organically certified sugar, the reality of producing the product is significantly more complex than perhaps perceived, due to the requirement that the process is organic from field to market. Organic production of sugarcane is not unusual in many countries. After a period of three to five years, organic farming can result in increased profit due to the low cost of inputs and higher productivity, using scientifically advanced and traditional soil
management techniques that avoid chemical inputs. The processing of the cane in an organic way is more difficult because the usual chemicals cannot be used in the process. This leads to low yields in the factory and a poorer quality product. In a number of instances this has led to processors abandoning this route as being uneconomical.

Organic food production is subject to statutory control. Once producers or processors decide to undertake organic food production and processing, they become subject to strict regulations according to their certification body. A comprehensive list of certification bodies is available in the ‘Organic certification directory’ which is available for purchase from www.organicstandard.com.

Those countries operating under the UK and EU standards, to which any exports into the EU will be required to subscribe, will be regulated by law which specifies a number of key standard issues, including:

- Management of a Control or Inspection Authority to implement the law and standards
- How organic products must be labeled.
- How the agricultural ingredients must be produced.
- What inputs are permitted for soil fertilizing and conditioning, and control of pests and diseases.
- How organic products must be processed.
- What additional non-organic ingredients, non-agricultural materials such as additives and processing aids may be used.
- The minimum inspection requirements to which all organic operators must be subject.
- The penalties which must be imposed when infringements of the Regulation are discovered.
- The mechanism by which amendments to the Regulation can be made.

The outcome of any organic regulation is that a producer, processor, or an importer of organic food from a non-EU country must be registered with an approved certification body and undergo regular inspections to ensure that they conform to the strict organic standards required. Only then, after vigorous auditing, can the products be labeled and marketed as organic. The benefit to an organically certified producer and processor will be access to a high price niche market and the development of low input sustainable management techniques.

### 2.2.4 Partner organizations

It is becoming increasingly common for partner organizations, particularly financing and investment partners, to develop standards for clients to facilitate sustainable management and to reduce their risk. The International Finance Corporation (IFC) has developed a range of performance standards and guideline documents to direct their investment officers in sustainable management and to enhance investments.
### Box 2.4 An overview of the IFC’s Performance Standards on Social and Environmental Sustainability

The International Finance Corporation (IFC) applies Performance Standards to manage social and environmental risks and impacts and to enhance development opportunities in its private sector financing. Together, the eight Performance Standards establish standards that the investors must meet throughout the life of an investment by IFC or other relevant financial institution:

- **Performance Standard 1**: Social and Environmental Assessment and Management System
- **Performance Standard 2**: Labor and Working Conditions
- **Performance Standard 3**: Pollution Prevention and Abatement
- **Performance Standard 4**: Community Health, Safety and Security
- **Performance Standard 5**: Land Acquisition and Involuntary Resettlement
- **Performance Standard 6**: Biodiversity Conservation and Sustainable Natural Resource Management
- **Performance Standard 7**: Indigenous Peoples
- **Performance Standard 8**: Cultural Heritage

**Performance Standard 1** establishes the importance of managing social and environmental performance throughout the life of a project. The standard promotes the development of an effective and dynamic social and environmental management system to be developed in a participatory fashion by the company, its employees, and the affected communities. The management system should be based on the recommended process of ‘plan, implement, check, and act’. The system should comprise the thorough assessment of potential social and environmental impacts and risks and provide order and consistency for mitigating and managing these on an ongoing basis. A good management system will promote sound and sustainable social and environmental performance, and can lead to improved financial, social and environmental project outcomes.

**Performance Standard 2** recognizes that the pursuit of economic growth through employment creation and income generation should be balanced with protection for basic rights of workers. Companies should acknowledge that the workforce is a valuable asset and that a favorable worker-management relationship is an important ingredient to success and can produce tangible benefits. Failure to establish good relationships can undermine productivity and job retention, and can jeopardize a business.

**Performance Standard 3** acknowledges that increased industrial activity can generate increased levels of pollution to air, water, and land that may threaten people and the environment at the local, regional, and global level. The Performance Standard outlines a project approach to pollution prevention and abatement in line with internationally disseminated technologies and practices. In addition, it promotes the private sector’s ability to integrate such technologies and practices as far as their use is technically and financially feasible and cost effective in the context of a project that relies on commercially available skills and resources.

**Performance Standard 4** recognizes that project activities, equipment, and infrastructure can often bring benefits to communities including employment, services, and opportunities for economic development. However, conversely, projects can also increase the potential for negative impacts from the activities including impacts on their natural resources and exposure to diseases. While acknowledging the role of public authorities in promoting the health, safety and security of the public, this Performance Standard addresses the client’s responsibility to avoid or minimize the risks and impacts to community health, safety and security that may arise from project activities.

**Performance Standard 5** focuses on land acquisition and the related resettlement and compensation programs that may be required during the development of a business. The Standard reflects good practices for developing resettlement, and compensation plans for both voluntary and involuntary resettlement. The Performance Standard strongly recommends the avoidance of involuntary settlement unless absolutely necessary due to the potential negative impacts on both affected communities and business relationships. Where necessary to use it, the Performance Standard provides recommendations or resettlement techniques and packages. Businesses are encouraged to acquire land rights through negotiated settlements wherever possible.
**Performance Standard 6** recognizes that protecting and conserving biodiversity is fundamental to sustainable development. The components of biodiversity, as defined in the Convention on Biological Diversity, include ecosystems and habitats, species and communities, and genes and genomes, all of which have social, economic, cultural and scientific importance. This Performance Standard reflects the objectives to conserve biological diversity and promote use of renewable natural resources in a sustainable manner, and addresses how businesses can avoid or mitigate threats to biodiversity arising from their operations as well as sustainably manage renewable natural resources.

**Performance Standard 7** acknowledges that Indigenous Peoples, as social groups with identities that are distinct from dominant groups in national societies, are often among the most marginalized and vulnerable segments of the population. Their economic, social and legal status often limits their capacity to defend their interests in, and rights to, lands and natural and cultural resources, and may restrict their ability to participate in and benefit from development. They are particularly vulnerable if their lands and resources are transformed, encroached upon by outsiders, or significantly degraded. Their languages, cultures, religions, spiritual beliefs, and institutions may also be under threat. These characteristics expose Indigenous Peoples to different types of risks and severity of impacts, including loss of identity, culture, and natural resource-based livelihoods, as well as exposure to impoverishment and disease. Private sector projects may create opportunities for Indigenous Peoples to participate in, and benefit from project related activities that may help them fulfill their aspirations for economic and social development.

**Performance Standard 8** recognizes the importance of cultural heritage for current and future generations. Consistent with the Convention Concerning the Protection of the World Cultural and Natural Heritage, this Performance Standard aims to protect irreplaceable cultural heritage and to guide clients on protecting cultural heritage in the course of their business operations.

The IFC has developed a comprehensive set of guidelines to aid companies to meet these performance standards.

A revised set of performance standards will be available from October 2011.  

(IFC, 2007. www.ifc.org)

A general guide linking both the IFC Performance and Bonsucro standards that have relevance to the production topic covered in each chapter is given in Appendix 5.
3. HUMAN RESOURCE MANAGEMENT

Human resources are the most interesting, complex and difficult to manage resources available to an organization. Equally, their importance to a company is unquestionable; there are few, if any, organizations and industries that can operate without them. As detailed previously, the profile of this resource and how it is managed is escalating; markets and consumers are placing increased pressure on companies to develop responsible and supportive human resource management practices. As a response to this demand a number of standards, codes of conduct and good management practices have been designed by a variety of specialist organizations to guide companies in developing their own management systems and practices.

3.1 Compliance

Companies wishing to engage in responsible human resource management programs must comply with a wide range of international labor standards in addition to upholding national laws and regulations. Compliance may require an investment to improve labor standards, and some companies will consider this a significant additional expenditure rather than an investment. However, many companies that have undertaken to improve standards have witnessed tangible economic benefits from the improvements (SAI and IFC 2010). Increasingly, companies are viewing improved labor standards as an investment that will produce economic returns through improved productivity and standards of work, in addition to reducing the risk of damage to a company’s reputation (SAI and IFC 2010). Companies are also becoming increasingly aware of their responsibility to monitor standards of labor conditions in their supply chains, as these too present a risk to the company’s operations.

Whatever the motivation for the decision to improve human resource conditions and management systems, it can be expected that positive results will be forthcoming, as better conditions will improve the relationship between the company and the employees and better relationships will result in lower staff turnover and improved productivity. Although baseline standards and conditions will differ by company and country, the basic standards and principles that must be met and conformed to will remain the same. SAI have developed a compliance standard SA8000 and a guidance document to aid companies to improve workers’ rights and conditions (www.sai-intl.org).

The IFC Performance Standard 2 has been guided by a number of international conventions instigated and negotiated by the International Labor Organization (ILO), the United Nations (UN) and the SA8000 standard, and thus provides a comprehensive standard to be implemented by companies wishing to improve human resource management (IFC 2007b). The overall objectives of Performance Standard 2 are to:

- establish, maintain and improve the worker-manager relationship
- promote the fair treatment, non-discrimination and equal opportunity of workers and compliance with national labor and employment laws
- protect the workforce by addressing child labor and forced labor
- promote safe and healthy working conditions, and to protect and promote the health of workers.

In addition, the Bonsucro standards Principles 1, 2 and 5 also present a range of standards to be met specifically by sugar industry stakeholders wishing to be certified.
3.1.1 International labor conventions

The foundations of most labor standards or codes of conduct come from the International Labor Organization and the Universal Declaration of Human Rights (SAI and IFC 2010). The countries which have ratified these conventions are obliged to reflect and integrate them into their own national labor laws. The first standard for companies to adopt is to obey the laws of the country in which they are operating (Bonsucro Principle 1).

With reference to human resource management, the sugar industry is recommended to comply with the following international standard instruments:

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<th>Box 3.1 Summary of International labor conventions</th>
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<tr>
<td><strong>ILO Convention 1</strong></td>
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Source: SAI: SA8000 and Bonsucro Production Standard Annex 2

In some situations, particularly countries with weak legislative frameworks and enforcement systems, and poor social service support and income levels, compliance may not be sufficient and should be considered as a minimum standard. Industries and companies are encouraged to engage in initiatives that go above and beyond the compliance standard. Brazil has one of the most comprehensive legislative frameworks and strict labor standards in the industry. The legislation incorporates the international conventions and extends significantly further to protect labor and improve working conditions, thus the industry will be used as a case study for labor improvement initiatives.

Despite its comprehensive legislation, in some states the enforcement and monitoring capacity remains low. The sugar industry in Brazil has also come together to improve labor conditions
through the development of a “National Commitment to Improve Labor Conditions in the Sugarcane Activity”. This comprehensive agreement developed through a participatory tripartite dialogue process, business, workers and government, aims to establish new rights and improved livelihoods for sugarcane workers. The dialogue process to develop the commitment focused on developing a commitment with two main objectives:

- To make manual cultivation of sugarcane more human and safe
- To promote occupational inclusion of workers who have become unemployed through mechanization (General Secretariat of the Presidency of the Republic, 2009).

The dialogue was based around eighteen discussion points:

- Working contracts
- Accommodation
- Schooling qualifications and relocation
- Meals
- Union organization and collective negotiations
- Community development
- Transparency in measurement of production
- Working hours
- Working conditions in the production chain
- Labor health and safety
- Transport
- Remuneration
- Child labor and forced labor
- Unemployment protection
- Programme for social assistance
- Migrant
- Child labor
- Production work
- Decent labor and labor similar to slavery

The Commitment provides the basis for establishing a set of actions to improve labor working conditions and assigning responsibilities to stakeholders to ensure implementation. The Commitment details measurable activities linked to good management practices that will be implemented in the sugar and ethanol industries and will be promoted and monitored by government through policies and programs. The National Commitment was signed in June 2009 after almost 12 months of dialogue and signifies a great achievement of unity amongst stakeholders for the improvement of the industry. The National Commitment provides a backbone for labor improvements in the country and equally can provide guidance to other countries in undertaking a similar initiative or can be adapted to suit companies. The commitment is detailed below for reference.

**Box 3.2 National Commitment to improve labor conditions in the Brazilian sugar industry**

**FIRST CLAUSE: THE OBJECTIVE**

The National Commitment has as its objective, the cooperation between the private and public entities represented in this act, to make possible a set of actions destined to improve labor conditions in the manual cultivation of sugarcane, valuing and spreading exemplary business practices.

**SECOND CLAUSE: BUSINESS PRACTICES**

Through voluntary adherence to the National Commitment, the companies promise to respect the following business practices:

I - Work Contract

a) to directly contract its workers for the manual activities of planting and cutting of sugarcane, with registration in the CTPS (Social Security and Laborbook);

b) to use the experience clause in the work contract only once for the same company and same employee, in the hiring of workers for manual activities in the growing of sugarcane; and

c) to eliminate the linking of remuneration for worker transport services, administration and supervision, carried out by their own or third party companies, to the remuneration of workers for the manual cutting of sugarcane, respecting the norms which are part of collective conventions or collective labor agreements which discipline the material.

II - Hiring a Migrant Worker

a) to use the intermediation of the Public Employment System when it is necessary to hire migrant workers in other locations who cannot return to their original municipality after the period of work. In places where there is no Public
Employment System or the number of workers is not sufficient, to hire directly;

b) to register with the Ministry of Labor and Employment a Declaration Certificate, which proves the regular hiring of workers and the conditions of their return to their place of origin at the end of the harvest, for the migrant workers hired in other localities and who are unable to return to their original municipality after the period of work;

c) to ensure good quality accommodation as in accordance with NR31 (Regulatory Norm of Labor Safety and Health in Agriculture, Livestock, Forestry, Forest Exploration and Aquaculture), for migrant workers hired in other localities and who are unable to return to their original municipality after the period of work; and

d) to supply access to means of communication in the accommodation for the workers hired in other localities and facilitate contact with their families.

III - Transparency in Measurement Production

a) to make available mechanisms for the measurement of production previously agreed with the representatives of the workers who manually cut sugarcane, duly written and fully disclosed among the sugarcane cutters, permitting them to evaluate the calculation of the salary due;

b) to inform the price to the employees beforehand and to use compasses with metal points for measuring the sugarcane cut in the presence of the workers, respecting the norms which are part of the collective conventions or collective labor agreements which regulate the subject, whatever the system used for paying the workers - meters, tons or other; and

c) to complete the daily payment corresponding to the basic wage for workers who do not reach such remuneration with their production for that particular day.

IV - Labor Health and Safety

a) to adopt better practices in the management of health and safety and give value to CIPATR (Internal Commission for the Prevention of Accidents in Rural Work);

b) to supply free EPI (Personal Protective Equipment) of good quality with a CA (Approval Certificate);

c) to make an effort, together with the workers, to adapt and improve EPI in rural work;

d) to make an effort together with the workers to make them aware of the importance of the use of EPI;

e) to guarantee two collective rest periods per day, one in the morning and the other in the afternoon;

f) to be strict in the admission exam, making use of complementary examinations when the responsible doctor thinks they are necessary;

g) to promote informative campaigns for workers who manually cut sugarcane, warning them of the importance of rehydration during work in the field, giving them free hydrating serum using at company doctor’s criteria;

h) to adopt, orientate and disclose the practice of labor exercises during the manual activities of planting and cutting sugarcane; and

i) to improve medical attention conditions for workers in manual cultivation of sugarcane in emergency situations.

V - Transport

a) to supply workers with free and safe transport to the rural work areas.

b) for the transport of workers, to maintain a system of control in accordance with NR31 and the legal norms of transport which include:

1. the material condition of the bus or adapted vehicles;

2. registration and licenses of the vehicles;

3. documentation and driving licenses of the drivers;

4. periodic inspection of the vehicles, with one required before the beginning of the harvest;

5. good practice in the use of vehicles;

6. management of the transport system; and

c) adopting a Plan of Mutual Help in Emergencies with agreements and local/ regional integration of private and public services.

VI - Meals

a) to supply a free thermal container - "chow pan" which guarantees conditions of hygiene and the maintenance of temperature; and

b) to ensure that there are tables and chairs for the consumption of food at the places of work.

VII - Union Organization and Collective Negotiations

a) to establish collective negotiations together with workers’ entities, exhausting all agreement possibilities and ensuring observance of the agreed conditions;

b) to ensure access to the workplace for union, federation or confederation officials from their respective territorial bases, if they are duly accredited and have advised the company with due notice, in order to verify eventual problems and seek out solutions together with the company’s representatives; and

c) to orientate team leaders on the importance of respect for union activities.

VIII - Responsibility for the Development of the Community

a) to disclose and support actions relative to education, health, culture, sport and leisure in the communities where the workers are living.

IX - Disclosure of Good Practices

a) to disclose and orientate sugarcane suppliers about the terms of this document and the good business practices adopted by the company.
THIRD CLAUSE: PUBLIC POLICIES
The Federal Government will help and encourage actions aimed at:
I - ensuring the adequacy of the EPI (Personal Protective Equipment) used by workers in the manual cultivation of sugarcane;
II - progressively increasing the services of intermediation offered by the Public Employment System in hiring workers for the manual cultivation of sugarcane;
III - promoting literacy and raising the schooling of workers in the manual cultivation of sugarcane;
IV - promoting the qualification and requalification of workers in the manual cultivation of sugarcane, with a view to their productivity; and
V - strengthening social actions and services in regions of immigration of workers for seasonal activities of the cultivation of sugarcane.

FOURTH CLAUSE: THE PROCESS OF IMPLEMENTATION AND MONITORING
The signatories of this Commitment will constitute “the National Commission for Dialogue and the Evaluation of the National Commitment”, whose attributes will be the following:
I - to establish criteria and procedures to implement, accompany and evaluate the results of the National Commitment, including the possibility of authorizing as independent audit for the activities of monitoring compliance with business practices;
II - to disclose this National Commitment and stimulate the adherence of businesses in the sugar and ethanol activity;
III - to propose and define mechanisms for eventual adjustments in the adherence to and permanence of the terms of this National Commitment;
IV - to deliberate on the establishment and disclosure of the mechanism for recognizing the companies which adhere and comply with the business practices established in this National Commitment; and
V - to propose and debate the revision of this National Commitment.

FIFTH CLAUSE: GENERAL CONDITIONS
This National Commitment will come into force on the date of its signing, with a period of validity of two years, which can be extended with the agreement of all parties.


The strong status of unions and the government in Brazil has resulted in significant improvements in conditions for employees in the sugar industry. Many companies have to provide social facilities for the workforce including canteens, recreation and restroom facilities within the factory site, and similar facilities in the field including shaded areas with access to cold water, catering and restrooms. The standard of these facilities at most companies far exceeds the standard of facilities provided in other countries but also reflects the economic and social environment of the region. The working hours are strictly regulated; employees are only allowed to work for a maximum of 7h 15 min per day and must have a mandatory one hour break, can undertake a maximum of two hours overtime and are not allowed to work seven days per week. At the USJ San Francisco mill the canteen, recreational facilities and restrooms are located outside the factory perimeter and each employee has to swipe a pass to enter and depart the internal environment. At lunch time, the automated security system will not allow an employee to pass back into the factory until the mandatory one hour is over.

3.1.1.1 Child and forced labor

The sugar industry, like many other agribusinesses, is unfortunately still plagued by allegations and occasional examples of the use of child labor and in some regions using forced or slave labor. In the Asian and South American industries, civil society groups such as Ethical Sugar report ongoing use of children in the industry. There are ongoing reports of slavery and child labor in Brazil, particularly in the remote Amazon regions (ILO 2009). In Brazil, the term slavery includes those employees who are paid, but are living and working in unacceptable conditions or indebted labor. In 2002, the ILO and the government of Brazil established a technical cooperation project entitled ‘Combating Slave Labor in Brazil’. The project was designed to build on the initiatives put in place by the government to
identify and eradicate labor abuses through a designated commission and the use of strongly enforced and supported specially trained labor and police officers. The project aimed at the identification of abuses, freedom of the labor and punishment of the companies involved. From the identification stage the government produces and regularly updates a ‘Dirty List’ to name and shame organizations using forced or slave labor (ILO 2009).

UNICA; the Brazilian Sugarcane Industry Association, have spearheaded the role of the sugar industry in the national initiative to combat slave labor and have extended it to include child labor. The industry is trying to regulate these issues by implementing industry guidelines and the national initiative through the use of partnerships with civil society organizations, private sector, NGOs and international organizations. These initiatives enable the industry and external stakeholders and supporting industries such as financial institutions, to take action against any company associated by any link to slavery or child labor through naming, blacklisting and boycotting, using the governments ‘dirty list’. These pacts include links through the supply chain to promote improved supply chain management and monitoring. For example, if a sugar company procures a service or product from a company that is found to use child or forced labor, both the service provider and the sugar company will be placed on the blacklist which will result in a boycott of credit, input and service supplies and product sales until the situation is rectified.

The ILO Minimum Age Convention 138, 1973, states that the minimum age for employment is after the completion of compulsory schooling and note below the age of 15 with the exception of countries where the educational system is not sufficient; after consultation with workers and companies this can be reduced to 14. The ILO takes the stance that work that is not harmful and does not impose on the education of the child or their health and personal development is generally a positive intervention as it contributes to family income and the development of the child (ILO 2008a). Child labor refers to work that is, “mentally, physically, socially or morally dangerous and harmful to children; and interferes with their schooling, by depriving them of the opportunity to attend school or by obliging them to leave school prematurely or by requiring them to attempt to combine school attendance with excessively long and heavy work.” (ILO 2008a). “Child labor is work that deprives children of their childhood, their potential and their dignity, and that is harmful to physical and mental development.” (ILO 2008a).

It is difficult to give a precise dictionary definition of the term ‘child labor’ that is applicable to all situations and all countries. In many low income countries, particularly those heavily affected by HIV/AIDS, the number of child headed households is increasing, resulting in a need for children to be able to earn an income for survival and also in outgrower areas relying on family labor. Given the dire circumstances of some children and the opportunities afforded to them it is difficult to identify and differentiate between ‘acceptable’ forms of work by children and child labor. Whether or not particular forms of work can be called child labor depends on the child's age, the types of work performed, the conditions under which it is performed and the objectives pursued by individual countries. The answer varies from country to country, as well as among sectors within countries, Bonsucro Standard criterion 2.1 states that the company must “…comply with ILO labor conventions governing child labor…” and the supporting notes state that “Work by children on family small holding is only acceptable under adult supervision and when work does not interfere with the child’s schooling and does not put at risk his or her health.” (Bonsucro 2011). There is a handbook available from ILO to guide organizations in the elimination of child labor available for download at: http://www.ilo.org/safework/info/instr/lang--en/docName--WCMS_110148/index.htm

3.1.1.2 Contractual arrangements
Development of clear, understandable contracts of employment between the worker and the employer go a long way towards improving relationships and productivity and towards compliance with good practice codes of conduct. Contracts should be negotiated where possible in a participatory manner to ensure that they are understood and represent the rights and requirements of all stakeholders. Contracts should always be between the worker and the company, eliminating intermediaries and developing stronger relationships. The contracts should clearly demonstrate what services and provisions are to be provided and under what conditions; i.e. health services, housing, nutrition, pension, transport, wages, bonuses, etc. Migrant and temporary workers should be provided with adequate contracts that clearly define the terms and conditions of their employment. Where pay is associated to productivity, clear guidelines and measurement standards should be provided so that employees fully comprehend what is expected of them. Where possible, companies should avoid the use of temporary labor and provide longer term employment to improve the standards of living and security for employees. In turn, this enables companies to retain skilled workers and the investment that they have made in the worker, which will result in improved productivity. The Bonsucro standard criterion 2.5 requires companies “to provide clear, equitable and comprehensive contracts” (or equivalent document), that employees must be aware of their rights and paid in a form and at a frequency that is suitable to them (Bonsucro 2011). Wages should be in line with ILO Convention 95, 110 and 131, and be at least the national legal minimum wage.

The recommended content of a contract according to the Bonsucro standard, which aims to improve the existing legal requirements or provide guidance in the absence of legal requirements, states that the contract should incorporate as a minimum:

- Hours of work
- Overtime payment
- Notice
- Holidays
- Wages and methods of payment (Bonsucro 2011).

Contracts should not discourage workers from joining and supporting workers organizations and groups and should not discriminate against workers that wish to join or form workers organizations (IFC, 2007a).

In many industries a number of non-core activities and services have been outsourced to service providers ideally to enable the company to focus on the core activities of producing sugarcane products. Field labor, in particular cane harvesting labor, is one of the main activities that have been outsourced. Although this can reduce the direct responsibility of the company to manage and provide services for the labor it is imperative that the company retains responsibility for the conditions of labor along its entire supply chain. This issue is identified in the Bonsucro standard 2.2 “to apply. Bonsucro human rights and labor standards to suppliers and contractors” which means that any contractor that is utilized by a Bonsucro certified organization must demonstrate compliance with the identified labor laws and regulations and this compliance will also be measured and audited. Contracted service providers will also be required to demonstrate codes of conduct for labor management (Bonsucro 2011).

3.1.2 Healthy working environment

The provision of a healthy working environment is essential for the development and sustainability of a productive workforce. Guidelines for establishing and implementing a healthy and safe working environment and an Occupational Health and Safety (OHS) management system are provided in parts 1 and 2 of this manual. It is imperative that this information is delivered to employees and the local community stakeholders to ensure compliance and benefit. Procedures need to be imbedded
into daily operations and routines; Sao Marthino company in Brazil implement a programme of employee exercises and discussion groups every morning to warm up muscles and focus employees on the tasks ahead. An external company is contracted to design a range of exercises specifically suitable to the task for the employees to implement before commencing operations. In addition, task teams are required to have short discussions about specific OHS subjects on a daily basis.

OHS initiatives must receive extensive and comprehensive visibility to ensure understanding and compliance by all employees. This visibility can be aided through:

- Posters and awareness campaigns
- Face to face organized training
- Toolbox talks at the beginning of daily activities to ‘remind’ workers about OHS practices relevant to their activity
- Exchange visits/audits between departments
- Regular policy/practices review
- Competitions
- Exposure of incidents.

There are a considerable number of handbooks and aids available for companies to improve OHS management systems through the main standards organizations and through international organizations such as ILO in addition to the guidance notes from Bonsucro.

3.1.3 Human resource development

The development of the workforce is a key element of the successful operation of a company. The sugar industry in many countries is currently suffering from a skills gap as young graduates move away from agriculture and processing into service related industries. With this in mind, it is important that companies retain employees and develop strong internal development plans to maximize existing resources and attract new resources.

Training and development within the industry should adopt a holistic approach which incorporates the development of industry and personal skills to result in optimum productivity and achievements. The utilization of external expert resources for industry and skills specific training such as the agricultural training packages operated by the related sugar industry organizations will significantly supplement internal training programs by providing strong foundations. Training programs should be industry specific and combine theoretical with field training. Employees need to be able to see a clear development plan for their careers and skills enhancement providing them with targets and rewards to maximize commitments.

3.1.3.1 Retrenchment and retraining programs

As operations within the industry become mechanized due to market changes, industry consolidation, improved technology and environment based changes such as green harvesting, there has been a significant reduction in labor requirement. Whereas this suits some industries suffering from labor shortages such as India, other countries such as Brazil and Mauritius have had to develop comprehensive retrenchment and retraining programs to support the former sugarcane workers. Mauritius was significantly affected by the European Union market changes in 2006 and utilized funds from the European Union Accompanying Measures Sugar Protocol, a response strategy from the EU to mitigate against negative impacts of the move away from subsidized quotas to develop a retraining programme to support sugar industry workers. The former workers were retrained as
sugarcane or alternative crop outgrowers, or as craftsmen or were provided with hospitality industry skills. The programme has aided the diversification away from sugarcane for those affected citizens.

**Box 3.3 Cane cutter retraining programme in the Brazilian sugarcane industry**

UNICA, in Brazil developed a multi-stakeholder initiative, the RenovAção project which commenced in 2009 in partnership with the largest labor union representing sugarcane cutters in São Paulo State, the Federation of Rural Workers of the State of São Paulo. In addition, in 2010 UNICA signed an agreement with Solidaridad, a leading international NGO with renowned expertise in sustainable commercial value chain development. The role of Solidaridad in the partnership is to strengthen the reach and implementation of the project and to increase the focus on gender equality and inclusion. RenovAção is also supported by the Inter-American Development Bank and sponsored by industry private sector partners. The project is a response strategy to mitigate the impacts of the expected loss of over 70,000 cane cutting jobs due to mechanization. The programme aims to retrain 7,000 former cane cutters per annum in skills areas within the industry to support the mechanization process in roles such as mechanics and drivers, or in alternative industries such as construction, catering and sports equipment manufacturing. In addition the program supports literacy training of the beneficiaries to supplement the skills learned.


### 3.1.4 Gender equality

The importance of women in rural economies is a well-documented fact. The multiple roles that they hold within the economy and the opportunities that they afford present sound prospects for sustainable poverty alleviation. However, these opportunities are persistently diminished by gender inequities that limit their access to decent work, which is necessary for economic empowerment, social advancement and political inclusion. Women continue to be discriminated against in many sugar producing countries in access to land, credit, technology, extension services and training, along with the ability to join representative organizations such as farmer associations and workers unions. These economic inequalities are often further aggravated by cultural, religious and social values and practices (FAO, IFAD and ILO 2010). In addition to meeting the ILO standards and legal requirements, companies must recognize the value of women in the workplace and develop active recruitment and training policies to encourage women in the industry.
4. SOCIAL WELFARE AND COMMUNITY INITIATIVES

When undertaking an Environmental and Social Impact Assessment, experts would consider the labor, their families and communities around the proposed site as ‘affected communities’. This is due to the fact that what the business does and how the business does it will have an impact on their livelihoods, either positive or negative. It is therefore the responsibility of the company to reduce any potential negative impacts and increase the positive impacts of its presence to these affected communities.

Negative social impacts are often aggravated by a lack of available information, poor communication and deficient preparation, making it difficult for communities to make free and informed decisions and understand what to expect. Mitigating against negative impacts and subsequent damage is often assisted by good communication at an appropriate level and transparency of operations and plans. Companies will benefit greatly from the development of comprehensive community engagement processes to develop communication platforms for discussion and decision making. The process must be developed with the capacity of the community in mind to facilitate the development of skills and resources to aid understanding; e.g. as women are generally the decision makers in issues regarding health, any initiatives or interventions that will affect health or healthcare services should incorporate women in the decision making process (IFC 2007a). Companies are responsible for improving the conditions and livelihoods of their stakeholders as a core function and aim of their operations, not solely as a ‘corporate social responsibility’ initiative. Ultimately, companies need labor and community support for sustainable and efficient operations and any initiative to improve the livelihoods of the labor and communities will have a positive impact on productivity.

The link between health and productivity has been well established and documented over the past three decades; poor health equates to low productivity and equally improved social services and living conditions will equate to improved productivity (ILO 2010). Unfortunately, the situation of the poor, who account for the majority of the sugar industry workforce, remains a problem for the industry and governments alike. Low income groups generally face higher levels of exposure to health risks, mainly as a result of poor quality housing and sanitation, bad nutrition, poor access to clean water, and working in hazardous jobs (ILO 2010). In addition, the low income groups also have financial constraints caused by the relatively high levels of illness and death within the family, and are not well placed to cater for the direct and indirect costs associated to ill health and death – leaving them unable in many instances to gain health care. Without intervention, the cycle continues and the situation worsens negatively affecting the industry.

4.1 Welfare service provision

Social welfare and the required provision of social services, particularly in low income countries where capacity of the state to intervene and provide support structures is low, often become the responsibilities of the industry. The ILO states, “when multinational enterprises operate in developing countries ... they should provide the best possible wages, benefits and conditions of work, within the framework of government policies. These should be related to the economic position of the enterprise, but should be at least adequate to satisfy basic needs of the workers and their families. Where they provide workers with basic amenities such as housing, medical care or food, these amenities should be of a good standard.” (ILO 2006). It is imperative for efficient industry development that social welfare is catered for and the industry will need to shoulder the burden where necessary and provide the necessary support structures and services.
4.1.1 Housing

As sugar is produced predominantly in rural areas due to the land requirements, and often in LDCs, it is common, particularly in estate cane areas, for processing companies to provide housing for staff during their periods of employment. Many skilled staff members are brought into the area purely for employment away from their home base. In many LDCs, the local infrastructure and towns do not have the capacity or standards to accommodate the numbers of employees in a suitable manner. Dependent on the scale of the industry, small towns may develop around the mill through the increased flow in income and opportunities, these can present opportunities for employees to live off the estates and facilitate an opportunity to invest in and develop more long term homes, such as at many sites in Brazil and India. In these cases, the companies often provide transport for employees from designated collection points to aid travel expenditure.

Where drawing employees from local communities or where importation of labor is required, companies often need to provide accommodation and develop housing estates. Although these developments are often subject to country standards, the rank of employee and comparable conditions outside of the industry, companies must ensure that they provide their employees with hygienic, safe and suitable accommodation. Inadequately planned and constructed housing with overcrowding, inferior ventilation, waste management and drainage can result in considerable health implications to the workforce and subsequent productivity downturn for the company. It is preferable, where possible, to house employees in properties that they own, to improve long term sustainability and livelihoods or at least provides the employee with security of tenure. It is also preferable to house employees with their families. Facilities to support families should also be considered; recreational and educational facilities and crèches. There are a number of key points to consider when designing employee housing:

- Location of the site, proximity to:
  - The place of work
  - Transport routes
  - Market places and shops
  - Healthcare services
  - Religious institutions
  - Educational facilities

- Supporting infrastructure:
  - Access to electricity or sustainable fuel supply
  - Access routes including roads and safe footpaths for safe passage
  - Provision of comprehensive waste management services
  - Provision of or access to recreational amenities
  - Security provision where necessary.

- Design:
  - Accommodate families
  - Well ventilated
  - Suitably spacious
  - Considerate of cultural traditions.

The houses should be developed to create a feeling of belonging and ownership with initiatives to encourage improved housekeeping and maintenance by the employees, such as best kept village, garden or property competitions, environmental, waste management and hygiene training to encourage good practices and safe environments.
Box 4.1 Example of a well kept employee housing estate

At the Tongaat Hulett owned Tambankula Sugar Estate in Mhlume in Swaziland, the employee housing estates are pristine, due primarily to the company policy to retain staff, provide long term contracts and encourage a feeling of family on the estate. Incentive based management of the housing areas, strong community groups and associations in the different villages and regular competitions to reward employees and their families for aesthetic improvement also add to the success. House maintenance has been outsourced to local contractors from the surrounding communities to encourage further ownership.

When developing employee accommodation and related regulations, ensure that developments are in accordance to the ILO Convention 110 Part VII Articles 86-88, which can be accessed at http://www.ilo.org/iloex/cgi-lex/convde.pl?C110. In addition, further guidance on community environmental health and safety which incorporates housing and related employee and communities management issues can be gained from the International Finance Corporation Guidance Notes: Performance Standards on Social and Environmental Sustainability; Guidance note 4 available at www.ifc.org. Specific to the sugar industry, the South African Sugarcane Research Institute (SASRI) has developed a comprehensive range of guidelines for environmental and social management incorporating employee housing and management, particular to the South African industry environment, yet generic enough to be adapted to suit alternative environments (SASRI, 2002)

4.1.2 Community industry engagement and environmental management

Although environmental impacts and management are discussed in Chapters 2 and 3 of the manual, it is important to consider how to communicate the environmental plans and management systems of the industry to the communities. Activities undertaken by the industry need to be explained, and where possible replicated or expanded by the communities, to increase the success and effect of the initiatives. Communities need to be encouraged to engage in reforestation, water conservation and environmental protection programs through training and development and the availability of resources such as seedlings for planting initiatives at school and community level. These initiatives can be driven by the company, but must be implemented by the communities to enhance ownership and sustainability. The industry organizations have the technology and resources to support environmental initiatives through capacity building and awareness raising campaigns. Some companies have developed interactive and accessible environmental programs that explain the industry and stakeholder roles in protecting the environment, whilst at the same time explaining the operations of the sugar industry. Outreach programs using schools, colleges and youth groups are potential ways of increasing the impact of initiatives and raising the profile of the company as responsible citizens and improving community relations.
Box 4.2 Sao Martinho Group, Brazil – Environmental Community Resource Centers

The Sao Martinho group has developed comprehensive environmental resource centers at each of their factories to interact with the communities that are invited to visit and to build awareness of the activities of the company and the importance of environmental protection and management. Particularly impressive is the new purpose built center at the Boa Vista factory, built entirely out of recycled material with interactive facilities. The environmental centers tell the story of the sugar industry from soil to end products using diagrams, models, photographs and texts, with supplementary films. The centers offer communities the opportunity to learn about the industry history, processes and products in a very ‘hands on’ and tactile manner through models, pictures, text and film without risking health and safety non-compliance through factory visits. The centers explain important environmental issues such as how soil is made, the different types of soils and surfaces, water usage, recycling and tree replanting, explaining clearly what the risks and impacts are and what can be done to mitigate the risk. For example, water conservation is one of the major environmental risks within the Brazil. The center has developed a site within the garden specifically designed to demonstrate the situation of water management commencing by demonstrating the world water resources then dividing it up into potable and salt water. It then divides the potable water into country resources and further into states, and demonstrates how potable water is lost into the sea.

The initiative then demonstrates water wastage activities such as teeth brushing with the tap left on versus with the tap off, car washing, showering rather than bathing to demonstrate to the communities where they can make a difference. The centers host local schools and community groups and employ full-time staff to manage activities.
4.1.3 Education

Many companies support education programs either through supplementary support to government facilities in or around the company or establish and run estate schools, or provide scholarships or school fee provision for employees families, or provide education support to alternative institutions such as tertiary education establishments to raise standards of education and to improve the skills of the future workforce. This is very much dependent on the educational facilities and structures in place at national and local levels. In Brazil, some sugar companies, particularly in the remote or newly developed areas, will find it necessary to support the state education structures through additional facilities and teaching aids to ensure that the quality and standards of education are sufficient. Whereas in the more established cane growing areas where income levels are reasonably high, the state structures have developed sufficiently to provide quality education and any supplements from the companies are more of a CSR initiative rather than a necessity. In southern Africa, it is often by necessity that companies have to engage in the education sector due to limited capacity and resources of the state facilities.

Although there are no guidelines on the provision of primary or secondary school services as a responsibility of the industry, companies need to consider how they will attract employees, both skilled and unskilled, to rural areas if access to good educational services in the vicinity of the workplace is a problem. Companies also need to consider where the next generation of employees will come from and the standards that they will achieve if good education services are not available. Engagement and support of adult education and literacy programs will also be of benefit to the company by improving the capacity of the communities and workforce. It may be valuable for a company to partner with experienced adult education institutions to develop and run suitable programs. To reduce the risks associated with poor education and increase the sustainability of the industry, companies should consider the value of investing in educational facilities and skills provision.

4.1.4 Health care

As with education and housing, the provision of healthcare services and to what level companies engage in the healthcare sector depends very much on the capacity and availability of alternative healthcare providers. It is common within sugar industries in many countries, not only low income countries, that companies provide some form of primary healthcare facility and service on site. The objective of the service is both preventative to reduce the risk of more serious illnesses and also for efficiency to reduce the lost time from travelling to doctors, clinics and hospitals for non-urgent cases. Many of these primary healthcare facilities offer basic health checks and guidance for all employees in addition to traditional primary care. Arunatilake (2000) established that programs to improve health status of workers and child care facilities in the estate sector had a positive impact on labor performance.

**Box 4.3 Health care service provision – Brazil**  
The USJ group owned mill in San Francisco is located in a previously undeveloped area of Brazil that was formerly predominantly pasture land with limited industrial or commercial development. The area is classed as a low income state resulting in the requirement of more social support services to be facilitated by the mills. USJ provides one part time doctor and one full time nurse available to employees and families. There are full medical testing facilities available and medical testing is mandatory for all new employees (including psychological evaluation) some by mill instruction and some tests obligatory by the Government. Those exposed to chemicals are tested for effects every six months. The clinic implements the Government HIV awareness programme although infection rates are low. In addition to company clinical services the company provides for 50% of medical expenses incurred outside of employment for employee and family through a Medical aid card. The company provides dental facilities on site at the factory offering primary care free of charge and also covers 50% cost of dental care outside of the factory clinic. The company also offers healthcare plans for hospital and specialist care and an ambulance service is available to local communities.
Box 4.4 The Royal Swaziland Sugar Corporation (RSSC): Corporate Social Investment program

RSSC have established and implement an extremely comprehensive and well integrated Corporate Social Investment (CSI) program based on the premise that improved quality of life will lead to improved productivity and improved profitability. The program is implemented through the CSI department and aims to provide services to employees, dependents, outsourced service providers and local communities. The service provision includes Employee Assistance Program, Social services; HIV/AIDS program, Education, Sports and leisure, HIV/AIDS outreach and Community support (charitable support − drought relief/school feeding programs/partnership with WFP). The CSI program is integrated well into the company mainstreaming many cross cutting issues such as gender, violence, HIV/AIDS/substance abuse/financial problems. The department provides a qualified counseling service for employees and families. RSSC allocates more than 7.1 % of budget to CSI (excluding hospitals and housing).

Despite improved healthcare services there are still a number of diseases related to the sugarcane industry, the main ones are malaria, schistosomiasis (bilharzia), HIV/AIDS, and heat related and nutritional related illnesses. The IFC Performance Standards on Social and Environmental Sustainability – Guidance note 4, general requirements 10 and 11 and Annex A and B provide guidelines and advice for companies wishing to mitigate against health risks and develop supporting health programs health programs and monitor the affects of any interventions. The document is available at www.ifc.org.

4.1.4.1 Malaria

“Malaria is caused by a parasite called Plasmodium, which is transmitted via the bites of infected mosquitoes. In the human body, the parasites multiply in the liver, and then infect red blood cells. Symptoms of malaria include fever, headache, and vomiting, and usually appear between 10 and 15 days after the mosquito bite. If not treated, malaria can quickly become life-threatening by disrupting the blood supply to vital organs. In many parts of the world, the parasites have developed resistance to a number of malaria medicines.” (WHO 2010). Malaria is often linked to irrigation due to standing water and the suggested related increase in malaria vectors. However, a study in northern Tanzania to compare malaria prevalence between three communities, one adjacent to an irrigated rice scheme, one adjacent to an irrigated sugarcane scheme and one adjacent to a standard rainfed maize crop, identified that the community adjacent to the maize crop encountered more cases of malaria during the study period than either of the irrigated schemes (Cheesman 2004). However, despite these findings, Malaria remains a serious problem and a major cause of death, low productivity and lost time. Companies can aid the eradication of the disease by providing comprehensive preventative and response programs incorporating the clearing of mosquito breeding grounds; distribution of treated nets; internal spraying of company property; provision of screens for windows and doors; provision of onsite testing and treatment services and the development of interactive awareness campaigns. It is useful for companies to partner with specialist organizations to address the disease to draw on their skills and experience. There are often National Malaria Control Centers at country level to aid the development of control and treatment interventions. In addition, the World Health Organization develops an annual comprehensive report on malaria which contains updated information at policy and implementation level about vector control and malaria treatments The 2010 report is available on the WHO website: www.who.int.

4.1.4.2 Schistosomiasis (Bilharzia)

Schistosomiasis is a parasite that is hosted by snails which contaminate sources of fresh water, such as dams, lakes and rivers. The disease can be easily diagnosed and treated with the anti-schistosomal drug ‘praziquantel’. However, if left untreated, the disease can cause significant damage to the urinary system, bowel, bladder and liver and can even be fatal, particularly to persons weakened by other diseases or malnutrition (Cheesman 2004; NHS 2011).

The development of irrigation systems has been proven to increase the prevalence of schistosomiasis due to the provision of a conducive habitat for the breeding of the host snails,
particularly in night storage dams (ODA 1997; Cheesman 2004). The control of the snails is necessary for the protection of employees working on the irrigation scheme and communities surrounding and using the irrigation scheme. The problem is compounded in many cases by the utilization of irrigation bulk water sources and canals for washing and bathing. A number of chemical water treatments have been trialed with limited success, control of the disease requires a multi focused approach with treatment of the symptoms, elimination and control of the host snail and reduction of human and water interaction by providing alternative washing and bathing facilities (ODA, 1997). The ODI study investigated a number of environmental and engineering control methods and makes comprehensive recommendations for management of the disease. This study can be accessed through the DFID Water Knowledge and Research program website www.dfid-kar-water.net or dfid-kar-water@hrwallingford.co.uk. Further guidance on control measures and treatment is also available through the World Health Organization www.who.int/schistosomiasis/en/.

4.1.4.3 Human Immunodeficiency Virus (HIV) /Acquired Immune Deficiency Syndrome(AIDS) The UN estimates that in 2011 there are 33.3 million people worldwide living with HIV and of those 22.5 million live in Africa. The social and economic challenges that HIV and AIDS present in the business community are stark and well documented. HIV/AIDS is a major threat to the sugar industry, particularly in sub-Saharan Africa, South America and Asia, and some areas of India where disease prevalence is high. The sugar industry is recognized to have extremely high prevalence, predominantly due to higher income levels, transient labor and contractors, major transport routes and population density.

Many companies are addressing the threat with multiple initiatives including awareness raising and infection prevention, and provision of Anti Retro Viral treatment. The UNAIDS coalition state that if the spread of HIV is to be brought under control, education is the key as people must know how the virus is transmitted and how they can protect themselves and others from it (UNAIDS, 2003). The private sector is well placed to contribute skills and resources and play a pivotal role in raising awareness, reducing the social stigma and finding ways to improve the livelihoods of those living with the disease. Engaging in the fight against the disease is not just part of a company’s CSR package, it is imperative in many cases for the sustainability of investments. A sick workforce reduces productivity and profitability so the development of a workplace policy for HIV/AIDS is imperative.

There is a wealth of information and support available at global level for businesses to assist in the development of a work based strategy for HIV/AIDS prevention and management, including the following valuable reports:

- Saving lives, protecting jobs (ILO 2008b)
- UNAIDS and Business: Working Together (UNAIDS 2007)

The ILO is the lead United Nations agency for HIV/AIDS policies and programs in the world of work and private sector mobilization. The ILO Program on HIV/AIDS and the World of Work (ILO/AIDS) plays a key role in the HIV/AIDS global response through workplaces. HIV/AIDS is an integral part of the ILO’s Decent Work Agenda. To provide guidance on the legal aspects of dealing with the disease and its impacts on the workplace and working environment, the ILO has developed a specific code of practice and guidelines to assist companies in addressing this disease within the workplace. A comprehensive ILO Code of practice on HIV/AIDS and the world of work is available at www.ilo.org.
In addition to the global support networks, most countries have an active HIV/AIDS policy and initiatives to advise companies on potential interventions and support mechanisms and numerous specialist civil society and health organizations. Many specialist organizations welcome the opportunity to partner with the private sector to develop programs to target HIV and AIDS.

**Box 4.5 Illovo Sugar Company HIV AIDS management**

Illovo Sugar Company has a well established ‘Awareness and Wellness program’, operational since 1990, to address HIV AIDS in the workplace. The program focuses on education, voluntary counseling and testing (VCT) and treatment through ARVs and good health management. The program is continuously developed in accordance with recognized international ‘best practice’ and standards. Illovo recognizes the importance of VCT as it enables an individual to become aware of their HIV status and empowers them to make informed decisions about the management of the disease. The company continuously promotes the ‘know your status’ slogan to its employees and families and provides resources to encourage and facilitate this and has a target to test 50 % of all employees annually.

**CHMI, 2010**

4.1.4.4 Heat related illnesses

Exposure to heat is common in both agricultural and manufacturing industries in tropical areas such as sugar growing areas. The risk of heat stress also increases according to the physical demands) that a task places on an individual, for example, cane cutters undertake an extremely difficult and physical task in cane that has often been burned and may still retain heat; they are at significant risk of being affected by heat related illnesses. Companies can mitigate the effects of such illnesses through the provision of suitable protective clothing and sufficient accessible cold water. Many companies undertake shifts to eliminate the need to operate in the open areas during the hottest period of the day. For severe cases, hospitalization and the provision of intravenous rehydration treatment is required. A study undertaken by Crowe et al. (2009) of the sugar industry in Costa Rica identified that severe dehydration cases are often linked to additional social issues, such as workers not seeking medical care because they lack official documentation or may be working in the fields whilst severely malnourished. In cases such as these, treatment has to be comprehensive to incorporate all problems. One recommendation of the study was to make rehydration formulas available to workers exposed to extreme heat as both a preventative measure and a cure for minor heat related illnesses.

4.1.4.5 Nutrition related illnesses

Poor nutrition is a common occurrence in sugar industries across the world, but predominantly in low income countries. The effects of this are seen in productivity and illness prevalence amongst employees and their families. Many companies attempt to address this through the employment of nutritionists who develop nutrition improvement programs through the provision of meals and ration packs for employees. Both the Royal Swaziland Sugar Corporation and Tambankulu estate in Swaziland supply a comprehensive labor feeding program developed by a nutritionist who provides a choice of cooked meals or ration packs in addition to sour porridge provided infield and cool water. The ration packs generally include dry foods; meat, beans, maize and oil, and cooking facilities are made available. In Brazil, many mill canteen menus are designed by a nutritionist to ensure a wide range of food types and to promote healthy eating. In some developing countries, infield catering is outsourced to local micro enterprises to facilitate infield cooking; it is, however, difficult to monitor the nutritional content of such meals. Tackling the nutritional requirements of a workforce is an important element of productivity improvement and the development of a comprehensive healthcare program.
4.2 Land and resource management

Land ownership and natural resources management are two of the most globally controversial subjects and causes of war and income disparages, historically and currently. Sugar industry development generally requires large tracts of land to maximize efficient production. Increased efficiencies and lowered costs of production are increasingly required as increased competition and reduced subsidies advance the need for economies of scale in the development of the industry. As such, industry expansions and green field developments require entry into the controversial area of land acquisition and land use conversion. Whether the development is based around procurement of land or the conversion of smallholder farmers from food and traditional crops to sugar cane, developments continue to make headlines. The management of these situations can dictate whether it is viewed as ‘land grabbing’ or a ‘development opportunity’ (Cotula et al. 2009).

In many of the sugar producing regions (e.g. Africa, Latin America and Asia), land is a high profile resource becoming increasingly difficult to negotiate and procure, predominantly due to rapidly increasing populations, the recent high prices of oil leading to substantial interest in fuel crops and the subsequent rise in staple food crops raising awareness of food security risks. These, coupled with notably poor land management systems, loose ownership laws, poor governance and the marginalization of existing land users in developing countries, have resulted in extremely difficult and high profile acquisition procedures (Cotula et al. 2009). The profile of the rural landholder and peasant farmer has also risen due to improved communication tools reaching into some of the most rural areas and publishing the plights of indigenous people to western markets increasing market pressure for fair and equitable transactions and agreements.

As land is central to people’s livelihoods, cultures and food security, it is imperative that it is dealt with fairly and transparently, which is difficult when dealing in situations without clear regulation, procedures and guidelines.

4.2.1 Land ownership

It is well documented that investment in large scale agribusiness can bring macro and micro economic benefits to a country through employment, technical capacity building, taxation, foreign exchange earnings and infrastructure development. The picture is not completely positive though, and the risks of such developments are often overlooked by investors and governments alike. There is a common perception in many countries that land is abundant and is unused; however, in many cases, the land is used, just not through a formal system due to undeveloped land user rights and laws. Thus investment will displace many people, reduce their access to crucial natural resources and culturally important locations and place their livelihoods at risk. An exception to this rule in sugarcane development is possibly Brazil, where many of the new sugar industry investments are to convert former degraded grazing land, displacing few, if any, people and development is subject to strict land use and environmental protection laws. This is not to say that development should not go ahead in other regions, but it should be recognized as the complex procedure that it is and planned, developed and managed as such through formal and informal multi-stakeholder dialogue to develop agreements that will meet the needs of all stakeholders.

Unfortunately, in the current climate, despite good intentions and the opportunities that may be created, investors are often perceived as ‘land grabbers’ and supporters of corruption, putting their own reputations at severe risk. These accusations need to be avoided as, once made, the associated stigma is difficult for a company to lose. There are a number of generic recommendations to assist companies when dealing with sensitive social and community issues involving land and natural resources that can be developed to suit the particular circumstances.
• **Comprehensive assessment:** Companies must ensure that they have a full understanding of the land, the current usage, cultural assets, communities and local resources prior to commercial engagement to secure the land. This will enable them to make an accurate assessment of the perceived value of the land and identify the potential issues that will be raised. An assessment will also enable them to identify the stakeholders related to the development for future engagement.

• **Stakeholder engagement:** The assessment will identify the stakeholders with whom the company needs to engage, this should include, but not be limited to; current land users and civil society, traditional leaders, local government authorities, national governments, local and international non-government organizations (NGOs) and civil society groups and other local businesses using the natural resources. These stakeholders need to be engaged throughout the process to ensure that all voices are heard, recognizing that stakeholder engagement is a long and drawn out process, but one that may reduce the risk to the company in the long run and cannot be avoided.

• **Communication and transparency:** The stakeholders should be included in the negotiation process wherever possible to aid the development of an agreement that incorporates all concerns and reduces risks to all parties. Stakeholders are entitled to information to enable them to give free, prior and informed consent to any development. Guidelines and communication routes must be developed to aid information transfer and mitigate against misunderstandings and subsequent hostility. Operating an open book and inclusive policy will significantly improve the potential success of a project.

Where possible, companies should investigate and implement inclusive models of land development that develop local communities as part of the industry and value chain through outgrower and small and medium enterprise development. This is developed further in section 5, which deals with outgrowers and cane supply partnerships.

4.2.2 Displacement and compensation

According to the IFC, “Involuntary resettlement refers both to physical displacement (relocation or loss of shelter) and to economic displacement (loss of assets or access to assets that leads to loss of income sources or means of livelihood).” (IFC 2007a). Simply put, where project implementation results in unavoidable resettlement losses to affected communities and individuals who have no choice but to resettle in alternative locations (ADB 1998). Where possible, involuntary resettlement should be avoided as almost certainly this will result in negative impacts on all parties concerned. However, if there is no alternative to involuntary resettlement, the development of well planned comprehensive and participatory resettlement and compensation plans are imperative. Experience of the IFC demonstrates that the direct involvement of the company in resettlement activities, rather than relying on governments and intermediaries to manage activities and agreements, can have a positive impact on developments. Direct involvement can improve the cost effectiveness, efficiency, and timely implementation of activities, as well as the development of innovative approaches to improving the livelihoods of those affected by resettlement. Companies must ensure that resettlement sites and packages provide an improvement on the previous livelihoods of the affected communities in order to be sustainable and attractive to the affected persons.

Voluntary resettlement or negotiated settlements are by far the preferable route if resettlement cannot be avoided in its entirety. Voluntary resettlement mainly eliminates the need to use force and reduces trauma and negative impacts of the development. Negotiated settlements can usually
be satisfactorily achieved through participatory approaches, good communication, and by providing fair and appropriate compensation and other incentives or benefits to affected persons or communities.

4.2.3 Cultural practice and cultural asset management

The IFC’s Performance Standards 7 and 8 deal with the contentious and high profile issues of engaging with indigenous peoples and cultural heritage. Developments that require businesses to engage with indigenous peoples as per the definition by IFC “social groups with identities that are distinct from dominant groups in national societies” must be managed with considerable care and caution. It is recommended that specialist expertise in the form of social anthropologist skills are engaged to ensure that these disadvantaged groups are included in participatory planning and discussions. The rights of indigenous peoples are addressed in the ILO Convention 169: Indigenous and Tribal Peoples and, due to the delicate nature of this convention IFC has developed a specific note on this convention and how it should be addressed by the private sector, detailing the roles and responsibilities of stakeholders (IFC 2007c).

The six UN Conventions of relevance to indigenous peoples are as follows:

- International Covenant on Civil and Political Rights
- International Covenant on Economic, Social and Cultural Rights
- International Convention on the Elimination of All Forms of Racial Discrimination
- Convention on the Rights of the Child
- Convention Against Torture and Other Cruel, Inhuman or Degrading Treatment or Punishment
- Convention on the Elimination of All Forms of Discrimination Against Women.

A list of the six UN Conventions and the countries that have ratified each of them is available at: www.ohchr.org/english/law/index.htm, and the ratification status of each convention by country is available at: www.unhchr.ch/pdf/report.pdf.

This social issue is of particular importance to the sugar industry, particularly when again considering the issues of land and natural resource use and ownership, as many cultures and identities, particularly of indigenous people, are intricately entwined with land and dependent on natural resources. These resources may have sacred or spiritual importance and will need to be identified and recorded for protection and conservation. The natural resources upon which people depend will also have to be identified and methods to make resources available and accessible will need to be developed to sustain the communities. If a company is planning to develop a project that will affect indigenous people there are a number of key steps that companies should undertake, particularly in countries that ratified Convention 169:

- Undertake a comprehensive survey of the area to identify all indigenous people and communities and the natural resources that they use and depend on.
- Where possible minimize the land area or operations affecting the indigenous people.
- Develop stakeholder communication platforms to facilitate engagement with indigenous communities, government and third party expertise if required.
- Carefully document all consultations with the indigenous communities and other stakeholders including attendance, the information dispersed at the meeting, concerns raised and commitments made.
- Develop a civic education plan in a format that will be easily understood to explain the plans and procedures of the company.
- Continuously involve the stakeholders throughout the development procedures and provide them with clear and transparent information to facilitate informed decision making.
- Companies planning to acquire businesses that affect indigenous people should carefully assess all documents and reports relating to the subjects, and make careful enquiries into any incidents or communications that took place before between the previous owners and stakeholders to assess the relationships and situation as part of the due diligence.
- Include, where possible, opportunities for indigenous people to be included in and benefit from the operations of the company.

Strictly documenting all procedures will legally aid a company should allegations be made that indigenous peoples were not considered and presented with clear facts about the development including the potential negative impacts. Developing the stakeholder communication forum will aid ongoing relationships and operations improving community relations and improving the public and market perception of the company.

For additional support, there are a number of clear and concise guidance documents and handbooks available to guide companies through these contentious and important issues. The main ones available are:

- Antoanella-Iulia Motoc and Tebtebba Foundation 2004. This document provides useful information on the principle of free, prior and informed consent.
- IFC 2001a. This handbook provides easy to follow guidance through the resettlement planning process including practical tools to aid the process, including implementation checklists, sample surveys and monitoring frameworks.
- IFC 2001b. A resource guide in establishing effective community development programs.
- IFC 2003. A practitioner’s guide to undertaking social impact assessment at project level.
- IFC 2007c. A guidance note to explain the implications of the ILO Convention 169 to the private sector.
- IFC 2007d. This handbook explains new and innovative approaches and forms of engagement with affected local communities, including guidance on participatory approaches to stakeholder communication, monitoring and developing grievance mechanisms.
- ILO 1989b. This manual provides definitions and useful guidance on ILO Convention 169.
- Secretariat of the Convention on Biological Diversity 2002. Guidelines on establishing legislative, administrative or policy measures on access and benefit sharing.
- Secretariat of the Convention on Biological Diversity 2004. Voluntary guidelines for the conduct of cultural environmental and social impact assessments regarding developments which are likely to impact on sacred sites and on lands and waters traditionally occupied or used by indigenous or local communities.
- World Bank 2004. This book provides guidance on resettlement design, implementation, and monitoring, and discusses resettlement issues particular to development projects in different sectors, including natural resource management and the building of dams – which may be of value for the sugar industry.

Social issues have a major influence on the success and sustainability of an industry. Inclusive management solutions will go a long way towards developing relationships that will assist industries to succeed. Including communities in the business so that industry successes and developments become community successes and developments will build a strong foundation for businesses to flourish.
5. OUTGROWERS

5.1 Outgrowers and the changing dynamics of the industry

The manner in which the upstream elements of the sugar industry value chain operate, such as cane supply, depends very much on the social, political, economic and environmental influence of the country and specific area in which the industry operates and the influence of external parties for socially responsible investment (Hopkins, 2007a). As land becomes an increasingly contentious and high profile issue, with stories of ‘land grabbing’ becoming headline news, the availability of additional land for new and expanding sugarcane businesses has become a major constraint to strategic planning in many countries. Population density, limited formal land Acts and laws, traditional land management and distribution practices prohibit or reduce the feasibility of the more traditional ‘miller cum planter’ estate development model and promote a change in business model for many sugar processing companies. The sugar industry value chain, particularly across the developing world, is altering its focus to acquiring cane supply from external sources, and promoting partnerships to maximize opportunities for both industry and community development. In addition to these internal country influences some consumer lobbies and markets are increasingly pressurizing companies to engage with local communities to further distribute the benefits and positive impacts of trade to development and potentially mitigate against negative social impacts of economic development (Hopkins, 2007b). Involving communities in the value chain has become less of a corporate social responsibility initiative and more of a sustainable business initiative as companies become increasingly more dependent on partners for cane supply.

In many LDCs and countries with a high population density, interventions predominantly involve cane supply from smallholder or outgrower farmers and in land rich countries such as Brazil interventions predominantly involve ‘landlords’. The terms ‘smallholder’, ‘contract farmer’ and ‘outgrower’ are often interchangeable, particularly in LDCs or low income countries where most farmers supplying into agriculture processing are operating on areas of less than five hectares and many on areas of one hectare or below. Outgrowers comprise private commercial growers, cooperatives and smallholder sugar producers normally contracted to deliver cane to the mill. It excludes the miller’s own cane (e.g. nucleus estate). Outgrowers vary according to ownership of land (freehold, leased or communal), size of holding (all sizes) and degree of independence (private grower) or interdependence (communal or in cooperatives). It is important to understand this broad definition of the term ‘outgrower’, as it can vary.

Large private outgrowers tend to operate at the same scale as the nucleus estate with regards to inputs, labor and machinery use. However, the small-scale outgrowers are often more dependent on external support for operations and services, provide a lower level of inputs, labor productivity is more variable and wages are often lower.

The outgrower usually grows cane under contract to a specific mill, often for an agreed period and to supply cane according to laid down procedures to ensure a regular supply of cane to the mill. The Sugar Act, where available in a country, often defines the relationships and procedures allowed between the miller grower and the country. It can vary from being very specific to offering a broad framework.

Increasing demands for land and water and the need to include the local population in any new development is changing the dynamics of the industry and is driving change, which also requires more robust outgrower models. As cane supply from outgrowers increases across the world sugar industry, the outgrower organisational models utilized by the industry have been developed
organically with continuous amendments and improvements reacting to the changing social, political and economic environments.

There are only a few sugar producing countries in the world that do not have to engage with outgrowers for cane supply. In Brazil, despite the vast land resource available, many companies have to engage with farmers and landholders using innovative models of land lease and crop management to acquire the necessary cane to support the factories. The difference here lies only in the scale of operations by outgrowers with farms of thousands of hectares and the reduced number of outgrowers that the processing plant is required to deal with. Compare the situation in Brazil with that of India, where processing companies in many states are unable to or are not allowed to own land for cane development and rely completely on cane supply from tens of thousands of outgrowers operating on one or two acres of land, and compete fiercely with alternative cash crops for command over the land. Yet despite the differences, many similarities remain in management models, and the necessity to build relationships, enhance trust and transparency, and manage and secure cane supply remains of utmost importance.

There are three main challenges facing most outgrower models: the first is lack of land ownership and tenure, which impacts on the ability to raise collateral; the second is social conflict often arising out of jealousy and misunderstanding within or between communities; and finally the impact of climate change at a time when water supply is limited. This is likely to impact on both rainfed and irrigated situations. These and other challenges are described in more detail in this chapter and each one needs careful consideration.

5.2 Important factors in outgrower development

The success of an outgrower scheme and model is dependent on a number of social and technical factors:

- The development of an open and transparent relationship between stakeholders, namely the mill, the outgrower and the service providers (Masuku et al. 2007).
- The understanding and reflection of society and culture in scheme development.
- Climatic conditions and the need for irrigation.
- Land tenure and existing land use.
- The appropriate method and model for development.
- Good governance of the outgrower organizations and stakeholders.

Models have historically reflected the technical requirements of the systems and schemes, but increasingly have to consider the social and civil society elements with equal importance. Unless the development satisfies the needs of both of these elements, success and sustainability will be a challenge.

5.2.1 Social and technical preparation

Careful social and technical planning is required to develop an outgrower scheme. Time must be spent with the communities on civil and social education as this will assist in building strong foundations and trust. It is often difficult for communities with no experience of commercial development and with low education levels to understand and absorb the concepts being presented to them and what it will mean to them, leading to elements of fear and misunderstanding. Many companies have found it beneficial to engage with an external service provider with skills and experience in social engagement and project development to aid with the preparatory phase. Unfortunately the social elements of the scheme are often overlooked or ignored in favor of the
technical aspects, which are easier to comprehend and manage. History, however, has proved that the social factors have the strongest influence on success; there are a number of examples of previously successful schemes that have failed because of this. Understanding the social and cultural beliefs of the communities with which the scheme will engage and those which will border, it is essential to ensure that the model developed is suited to the local conditions. Jealousy and conflict resolution have to be dealt with by the outgrowers and such issues have to be addressed at the outset to ensure a single objective; success is what all stakeholders should be striving for.

Governance of outgrower organizations is also a major component of outgrower development. Promoting and developing good governance is a major success factor, as transparent and supportive leadership is paramount.

5.2.2 Demand driven approach

Success is achieved by a demand driven approach for all services (Garforth 2004):

- Communities and individuals have to want to become outgrowers.
- The crop must generate sufficient income for it to be an attractive proposition for the outgrower.
- The mills must have the capacity and willingness to procure this cane.

In the Uttar Pradesh state in India many mills are operating at below 50% capacity due to low cane supply caused by farmers’ preference to grow traditional cash and food crops. The crops are short term, providing quick income and flexibility. In comparison, sugarcane requires a considerable investment in development, provides only a single annual payment and requires additional manpower. In these areas, companies have to develop incentive schemes and undertake marketing programs to convince farmers of the benefits of growing sugarcane if they are to sustain their processing operations.

- The producers must buy into the scheme for the long term to facilitate meaningful commercial development and income generation.

In many countries, sugarcane outgrower schemes are seen as a way out of extreme poverty for rural communities. In most cases, schemes offer access to a sustainable and reliable market, which exceeds most other commercial crops in security of income. Although this is generally known and accepted at industry level, it is not always known at community level. Fear and uncertainty of becoming involved with a large corporate needs to be addressed using a comprehensive awareness program.

- The model should not demand significant individual input in areas where employment or alternative income generating opportunities are prevalent.

Where employment levels are high and income sufficient people may feel less inclined to participate in an outgrower program. An example is the Kaleya Smallholder Sugarcane Scheme in Mazabuka, Zambia. This scheme was established during the peak of the country’s copper industry boom when employment was plentiful. The developers advertised for potential outgrowers and received few expressions of interest, so employees of Zambia Sugar Corporation who were close to retirement were encouraged to participate. This in retrospect provided a sound foundation for the scheme due to the capacity and competence of the original outgrowers. In addition, the scheme is responsible for many of the outgrower services and operations.
- There should be demand for the scheme from local external stakeholders.

There should be a demand from local service providers to get involved in the scheme providing inputs and services on a commercial level. The national and local government authorities should demonstrate political will and local authorities should help to oversee the development of the scheme. These levels of support will minimize later disruptions and problems.

5.2.3 Land

Land ownership and how the land is managed is a sensitive and highly publicized issue in most countries. In many sugar producing countries, specifically in sub Saharan Africa, there are no formal land ownership systems, and land distribution remains in the power of traditional chiefs and authorities. Individuals very rarely hold land titles and land ultimately belongs to the state. This makes investment difficult and risky. Land typically cannot be ‘purchased as freehold’ as the maximum is usually a 99-year lease with the Government. When developing infrastructure on this land, compensation mechanisms will have to be developed and agreed.

Developers are coming under pressure to meet the conflict between high productivity over a confined area without displacement of people or disruption of traditional land management systems. The sugar industry has developed a number of land management systems and models to engage smaller scale outgrowers in commercial farming. This is a move away from the traditional scattered and informal land management system.

Models for intensive land use require clear and comprehensive mechanisms for land allocation with improved governance, transparency, sustainability and rightful allocation. Development of criteria for grower selection will depend on the existing land use and the land management system. For example, where the land is occupied, the existing farmers must be included in the outgrower scheme. They may be allocated less land due to the expected increase in productivity and to include additional persons but this must not reduce the individuals’ income. Where greenfield sites are to be utilized it is possible to develop more selective criteria.

The caliber of the outgrower is critical. A set of criteria should be designed to ensure that wherever possible potential outgrowers meet acceptable standards. Land availability, location and conditions should determine plot size to ensure equitable production where feasible. Basic business awareness and commercial orientation are components to success. It is important to ascertain the level of support needed to facilitate this business development. Agricultural knowledge and experience is desirable but it can be taught on site. The capability of an individual is generally known locally through the success or failure to produce food and other commercial crops.

Box 5.1 Land Allocation at Kasinthula Sugarcane Growers Scheme, Chikhwawa, Malawi.

In March 2009, the European Union, through its Sugar Accompanying Measures, signed a grant to facilitate the expansion of the Kasinthula Sugarcane Growers Scheme (KSCGS) under the Shire Valley Cane Growers Trust (SVCGT) in the southern region of Malawi. The existing scheme was developed in two phases, phase 1 consisting of 312 hectares developed in 1997 and became operational in 1998, and phase 2 of 443 hectares plus 30 hectares of food crops became operational in 1998. The first two phases support 272 outgrowers and utilize furrow irrigation. The expansion proposes the development of a further 400 hectares using center pivot irrigation to support a further 200 outgrowers.

The southern region of Malawi is one of the most densely populated and poverty stricken regions in the country; education and health levels are low, and pressure on land is great due to poor productivity as the area is prone to floods and drought. The expansion of the outgrower scheme presented an attractive opportunity for development, but given the high cost of development of irrigated sugarcane in Malawi, exceeding $10 000 per hectare, the scheme could only support a limited number of households. Therefore a comprehensive selection criterion was required for land areas and potential beneficiaries.
The area to be developed was identified through demand from traditional leaders and communities, followed by comprehensive mapping, soil and topographical surveys to establish the optimum site. A full economic and institutional feasibility study and environmental impact assessment were also undertaken. The allocation of land was one of the main focal areas of the institutional review and a selection procedure was developed with the stakeholder to provide an open and transparent mechanism.

Priority was given to those historically farming on the proposed land. Available plots after allocation to existing occupants were subject to a selection procedure. A list of basic criterion was developed, with additional criteria for persons wishing to be representatives on committees. These criteria were used during the selection process:

1. 1 plot per household
2. Minimum age 18 years
3. Experience in cash and food crop farming
4. No unspent criminal record (severity of record to be discussed)
5. Local inhabitant
6. Literate

Points 6 and 7 are relevant only to those wishing to be committee representatives.

A selection committee was established incorporating local government, SVCCT, traditional leaders and local NGOs to aid the decision making process. The Village Chiefs and Headmen provided the committee with the preliminary list of beneficiaries and the committee used the criterion for further deliberation. The final list of beneficiaries was presented to the Traditional Authority and Board of Trustees of SVCCT. The Paramount Chief provided an arbitration role for any unsatisfied parties.

SOURCE: K MATHIAS, KASINTHULA CANE GROWERS LTD AND SHIRE VALLEY CANE GROWERS TRUST

5.2.4 Climatic conditions - irrigation

Climatic conditions and whether or not irrigation is required has a large impact on the model in terms of viability, risk, capital, labor and management. Irrigation is capital intensive and places more pressure on the economic viability and responsibility of outgrowers. Irrigation is often perceived to be essential to outgrower schemes as it reduces the risk of crop failure from drought, but it intensifies management and social risk. Irrigation, due to its technical nature and the capital investment, intensifies land management issues and increases the complexities of operations, as these are time sensitive, and equipment and infrastructure requires continuous maintenance and competent management. Therefore, the model developed for an irrigated scheme requires more professional, technical management and outgrowers need a higher level of expertise on all aspects of production to ensure sustainability.

Potential yields on irrigated schemes have to be higher to cover the costs of irrigation. Irrigation increases the cost of development considerably; in southern Africa the cost of developing irrigated sugarcane is more than ten times that of developing rain fed cane. It requires a significant investment in infrastructure and this cost has to be recovered. Other forms of finance or grants are often required for small scale outgrower irrigation schemes in developing countries.

Where irrigation is not required, farmers are able to operate individually on their own land, managing the farms with family or hired labor. This freedom to develop depends heavily on access to finance, inputs and services. Success depends on good practices in the field. Cane must be grown in suitable areas within economic haulage distances to the mill.

The mill must have the capacity to procure the cane. This regulation may come from government bodies, Acts and Bills, or may come through industry self-regulating bodies such as Associations and Trusts that organize and represent outgrowers and may set standards for cane supply to their
members. The freedom to develop individually and on one’s own traditional leased or procured land reduces many of the social risks associated with block farming. In block farming individuals are required to work together and pool resources and this can be an area of conflict.

Many rainfed outgrowers join grower associations to coordinate cane supply and gain access to finance and inputs, and for political reasons. However, membership does not impact on their degree of independence on their farm. The processing company often supplies inputs and extension services, and facilitates finance and recovery of debts on behalf of service providers.

The impact of climate change on both rainfed and irrigated models needs careful consideration, as outgrowers have difficulty facing adversity and cannot afford the risk of climate change impacts.

5.2.5 Capacity

The capacity of the potential outgrowers is a key factor for consideration when deciding on an appropriate model. Schemes should, where possible, select farmers who have successfully developed cash crops and income. To change the mindset of a subsistence farmer with no experience may prove an obstacle to the development of a scheme. Where this is not possible capacity building, training and extension are paramount and this must be considered as a key cost and technical factor in the development of the model. In this situation, either a model not requiring considerable technical input from the outgrower or low technology schemes with substantial support mechanisms are required. An additional consideration is the availability of skilled employees for any outgrower management companies or scheme along with the financial implications of this. Often in sugar growing areas, the skilled individuals are employed by the milling companies. To entice them to work for an outgrower organization, conditions of service will need to be attractive and sustainable, whilst bearing in mind that all costs will be borne by the outgrower.

5.2.6 Ownership

The level of involvement and feelings of ownership of any development or scheme by the outgrower largely determines the success of the scheme. Outgrowers must consider the scheme, the infrastructure, the equipment, the sugarcane, the activities and the model as theirs and engage fully with its objectives. Regardless of the model developed and the physical level of involvement by the outgrowers in daily activities, the attitude and understanding of the outgrowers must demonstrate full ownership and responsibility. Even where an intermediary organization manages or oversees commercial operations, it is important that outgrowers are trained and encouraged to undertake activities on the scheme. Where possible, outgrowers should be involved in decision making to enhance the sense of ownership. Many schemes have failed due to the disassociation of outgrowers and the development of a blame culture. Whatever happens to a scheme, the outgrower should be ultimately responsible for its success or failure. Outgrower representatives must perform and communicate between the outgrowers and other stakeholders to competently represent their views and transfer information to the masses. This mentality will increase the understanding of the individual outgrowers and their subsequent monitoring of service providers, management companies or organizations and millers.

5.2.7 Culture and tradition

In addition to cultural and traditional land management systems, these social elements play a considerable role in the success or failure of an outgrower scheme. Breaking traditional practices is a long and drawn out process regardless of whether it is considered to be in the best interest of the individual, community or nation. Comprehensive civil education and social awareness programs are
required prior to any development and should integrate local traditions and culture. They should not be considered as many initiatives do, as cross cutting issues only to be addressed in order to tick a box for development partners and funding agencies.

5.3 Outgrower models

There are no right or wrong outgrower models, and what suits one situation cannot simply be reproduced in an alternative area. Models have been implemented that can provide useful guidelines and examples to aid new schemes. A good outgrower scheme should pave the way to a fully commercialized supply chain incorporating producers, service providers and processors. Each party should know and recognize its roles and responsibilities and undertake them in a responsible, profitable and sustainable fashion (Leys 1996:164). It should be recognized that if, within this chain, any link is not running efficiently the profitability within the chain will diminish. The model should promote the move away from donor dependency and subsidy towards a self-sufficient and economically viable model.

Schemes should have a clear organisational structure, enabling parties to undertake their mandated tasks free of politics. Political interference in schemes can damage the commercial foundations required. It should be instilled in all stakeholders that this is a commercial venture.

Outgrowers require a range of services including but not limited to organizational management, extension, training, providing technical support, and research and technology transfer. Outgrower organizational models must incorporate methods of management for both the farmer and farm, with clear roles and responsibilities. The model must identify those carrying out activities such as extension, training and inputs, and to determine how they are to be financed. Clear routes for communication need to be established between all stakeholders to ensure timely and efficient delivery of cane to the mill and payment to the outgrowers.

Outgrower schemes are inherently difficult to develop and sustain given the demands and expectations of the multiple stakeholders involved and the cultural differences between corporations and communities generally in existence. However, providing all stakeholders understand their basic roles in the production, supply and marketing chain the scheme has a chance of survival. This is even when the specific objectives and the reasons behind the development differ. The model developed will need to be flexible and able to change as social, environmental and technical factors evolve.

5.3.1 The individual outgrower model

Where there is an opportunity for outgrowers to develop sugarcane individually a considerable amount of support and extension is required and must include mill cane supply management. Outgrowers must have considerable commercial, agricultural and technical capacity to be able to develop a successful business. In Africa this individual management model is predominantly only used by larger scale outgrowers with land title, who have the ability to raise working capital. In India the individual grower develops his land with his own resources or with local contractors and undertakes all crop husbandry activities including delivery of the sugarcane to the mill.

A major disadvantage of this system is the mill having to manage thousands of individual growers (e.g. India and Kenya). This requires a comprehensive management information system (MIS), and data collection and communication systems. The mills must provide strong extension and timely advice and guidance, and help with inputs, operations and labor. Coordinating harvesting and delivery is crucial to secure timely delivery of quality sugarcane. New sophisticated technology is
assisting in this regard. GPS, GPRS coupled to Google Earth and fleet management systems, and remote satellite imagery all help to coordinate cane supply. This can have a positive impact in remote areas where linkages to central business hubs are thousands of miles away.

Although currently this model is working in many areas of India there is a shortage of manual labor as a result of government social programs, and better standards of education. Outgrowers and millers are considering adaptations to the model to sustain the industry.

5.3.2 The block farm model

Increasingly outgrowers are encouraged to block farm with their neighbors. This improves economies of scale and reduces the cost of management. A ‘Block Farm Scheme’ is usually defined as an area encompassing a number of outgrowers farmed as a single field/block with no physical divide. Block farming offers a number of benefits and constraints, each of which has to be considered when designing the out grower model.

As individual land holdings across the world decline, the economic feasibility of operating individual plots declines. This is particularly so in LDCs where, upon death of the parents, the land is divided into smaller areas per block as offspring ‘inherit’ their portion of land. In countries where tradition or laws do not discourage the practice, a new owner can then choose to build a property, thus further reducing the individual land holding and compromising economic viability as an individual plot. Cane supply in India, Kenya and South Africa is suffering considerably due to this trend. Block farming enables the land holding to effectively be divided, through the division of income, without any loss of land area or cane supply. Other benefits of block farming extend to the ability to procure sugarcane from land occupied by absentee farmers. Previously underutilized areas of sub Saharan Africa are increasingly feeling the effects of HIV/AIDS and other endemic diseases that reduce the capabilities of the population. Block farming offers an opportunity for income generation from agriculture without necessarily having to be present in the field.

The management of the block is often organized by a committee, management unit or company. The procurement of inputs and services are provided in bulk to improve economies of scale. Labor is often employed to undertake activities, reducing if chosen, the requirement for the farmer to be in the field and creating employment opportunities. It also provides an opportunity for the farmer to be employed as labor on the scheme to aid household cash flow through provision of a regular income, despite this being deducted from the cane proceeds.
Whilst bulk purchase and larger areas of land for development and management may result in decreased costs, the employment of a management unit can reduce ownership and responsibility. Management units will incur costs that must be borne by the outgrowers. Transparency of costs and services is imperative for outgrowers to recognize the value of block management, as they must each contribute towards management costs. It is important that the management organization develops a clear penalty strategy for outgrowers who do not comply with agreed policies. For example, the management unit will request outgrowers to undertake a particular task at a certain time. If the outgrower does not undertake this task it could jeopardize the block, thus the management unit must be able to employ labor at a cost to the outgrower without the outgrower’s prior approval. The mill will consider the block farm as a single outgrower, channeling payments through the management unit, which will reduce administration considerably for the mill.

Schemes can benefit from the development of a core estate to produce income to cover operational costs of the management company. This will reduce the burden assigned to the outgrowers, assist in loan repayment and utilize the model farm for demonstration purposes. This has mainly been observed in previously state owned land areas where land has been handed over to the communities for development and does not fall under traditional or tribal land holding, as is the case at Kaleya Smallholder Scheme in Mazabuka, Zambia, or former parastatal control boards such as at Dwangwa Cane Growers Trust in Nkhotakota, Malawi, which was assigned the assets of the Smallholder Sugar Authority when it was privatized.

In spite of the obvious advantages of block farming, it is not without its inherent issues. Organizations operating in countries with negative experiences of cooperative farming may find the establishment of block farms difficult, due to people’s reluctance to ‘hand over’ or ‘lose control’ of their land. Social issues can make or break an outgrower scheme, so due attention must be paid to these issues and these concerns must be overcome prior to development of the scheme. A comprehensive program of civil education and social awareness and capacity building may help to overcome these concerns. The employment of a specially trained third party organization can assist. In India, many companies employ social workers to aid communication with stakeholders. Also in Tanzania, when considering the development of block farms and irrigation, the Sugar Board of Tanzania contracted a sociologist as part of the design and feasibility team.

An element to be considered when establishing the block farm and equally, any irrigation model that relies on outgrower groupings, is the exit strategy for any outgrower wishing to leave the scheme. Although currently not common, in future generations this situation will arise due to urbanization and a move away from agriculture. Prior to commencing the development, stakeholder discussions must be held to establish how land ‘sale’ or ‘transfer’ will be dealt with and what the legal constraints to this are. In Swaziland, at the Lower Usuthu Smallholder Irrigation Project (LUSIP), the stakeholders are considering an innovative approach of converting each block into a company and outgrowers will be allocated shares in that company according to the land holding that they have. Should an outgrower wish to leave the scheme, he/she will simply sell the shares in the scheme. The risk of this route is that outgrowers may sell their shares to external parties, not always rural farmers. However, at the commencement of the block, criteria of shareholders can be established along with the ‘exit’ procedure to avoid future problems.
5.3.3 The trust and management company model

A recommended method of creating this commercial approach to developing the scheme is to form an operational management company to manage the scheme on behalf of the farmers. This separates the commercial responsibility of the scheme from the non-commercial farmer-groups activities. If necessary, a professional management company should be contracted to manage the company for an interim period whilst building the capacity of the farmer organizations and company staff. This model is similar to the block farm model and management unit, however, technical capacity within the company should be superior, thus an important aspect of the company is that key staff are employed based only on skills and merit. The company should manage all aspects of production including outsourcing of non-core activities. It should present budgets and plans to the involved parties for approval prior to implementation to ensure transparency and development.

The management company should be paid for by the farmers. This almost certainly will result in initial concerns about the cost. The benefits from developing a professional company should be justified through increased revenue from the crop. Any external management company should be contracted for an agreed period, with strict and clear terms of reference and an exit strategy. The contract must clearly state the expected output from the company, the reporting procedure and the termination process. The contract should be incentive based on production and quality enhancement to ensure that the company has a commercial focus. A further contract between the management company and the farmer organizations or representative bodies must also be designed to detail roles, responsibilities and reporting procedures. It may be beneficial to have staff with incentive based payments to promote productivity. It is also important for the company to develop a clear penalty strategy for outgrowers not complying with company policies.

Cane payments should be managed by the management company enabling the mill to deal with a single entity. The management company then deducts payment for services and inputs and maintains a detailed farm and financial record for each outgrower. A management information system should be developed to facilitate ease of payment to the outgrowers through automatic deductions for credit, service and input recovery against crop deliveries. The company should manage the payment to the outgrowers through bank, savings or credit accounts as agreed with the farmers.

The ownership of the operational company is a key sustainability issue, which is currently an issue in a number of schemes. Ideally, the shareholding of the company should lie with the farmers to ensure that the sole objective of the company is to make a profit for the farmers. However, this may prove disadvantageous for newly developed schemes that are required to raise capital or increase security of ownership. Where external shareholders are required, a clear exit strategy is needed to
ensure that the opportunity for acquisition of shares lies primarily with the outgrowers. The objective of the company is to make money for the outgrowers.

A number of irrigated outgrower schemes in sub-Saharan Africa have established a legal Trust to represent the farmers and provide a route for finance and support. The Trust can include representatives of financiers, government, industry, social action groups and other involved parties. The role of the Trust is to represent the best interests of the outgrowers and oversee the scheme. The emphasis of the Trust should be to create a commercial scheme with sound management and operational practices favorable to outgrowers. In some cases, the social and political needs of the outgrowers in these schemes are represented by farmer associations, with membership on the Board of Trustees. The associations should clearly define their activities, and areas of proposed intervention and support to the farmers. The funding for this must come from a levy deducted per tonne of cane or from funds from cane payments through the company.

It is important that the roles and responsibilities and interactions of the different stakeholder organizations are clearly defined in the model and then understood by all. For example, if there is an operating company involved in the scheme, the linked association or Trust should not become involved in the commercial activities. The company should focus only on the business and not on the social or political activities.

In irrigated sugarcane, which is capital intensive, external financiers and development partners are becoming increasingly involved through concessional or donor finance. This places external demands on the governance of management structures and the participation of all stakeholders. Through provision of finance and support services, these institutions become stakeholders in the industry and need to be considered when reviewing the roles and responsibilities of stakeholders. The provision of external finance and support can bring with it significant development benefits and opportunities. This is not without some potential risks of cumbersome bureaucracy and external demands that may not be compatible with the industry. These aspects should not be overlooked.

5.3.4 The Association led model

In some countries outgrowers choose to belong to Farmer or Outgrower Associations, predominantly for the benefits of having a single stronger voice, but also in some countries the associations play an active role in service provision for the outgrowers, particularly where individual
outgrowers operate. Associations predominantly negotiate with the mill and with contractors on behalf of the outgrowers, and assist the outgrowers to gain access to finance, agricultural services, inputs and social services. Many Associations have developed successful credit and savings cooperatives to access finance for crop production and improve cash management. In some cases, where financial support has been received to procure equipment, the Association provides services to the outgrowers. A constraint of this system can lie in the low technical and commercial acumen of the Association resulting in poor or unreliable services. An example of this is the lack of maintenance and poor management of machinery.

5.3.5 The Community Trust farm model

This model is not a standard outgrower model as it does not involve individual outgrowers. It focuses more on community involvement and enrichment. It is generic by nature and can be adapted to suit different social needs and environments. It is driven by the need to uplift larger proportions of the community by providing a source of sustainable funds to support development initiatives. A Community Trust (the Trust) is established, usually as a charity, for tax reasons, with an objective of supporting community development initiatives. The Trust then leases an area of land, preferably for nominal ‘peppercorn rent’, either from the mill, a private landlord or the community for the development of a commercial farm. The farm may need to be established as a separate company and is developed and managed by a professional organization at cost. The net proceeds from the sugarcane supply are donated to the Trust. The Trust invites the benefiting communities to identify and develop projects for financial support and retains as much management control as is necessary to ensure sustainable development. The benefits of this model are to provide professional management, security of cane supply, and sustainable finance for development. The disadvantage is that it does not directly build the wealth and capacity of the farmers although the programs funded by the revenue could.
The Kilombero Community Trust (KCT) and its programmatic predecessor, the Kilombero Business Linkages Project (KBLP), were initiated by Kilombero Sugar Company Limited (KSCL) and the IFC in Kilombero, Morogoro, Tanzania in 2002. The model utilizes linkages to a strong private sector company to develop rural communities through agriculture, business and social initiatives. The Kilombero Community Trust and the Kilombero Business Linkages Project demonstrate the significant potential of ‘public-private partnerships’ as they deliver economic benefits via a strong working relationship to both a private company and its surrounding community, in this case the Kilombero Sugar Company and the remote, agriculture-based community at Kilombero, Tanzania.

The Trust’s primary source of revenue is the Kilombero Community Trust Farm; an arrangement under which the Trust leases 1,200 hectares of rainfed cane land from KSCL and contracts KSCL to manage the farming of cane on the property. The cane is sold to KSCL for processing and profits from the Trust Farm are directed toward community development and include financial support of infrastructure improvements, as well as continued training and financing programs.

By promoting linkages between the company and the outgrower farming community, the initiatives have assisted upwards of 10,000 subsistence farmers in the impoverished area to gain sustainable new sources of income from the sale of sugarcane. Through innovative financing mechanisms and capacity building programs, the Trust activities are enabling new farmers to enter the market and existing farmers to expand and improve their cane farming activities.

To further support outgrower development, the Trust leveraged commercial and donor funding to support vital infrastructure development, created a management information system and delivered much needed agriculture and business training to farmers, farm groups and other local entrepreneurs, as well as microfinance in support of these economically active groups. Additionally, the Trust has recently added programmatic components in support of the larger social and economic challenges facing the Kilombero community. Examples of this include plans for rural electrification, mobile health clinics, and HIV education, VCT and support.

Due to high taxation reducing the potential funding available for development initiatives, in 2009 KCT underwent changes in structure to reduce the tax burden and is now established as a charitable organization.

5.3.6 The joint venture model

The joint venture model promotes a strong partnership between outgrowers and a technical partner. It is more suited to irrigated schemes where significant financial and technical support is required. In this model a company is established with joint shareholding between the outgrowers and the technical partner. The land holding of the outgrowers must be valued and utilized as their equity, whilst the technical partner will also provide equity to develop and operate the scheme. The technical partner will be contracted as the management agency to ensure the repayment of the development costs and ongoing income generation. The partner can choose whether to reduce its shareholding once the debt has been recovered whilst retaining the management contract. This can
be agreed when developing the company legal documentation and agreements. The sharing of profits is an incentive for both parties to maximize their input to promote increased profits, and should lead to strengthened relationships between partners.

This model is generic and should be adapted to suit the technical and financial capacity of the partners. It is advantageous when mills require control over cane supply but lack land resources to develop MCP cane and so take the role of the technical partner, or where absentee landlords are common. The benefit of this scheme to the out grower is the technical and financial assistance that the partner organization will introduce whilst equity is retained by the outgrowers. A major advantage of this model is that both partners need each other for success.

5.3.7 The partnership model

This model is similar to the joint venture model, but is a partnership between the mill and the landholder. It is common in Brazil, where individuals hold vast tracts of land planted to cane under rainfed conditions. The model reduces the capital investment, and can be adapted to suit a range of environments. It is of specific value where absentee landlords are common, or where control over cane supply is required by the mill if land is not available for MCP development.

In Brazil an agreement is drawn up between a technical partner and the miller. It could be with any technically competent partner. The landholder ensures that the technical partner undertakes all development and management operations and in return will retain a percentage of the sugarcane for payment. The remainder is supplied to the mill in the name of the landholder and is the ground rent, which attracts much lower taxes. It is therefore in the interest of the technical partner to maximize yields. As yields, which are equivalent to a land rent, are out of the control of the landholder, a minimum yield clause should be inserted into the agreement to protect the landholder and ensure a minimum payment. This model is also common in Africa and has been implemented in Malawi at Sande and Kaombe in the Lower Shire, and at Nakambala mill in Zambia.
5.4 Building capacity

Building the capacity of outgrowers is a continuous activity undertaken by multiple stakeholders. Technical skills are predominantly transferred through training and extension. The provision of training, extension and capacity building are intrinsically linked and all help determine the sustainability and ongoing development of the model. The key to successful training and extension is basing all interventions on a ‘demand-led’ approach (Scarborough et al. 1997; Garforth 2004).

5.4.1 Training

Training is used to equip outgrowers, extension officers, farm workers and management staff with up to date knowledge and skills required for cane growing. The prime objectives are to maintain and improve production levels, increase sustainability and adopt good management practices. This is based on ensuring that each operation is carried out to an accepted standard and on time.

Training is provided at different levels to suit the needs of the proposed recipients. This can vary from provision of basic requirements for new farmers who have never before planted cane, to providing advanced training to experienced staff and/or outgrowers. Extension workers need to know the correct cane growing practices and how to transfer this knowledge to farmer recipients. A comprehensive analysis of training needs should be undertaken prior to implementation. The analysis must identify both the needs and appropriate methodology for implementation.

Topics for training outgrowers often involve, but are not limited to, the following:

- Accepted husbandry systems
- Introduction of new techniques
- Business and finance management
- Record keeping
- Regulatory framework.

A major challenge of training is to reach all the outgrowers and to obtain the same desired impact and results. Traditional models include the delivery of mass training by mill, estate, operating company staff and institute staff providing training directly to outgrowers. This tends to be an expensive and slow method, but provides manageable quality control of the training.
Outsourcing the training function to an external body and/or training specialist or consultant is also a commonly found model in the industry. This is usually expensive and can be unsustainable if the correct structures for sustainable implementation and ongoing support are not put in place. The benefit is that it tends to be less subjective to social and cultural issues than some of the other models.

A selection of training models and methods are described below.

5.4.1.1 Mill
Milling companies will usually have an in-house Training Department with skilled training officers who implement a structured program to train company employees, who in turn will become the trainers of the outgrowers.

5.4.1.2 Industry institutions
Industry institutions provide formal and structured training sessions on all associated subject areas at different levels to suit the trainees. These training courses have often been developed over a number of years and keep up to date with the changes.

5.4.1.3 Outgrower organizations
Outgrower organizations can employ extension workers and train them as in 4.4.1.2 above.

5.4.1.4 Commercial training organizations
Commercial training organizations can provide specific training courses to identified beneficiaries. These courses should be developed specifically for the user group and imparted professionally and effectively. Outputs should be monitored, met and an exit strategy put in place at the outset.

5.4.2 Methods and models for training outgrowers
A number of techniques have been tried and tested in the actual delivery of training. Gleaning from these experiences the following are relevant:

5.4.2.1 Training of the trainer
This method has proved to be successful in a number of countries and industries. Selected Leader Farmers are trained on the basis of their natural leadership and agricultural skills. They are trained to pass on the subject matter to fellow outgrowers in their respective communities. This is a proven method and allows for intensified regular training in smaller groups. The result has been improved uptake and transfer of knowledge. The Leader Farmers should be equipped with the necessary training aides and return to their growing areas to roll out the knowledge they have gained. During the rollout the Leader Farmers should be able to reach many more farmers and provide continuous sustainable support if they also continue to receive ongoing support.

Box 5.3 Example of a good management practices profile of an innovative lead farmer in India
For the past 12 years, Mr N Gopalakrishnan (Mr. NGK) of Mambala Salai, Trichy, Tamil Nadu state, has operated a 25 acre organic farm in the command area of the EID Parry Pettavaithalai mill. The farm has been 100% organic since 1995 and Mr NGK farms sugarcane on 20% of the land, and turmeric, bananas, yams, paddy and onions on the remaining area. Mr NGK converted to organic farming methods for environmental and economic sustainability reasons. He recognized that the pH value of his soil was too high, the cost of inorganic fertilizers were increasing exponentially, his soil was of poor health and his crop yields were declining, creating a negative spiral of cause and effect. Mr NGK had seen examples of organic farming elsewhere and had been inspired to try it on his own farm.
Mr NGK is a great proponent of improving soil health and firmly believes in knowing and understanding one’s soils before developing on them. Originally, Mr NGK focused on revitalizing the health of his soils through developing a solution to address the problem of salinity, developing a vermicompost and transferring production to drip irrigation techniques. Although he suffered a loss in yield for approximately three years whilst the soil was under conversion, he began to achieve higher yields than his neighbors using conventional farming techniques, with an average of more than 50 tonnes cane per acre. In addition to improved yields, his cost of production decreased significantly; Mr NGK has proved that organic vermicompost costs one quarter of the price of inorganic fertilizers and of course significantly reduces the carbon footprint of the production process. Vermiculture and vermicompost are now focal areas of activity on the farm.

After witnessing his success, other farmers demonstrated interest in his techniques and products and Mr. NGK began dispensing advice and selling the organic inputs, gradually developing a business producing and selling organic agricultural products commercially. In addition to earthworms and vermicompost, Mr NGK also produces and sells organic soil fixing solutions, one such product for salinity, which is a common problem in the area particularly where furrow irrigation is in operation. The solution incorporates the use of fish and molasses and is diluted with water for fertigation.

Mr NGK focuses on technology transfer and has developed strong relationships with research and university faculties to obtain advice and guidance to enhance his operations. He has developed an institute to promote organic agriculture, the Rural Agriculturalist Development Integrative Organization (RADIO). He regularly hosts workshops locally and internationally to transfer technology, knowledge and skills in organic farming to other farmers, and produces training aids and literature in the form of posters and leaflets providing guidance notes and solution recipes. He also undertakes site visits to assist farmers with diagnosis and problem solving. Mr NGK estimates that he has reached in excess of 60 000 farmers in India, Malaysia, Singapore and Thailand. The Organic Farming Association of India recognizes Mr NGK as an expert in his field and utilizes his farm as a training centre for organic farming. His innovations and contributions to organic agriculture have been publicized in various media, from printed matter to television.

INFORMATION SOURCES: MR N GOPALAKRISHNAN, NOVEMBER 2010
TAMIL NADU AGRICULTURAL UNIVERSITY. ttp://agritech.tnau.ac.in/kvk/kvk_karur_success.html

5.4.2.2 In situ training
Training is field based and in a familiar environment for outgrowers. The training is done at relevant times for each specific operation and can comprise modular training to cover a range of topics.

5.4.2.3 Training aids
Field manuals and educational posters benefit recipients by helping them to understand and retain knowledge. Aids should be developed in local languages to explain and visually illustrate themes and activities. They should aid outgrowers to identify situations and activities. These aids can be used by Leader Farmers, extension workers or trainers for visual demonstration.

5.4.2.4 Demonstration plots
The demonstration plots show the practical benefit of different techniques and practices. The organization of field days and exchange visits to demonstration plots between farmer groups is extremely valuable for visual impact. The grower is able to see the potential of his own land.

Box 5.4 A partnership between the South African Sugarcane Research Institute (SASRI), the KwaZulu-Natal Department of Agriculture, Environmental Affairs and Rural Development (DAE&RD), the Noodsberg Cane Growers Association and outgrower communities

The objectives of this partnership are to improve the sustainability of sugarcane outgrower production and to increase cane supply to the industry. To achieve this SASRI has seconded an experienced extension officer to the government to provide technical assistance to the existing extension officers, and has developed a working relationship with the Noodsberg Cane Growers Association. The program has also developed partnerships with the financial sector, other government departments, millers and donors to provide loans to the outgrowers for the development and maintenance of rainfed sugarcane.

Through practical experience the program has developed an effective 10-step approach for development, using demonstration plots and seedcane support services:

Prepared by PGBI Sugar & Bio-Energy (Pty) Ltd.
Step 1: Community consultation to establish the level of interest in cultivating sugarcane as a commercial crop.

Step 2: Facilitate access to finance for the outgrowers through partner institutions.

Step 3: Select a cooperator; a local person with a strong personality, who is financially stable and located in a secure situation. This person will plant seedcane as a demonstration plot enabling other outgrowers to visit the plot to view operations and will provide technical advice. The extension officer must ensure that the person is capable and willing to be involved with all steps.

Step 4: Identify an appropriate site on the cooperator’s land. The soils and topography of the site must be representative of the area and the site must be accessible to vehicles.

Step 5: Develop an implementation plan with the cooperator for activities and field days for other potential outgrowers to attend.

Step 6: Undertake a full land assessment as a demonstration for farmers, including soil sampling for soil type identification and an environmental impact assessment. This assessment must fulfil local legislative land requirements.

Step 7: Formalize the management agreement between the cooperator, the Department of Agriculture and the mill. This agreement will provide guidelines for management procedures and provide detail on partner roles and responsibilities.

Step 8: Arrange seedcane and transportation, land preparation and planting services, using each activity as a demonstration.

Step 9: Develop a Program of Work with the cooperator and the local extension officer detailing inputs, man day requirements, suppliers, agronomy of the crop, business skills and pricing of the seedcane.

Step 10: The cooperator will become the seedcane provider for new developments using plant and first ratoon cane, and will then supply all future cane to the mill.

A new cooperator is to be identified each year, enabling the demonstration plot system to be sustainable and support development of sugarcane in the area. Training and extension aids in the form of posters and leaflets are provided to the extension workers and cooperators to aid ongoing training and extension. Continued extension and support from the partner organizations is provided.

At the end of 2010, the program had supported technology transfer to 617 growers on 912 hectares and developed new outgrowers in a sustainable manner, with local ownership and management in the mill supply area of the Illovo Sugar Noodsberg factory, in the KwaZulu-Natal province of South Africa.

INFORMATION PROVIDED BY F MITCHELL (KZN DAE&RD), W. GILLESPIE AND M. WAY (SASRI) AND T.WEBSTER. OCTOBER 2010

5.5 Extension services

Extension services are one of the single most important factors in successful outgrower scheme management and industry sustainability, particularly where a significant proportion of cane supply is produced by external suppliers. However, many industry players have reduced their financial investment in extension at a time when the need for improved, comprehensive extension services to secure cane supply is necessary. Extension plays an important role in maintaining basic principles, introducing new technologies and ensuring that good management practices are implemented to protect the industry and the environment.

The extension officer, however, should not be expected to undertake a policing role, as this can compromise the position. Consequently, aspects such as statutory regulations for pests and diseases, and compulsory ploughout, should be dealt with by a separate body through the regulatory framework.

The main objectives of extension are to:

- Secure cane supply
- Ensure control of diseases
- Provide crop growing recommendations
- Maximize production
- Maximize sustainability
- Introduce new developments and techniques
- Advise on soil conservation and environment
- Prepare farmers for new legislation or regulations
- Monitor industry regulations
- Educate outgrowers on how the industry operates
- Communicate industry information to recipients
- Facilitate the use of micro credit for crop improvement
- Advise on records and management.

A participatory approach to planning of extension is advised to enable stakeholders to receive valuable input on constraints and opportunities within the wider community (Hickey and Mohan 2004:11). The extension model should be decentralized to reduce costs and increase the ownership by the outgrowers. It is imperative that the outgrowers are aware of the cost of the service, to ensure that they utilize it effectively and monitor the service. It is important to appreciate that good extension personnel are those that can empathize with the growers. The grower should be given the advice in such a way that he feels that he has made the decision for himself. Extension keeps industries abreast of change, helps network with other growers, promotes the use of GMPs and stimulates change and success (Lakshminarayan et al. 2009).

5.5.1 Extension service providers

Some of the more common models of extension service provision within the sugar industry are listed below.

5.5.1.1 Mill
This model is common where the mill is highly dependent on outgrower cane supply. There has been a move away from this model as it was regarded as paternal and not in line with the changing social climate. Due, however, to the perceived failure of the replacement models and the decline in cane supply and quality in some countries, millers are considering reintroducing this model.

The risk with mill based extension is that the services tend to concentrate mainly on cane procurement. This is because it is a priority for the miller and also an area where the grower needs assistance, but which can be at the expense of advice and technology transfer. Extension workers employed by the mill will in many cases live on the mill estates which can potentially reduce confidence and trust in the relationship with the outgrower.

The quality of the extension is variable. Emphasis must be on specific methods and skills to transfer this technology and knowledge to outgrowers in the form of extension. The relationship between the extension providers and the outgrowers is a key contributing factor to the potential success or failure of the model. India provides a number of examples of successful miller led extension models, but there are few examples of successful implementation in southern Africa. This is predominantly due to the diminished focus on extension as a specific skill and a general assumption being made that if an individual can manage estate cane, by default he can provide extension.

Box 5.5 A partnership for sustainable production the EID Parry way

EID Parry India Ltd is part of the Murugappa group, an organization with a diverse industry profile including sugar in three regions of India. The group has five guiding principles for all of its operations: integrity, passion, quality, respect and responsibility.

The sugar portfolio in Tamil Nadu and Puducherry, Andra Pradesh, and Karnataka, supports nine mills, crushes over 32 500 tonnes cane and produces 146 megawatts power per day. In addition the group operates four distilleries. The cane supply is all outsourced, from over 150 000 outgrowers, predominantly small in scale and landholding. The mills typically operate within a 20 km radius command area where agricultural crops account for only 2% of the land area and sugarcane only 11% of that, with paddy being the primary crop followed by pulses.
and oilseeds. Outgrowers generally work individually but are linked to associations in some areas to manage irrigation and water supply, to raise finance and to provide and receive extension and technical support.

EID recognizes the importance of the outgrowers and their intrinsic role within their business, as without their cane supply the mill and business would fail. EID therefore have developed a comprehensive support system for their outgrowers, viewing them as ‘investors and partners’ within their business. The main constraints faced by the outgrowers within the EID command area reflect the constraints of many outgrowers in India, which are:

- The reduction of landholding due to increase in population size
- Poor land usage
- Low yields due to
  - poor access to quality, viable seed varieties
  - cost and availability of farm inputs
  - financial constraints
  - technological capacity
  - pest and disease
  - climatic conditions
- Cost and availability of labor
- Comparative price for sugarcane
- Cash flow management
- Environmental management.

In response to these constraints and subsequent threats to the industry, EID has developed a progressive system for interaction with the outgrowers that addresses such issues. The support system is based on the principles of ‘simplicity and transparency’ and demonstrates a continuous support cycle where each operation is dependent on the other.

- Seedcane supply - EID developed a sugarcane varietal development program focusing primarily on developing appropriate cultivars for the outgrowers that are suitable to the climatic and soil conditions in the area and are able to resist the main pest and diseases. The company developed two cultivars that produced 20% better yields than the existing cultivars.
- Input supply – the company provides a soil testing service for all outgrowers to enable appropriate agricultural inputs to be identified and supplied, and training to ensure the correct use of inputs. EID has developed a number of leader outgrowers and entrepreneurs to supply inputs and advice through outgrower service centers called ‘Parry Myyams’. Often these entrepreneurs provide additional farm services such as land preparation and mechanized planting.
- Technical support – EID has engaged in significant crop specific research and development, extension and training using demonstration plots and field days to transfer technology to the outgrower. The company has also engaged with partners to promote the use of drip irrigation and fertigation to promote improved water management. EID has developed a comprehensive ‘farm process outsourcing’ model that develops village level entrepreneurs to introduce ‘green’ integrated pest management services through biological controls for pests and diseases (P&D) (Bio Control Production - Farm Processing Outsource (FPO) model) at village levels with entrepreneurs establishing biocontrol production centers and a distribution service to surrounding outgrowers to treat pests using ‘Tricho’ cards. Cane stem borer is the major insect pest in the area and is managed through the production and distribution of biocontrol agent, Trichogramma covering 80% of outgrowers’ area without using any chemical pesticide for the past 15 years. The implementation of the program is through village entrepreneurs who provide the control service and are paid by EID through deductions from outgrower cane proceeds. This system requires no financial investment by EID as it is a business, just technical support and training;
- Risk control – EID provides a comprehensive risk mitigation program incorporating weather forecasting, crop surveys, P&D monitoring and control, and crop insurance. EID supports a center for mathematical modeling which monitors weather parameters in five locations. The center gathers multi source data and synthesizes with onsite observations to generate location specific weather information. Day to day and seasonal forecasts are provided and models are built to analyze long term trends and patterns of local weather.
- Labor provision – EID provides a harvesting and cane supply service to its outgrowers along with P&D control and support through third party entrepreneurs. Thus the company deals with third party contractors and entrepreneurs to coordinate 40 000 harvesting labor, 10 000 hauliers and 50 000 farm workers. A total allocation of 35% is for harvesting and loading, 21% for land preparation, 16% for planting, 10% for
weeding, 10% for fertilizer application and 8% for irrigation. As labor becomes more scarce and expensive, EID has developed a program to support mechanization and improved land utilization of small farms. It supports the development of local enterprises, usually owned by sugarcane outgrowers, to provide mechanization services. It is difficult to assess labor standards as many outgrowers undertake their own operations or use local small contractors; however, as field labor becomes increasingly scarce, its value and cost increases. EID quotes the labor situation as ‘from vulnerable to bargaining table’. Standards are more difficult to judge as there are not any comparable standards where small operators are involved; however, EID has set standards to which they encourage their partner operators to adhere.

- Financial support – EID ensures that it operates a fair, transparent and timely cane payment system with a pricing system that incorporates sucrose, bagasse and molasses in addition to the Central Government’s announced fair and remunerative price (FRP). EID implements a number of initiatives to relieve the pressure on the outgrowers. EID does not operate with formal cane supply agreements; the relationship is based on ‘gentlemen’s agreements’ for cane production and supply. Each year an out grower registers with the company and is paid an advance against delivery to aid commencement of cane operations. In addition, EID supplies agricultural inputs, and advances infrastructure term loans to be deducted at harvest to facilitate the timely availability of these inputs and ensure required cash flow on time or cashless operations.

- Land management – EID has commenced a support program to improve the global competitiveness and viability of small scale outgrowers with a focus on efficient and sustainable land use. Small scale outgrowers in most areas will only farm about 30% of their land to sugarcane, also growing local crops such as paddy, bananas, tapioca, and maize (in the south). Sugarcane is generally grown for only two ratoons (first and second), after which it is ploughed out. A rotation crop is planted for at least 3-6 months before planting cane again. EID promotes intercropping with symbiotic crops such as legumes, to provide additional income to the outgrowers while improving organic carbon content in the soil. Once the crop is harvested, the roots and waste are ploughed into the fields to provide valuable nutrients to the sugarcane crop. In Trichy, a high level canal feeding from the river into feeder canals was developed some 50 years ago and is still operational. It is managed by the State at bulk water supply level and by the villagers and outgrowers at field level. It is critically maintained as it is viewed as the lifeline to the area.

Environmental management – EID has a strong focus on environmental sustainability as a core philosophy. It has undertaken numerous studies on the effect of global warming on their business and the areas in which they operate. They recognize the impact of changes in rainfall and temperature on crop yield, and that small scale outgrowers are most vulnerable. EID has supported a number of organic outgrowers that have developed organic farming techniques for the improvement of soil structure, including salinity control, also earthworm farms, and composting from local resources such as cattle manure and urine, filter mud and farm and street organic waste. EID strives to improve its sustainability through developing environmental management systems and operations beyond industry standards, engaging the communities in environmental rehabilitation programs such as tree planting and water management, and is one of the first companies to apply for Bonsucro certification.

The model operated by EID demonstrates that cane supply from small scale outgrowers can be sustainable and profitable, and provides a lesson for many countries. Much of the success of the EID model can be linked to the strong partnership between the mill and the outgrowers, developed through transparent actions and an integrated participatory support program made possible by the professionalism of both company employees and outgrowers. Sustainability appears to be the core belief of the company and its outgrowers; all activities are viewed as investments for the future generations.

5.5.1.2 Industry institutions
This model occurs where a number of millers buy from a pool of outgrowers with similar interests. The institutes are usually funded by the industry (levy or cess) or with a Government subsidy. Institutes usually carry out applied research and disseminate their work through extension and outreach programs. The institutes often monitor practices to ensure compliance to regulation. The model usually uses extension workers who will visit farmer communities with a specific task or instruction to fulfill. They will have as advantage that they are mobile and can assist with adopting new techniques quickly. The disadvantage is that this is not a demand driven approach and officers cannot always provide guidance or advice when it is needed. In addition, as extension workers are not resident within the community trust levels may be reduced resulting in limited uptake of advised practices.
This model, however, is successful in many countries where the institute is effective and efficient and where there is close contact with the industry stakeholders, and who often have joint venture initiatives with other organizations.

5.5.1.3 Government
In countries where the government agricultural extension services are efficient and adequately funded, mills can rely on these departments to provide the extension services. However, they will obviously not have the same level of operational control/interest as the two examples given above. Government extension is likely to combine the cane extension with other crops and livestock, which is relevant for outgrowers. Problems occur when different levels of commitment between the millers and government are found. In addition, many Government extension officers are trained specifically in subsistence crops. They lack technical expertise in sugarcane unless specifically trained by the industry. However, a major constraint in Tanzania, for example, is the lack of reward for productivity. Government extension officers are paid a monthly salary, which is not related to performance or results. With this scenario, the extension worker often lives within the farmer community and shares his/her knowledge, with and provides guidance to, the farmers across the entire crop cycle. It has as a benefit that the farmers gain a lot of confidence in the mentorship; however, this model is often slow to respond to introduction of new techniques and practices as it is physically difficult to reach individual extension workers. Consequently, the level of service and interaction required by the outgrowers and industry suffers.

5.5.1.4 Commercial suppliers
Private companies that supply products or services are becoming increasingly involved in direct extension with their outgrower customers. This type of extension is usually very specific and is driven by the commercial interests to increase the uptake or security of a certain product or activity (e.g. agrochemicals, fertilizers, implements and finance).

Many banks providing finance to outgrowers are utilizing models that enter into a ‘tripartite agreement’ (bank, miller, outgrower) to ensure that credit repayments are paid from source. This reduces the risk to the bank. In addition, some banks get involved in the management of the outgrowers and the provision of extension. This improves the profitability of the outgrower and the security of the bank.

Box 5.6 Focus of “Opportunity International Bank of Malawi (OIBM)"

OIBM is a member of Opportunity International (OI), a worldwide network of microfinance banks with partners in 45 countries worldwide, and operating in eight countries in Africa. OIBM is a commercial bank with focus on the economically active poor and marginalised people of Malawi (both urban and rural) and offers a wide range of financial services. OIBM follows a ‘Triple Bottom Line’ approach in its operations to help its clients transform their lives through access to financial products and services. The three elements are; Profitability, Outreach and Transformation. OIBM maintains a policy of ‘know your client and know your crop’.

**Know your client** – For seasonal loans for input provision, OIBM provides a GPS service to the outgrower’s land to ensure that input estimates and related financial support is accurate. In the case of sugarcane outgrowers, OIBM also measures the distance from field to mill, as haulage is a significant portion of the budget. Where possible OIBM access data from the mill about the past three years of cane supply to provide information on actual and potential yields and a comprehensive overview of the cane payment system. Once OIBM has acquired the necessary data on the outgrowers, the environmental and the agronomic components, they compile individual budgets for each grower, calculating both a return on investment as well as the outgrower’s retained earnings.

In addition to seasonal loans, based on this comprehensive knowledge of the client, OIBM have also been able to offer capital loans over a four year repayment period. In addition to the GPS mapping and household profiling, OIBM also look at...
the outgrowers’ current fields and production, and where fields are not maximising their yield potential (normally due to vacancies), replanting or in-filling with capital development loans are recommended.

**Know your crop** – It is OIBM’s policy to understand the cropping requirements, both from making available the correct inputs at the right time, as well as understanding the complete cycle and financial pressures from planting to delivery to the mill. It is imperative that the budget must cater for all operations, irrespective of what the farmer intends to contribute. Part of OIBMs’ ‘know your crop’ initiative is to ensure that the farmers are following a Good Agricultural Practices (GAP) policy to maximise yield from a limited portion of land by applying the correct inputs. OIBM engaged with the mill when developing the product and modified the list of inputs to achieve the GAP standards.

**Technical support** – OIBM has engaged a field technician to supervise operations on the ground and be available to discuss financial issues relating to production. OIBM does not advocate giving the farmers agronomical advice, as this is not core expertise but facilitates acquiring advice from the mill or other technical organisations to assist the outgrowers.

**SOURCE: JIM HENDERSON, CONSULTANT TO OIBM**

5.5.1.5 Commercial companies

Mill management or outgrowers may source technical assistance from commercial companies, which specialize in training and extension. Companies can provide a wide range of sugarcane expertise. Their input should be based on an assessment of the outgrowers’ needs. The company will then develop a comprehensive package with supporting material in a format suitable for the outgrowers, and a plan of activities to coincide with crop timelines enabling demonstration.

**Box 5.7 A commercial approach to sugarcane production training – Agricane Limited**

Agricane is an agricultural engineering and development company incorporated in 1996. Agricane is operational in many plantation and smallholder sectors with the objective of establishing environmentally, economically and socially sustainable agricultural developments and production in Africa. Although experienced in a number of crops including tea, coffee and jatropha, the company provides specific focus and expertise in sugarcane cultivation and management providing comprehensive services from feasibility and design, installation and development, to staff training and extension services.

**Methodology**

Agricane provides a holistic approach to sugarcane production training incorporating theoretical and practical methods of technology transfer utilizing a range of expertise and training aids. Appreciating that not all training requirements are the same and social, educational and environmental issues will influence the training requirements and approach, Agricane will develop training programs together with the client so as to customize training opportunities for specific conditions. Comprehensive training packages focus on a ‘back to basics’ approach to ensure full understanding by all participants regardless of employment, position or level. The company commences a relationship with a client by undertaking a comprehensive Training Needs Assessment (TNA) to identify focus areas and develop appropriate methodologies. The company has developed generic cane grower modules for junior, senior and small scale out grower clientele that are developed according to the outcomes and recommendations of the assessments. Agricane believes that training costs should be recovered through increased productivity and/or lower production costs and thus focus on delivering training programs with measurable results.
Holistic Training Approach

Continual operational assessment & production success
Instil motivation
Improve practical & managerial skills
Increase knowledge base
Formal interactive lectures
Practical assignments
Continual operational assessment & production success

Project examples:

**Malawi**
Agricane has entered into a partnership with Concern Universal (CU), an international NGO funded by the European Union delegation in Malawi to implement a comprehensive capacity building program to the sugarcane outgrowers. Agricane is mandated to provide technical training in sugarcane and food crop development to the outgrowers over a two year period. The company and CU undertook a full TNA to identify the focus areas for development recognised by the experts and the outgrowers and the optimum way to implement the training. The company has developed a range of training aids, from flipchart posters to a comprehensive manual in both English and the local dialect. The methodology will include direct training to outgrowers, outgrower management company employees and contracted labor through theoretical and practical training on demonstration plots. The technical training complements a range of capacity building programs being implemented by CU in business understanding and skills development, environmental management improvement and civil education.

**Kenya**
Agricane developed a full range of training programs for management, employees and outgrowers at Mumias Sugar Company (MSCo) to focus on improving the crop management standards and cane supply. The majority of cane supply is provided by approximately 68 000 rainfed outgrowers operating on approximately 0.8 ha of land per farming family. In recent years, the previous outgrower support model using an outgrower company to coordinate and supply extension and services collapsed, leaving a void in service provision to the outgrowers which resulted in declining yields and quality of cane. To fill this void, MSCo are required to provide a comprehensive range of field and extension services to the outgrowers including, but not limited to, land surveying, outgrower registration, land preparation, seedcane supply, input provision and supervision, harvesting and labor coordination. The capacity of MSCo staff required considerable development to enable them to provide these services. Agricane developed a range of good management practice guidelines and trained the participants in implementation methods and methods of technology transfer to enable the employees to impart knowledge to the outgrowers.

5.5.1.6 Outgrower organizations

Most outgrower model based irrigated schemes are increasingly being considered for rainfed schemes, i.e. utilizing an operating company to oversee and implement operations of the scheme. In many cases this company is tasked with providing extension to the outgrowers as part of its daily operations. The constraints to this method lie predominantly in the technical skills level of the company, and its human and financial resources to support an extension service. Often daily operations are given priority over extension, gradually reducing the capacity of the outgrowers and thus their ability to perform activities effectively, leading to less involvement as the company takes over activities to ensure production. In some cases, outgrower associations also provide extension to their members and can suffer from the same capacity issues.
5.5.1.7 Non-government organization or development partner funded programs

In the past decade development finance has been increasingly channeled towards commercial crops on the basis of trade for development. Development partner agencies and governments are realizing the value of sugarcane as a cash crop and the value of the sugar industry to national economic and social advancement. Non-government organizations (NGOs) and programs funded by development aid are now commonly present within the industry across the world providing extension and training to outgrowers in a bid to improve productivity and income generating potential for rural communities.

Many of these programs present the opportunity to move away from traditional patriarchal methods of technology transfer to more participatory processes, although it is important to ensure that the participatory approaches used actually add value to the process and are not just used as a low cost option (Cooke and Kothari 2001). It is imperative that these programs link closely with other industry activities to avoid confusion and the spread of inaccurate information to the outgrowers as generally, unless third party technical expertise is employed by the program, technical and industrial skills within the NGO/donor community are low. These interventions are often free to the outgrowers and, if not managed correctly, can distort the value chain in schemes where outgrowers are charged for extension services. In addition, it is important that programs carefully consider their ‘exit strategy’ to ensure sustainability of service.

5.5.1.8 Mentors

Mentorship occurs when farmers with skills, expertise and experience are able to assist adjacent newcomers in the industry. In countries with competent commercial farming outgrowers surrounded by smaller and less technically capable outgrowers, a number of mentorship schemes are being implemented with the larger farmers providing technical input and extension to neighboring small scale schemes. This provides a sustainable hands-on method of support as it remains in the interest of both parties to continue the program. For the larger farmer, improved livelihoods of the communities surrounding his farm increases security of land and equipment and productivity of the workforce, whilst the smaller outgrowers benefit from an improved income source. In South Africa, new sugarcane farmers entering the industry through land redistribution programs are encouraged to build relationships with other stakeholders to obtain key industry information and to learn from their financial and production experience (Floyd and Darroch 2009).

India has taken a ‘lead farmer’ or ‘mentor’ approach, targeting successful outgrowers to provide extension and advisory services to neighboring farmers. A fee is sometimes charged, so developing a small business. The benefit of this lies in the relationship of the farmers and the accessible and localized nature of the service. The mill trains the lead farmer and will back-stop and provide additional support where necessary. It is important though to ensure that this method does not serve solely to increase the power of a few thus driving away other stakeholders (Cooke and Kothari 2001).

Box 5.8 A mentorship approach to technology transfer – the Noodsberg Cane Growers, Gqugquma partnership

The Gqugquma outgrower scheme was established in 2002 by the Noodsberg Cane Growers Association (NCGA) and the Illovo Sugar Company Ltd operated Noodsberg mill, as a response to a need to involve local communities in the industry and increase cane supply to the mill. The scheme was established as a mentorship program to develop small scale outgrowers around the successful large-scale farmers. This scheme is one of a number of increasingly successful schemes in the area being developed by a number of key development partners; the Department of Agriculture, Environmental Affairs and Rural Development (DAE&RD), the South African Sugarcane Research Institute (SASRI) extension officers, the NCGA, the World Wildlife Fund (WWF) and community groups.
NCGA has 180 commercial growers farming approximately 33 000 ha and 400 active smallholders farming on 520 ha as individuals and cooperatives, and is a progressive association with a core focus on sustainable development. There are two mills in the area, the Illovo owned Noodsberg Mill and the UCL Company Ltd with a catchment area of 50 000 ha. There is an estimated 8 000 ha of smallholder land suitable for cane development in the vicinity of the mills. NCGA is the organization that developed the ‘SusFarms’ sustainable management system that is being adopted across RSA and more recently into sub Saharan Africa. The development partners predominantly follow the DAE&RD and SASRI 10-step development approach, with additional extension and mentorship from NCGA.

Gquqguma was originally planned to be financed by the Government; however, the finance was not forthcoming, so alternative methods were employed. Commercial farmers in the area provided the seedcane, NCGA took out a 2-year loan to finance operations, the Illoo mill financed land preparation, and the DAE&RD supported weed control and fertilizer inputs for the plant crop. Development was done slowly on a block by block basis with each plant crop being used as seedcane for the next development; the growers were obliged to sell the seedcane to the next members at a subsidised price as they had received it subsidised. The growers provided labor and constructed fencing to protect against cattle.

The Gquqguma outgrower scheme is in an area with soils ideal for cane growing, and operates under rainfed conditions. NCGA developed the scheme with local communities in blocked areas for conservation reasons, following strict land use plans and avoiding housing areas, sacred sites and environmental hot spots and developed the scheme with sustainability in mind. The scheme is run as a cooperative, is 126 ha and has 91 members. Gquqguma is divided into seven areas, each with a chairman and small committee. Payment is made to the cooperative and is disbursed according to land area, not individual yield, as the area is managed as a block and not as individual areas.

The scheme pays a levy for P&D control which is managed by NCGA, who send in two teams on a monthly basis to inspect and control. Each block also has its own inspector/manager, who is subsidised by the commercial growers.

Historically, the scheme has been closely managed and controlled by NCGA, using external contractors for services. However, more recently responsibility has been handed over to the cooperative and NCGA provides a mentor to the cooperative paid for by the coop, but subsidized by the commercial farmers. This mentor provides technical and business advice and management assistance. As local contractors continuously increased prices, some growers have invested in machinery and now provide services to the scheme.

The sustainability of this partnership is rooted in the needs and participation of all stakeholders. The large scale farmers acknowledge that their own businesses will benefit from the improved livelihoods of the communities surrounding them. Productivity of their employees will improve and theft will decline as the feeling of being part of an industry and partnership increases. The success of Gquqguma has lead to more smallholder schemes being developed in the area in partnership with NCGA using the 10-step approach, focusing on sustainable practices and demonstration plots.

This model demonstrates how mentorship and support can lead to durable partnerships and that cooperatives can be successful in commercial operations with strong leadership, careful management and strong partner support mechanisms.

**5.5.1.9 Partnerships**

Provision of extension to outgrowers is complex, yet essential to secure cane supply at both outgrower and mill level. Stakeholders are acknowledging that there is no single body capable of meeting the full needs of the outgrowers (Malaza and Myeni 2009). A number of partnerships have evolved out of a combination of some of the scenarios listed above in order to improve cane supply and outgrower performance.

**Box 5.9 Technology transfer partnership - DSCL Sugar and the International Finance Corporation**

Uttar Pradesh is the leading producer of sugarcane in India, accounting for approximately 50 % of the total sugarcane acreage and 40 % of the total sugar production. However, per hectare yield of sugarcane is low at an average of 55 tonnes cane per hectare. The primary reasons for low yields are the shorter growing season and severe winters, low capacity of outgrowers, small land holdings, low household income, and poor access to inputs. In addition sugar recovery is low, partly on account of low crop maturity, unsuitable sugarcane cultivars and poor agronomic practices.

DSCL is a part of the DCM Shriram Consolidated Limited business conglomerate with its headquarter in New Delhi, India. Originated over 100 years ago in the DCM Group, DSCL is today a diversified business conglomerate with annual turnover of over US $1 billion. DSCL Sugar commenced operations in 1998 and has four functional sugar mills in Central Uttar Pradesh with a crushing capacity of two million tonnes, a consolidated command area of over 288 000 hectares and approximately 150 000 to 200 000 outgrowers.
DSCL is working in partnership with IFC Advisory Services to address issues of low farm productivity and incomes. This is being achieved through a pilot project covering sugarcane agronomy, outgrower training and capacity building, training of extension workers, and access to affordable, quality farm inputs. DSCL has established interventions to address some of the most pressing issues preventing development and improved cane supply by outgrowers.

**Inter-cropping:** Many small farmers are reluctant to grow sugarcane due to its annual harvest and payment cycle, and low income per acre due to low yields and sucrose recovery. To address this, the program is promoting intercropping of symbiotic crops such as potato, mustard, green gram and lentils, planted in alternate rows with sugarcane to provide additional income and agronomic benefits.

**Promotion of trench planting:** One of the reasons identified for low yields is the practice of ‘close spacing’ of sugarcane rows which does not allow for adequate sunlight, water and other nutrients to reach the root zones of the crop, leading to poor plant health and low yields. To address this, the firm has been promoting the ‘trench planting’ method to aid germination as well as better tillering of the plant, and improved agronomy practices such as seed treatment for fungal infections, and soil treatment for termites and other pests.

**Mechanization of sugarcane:** Rural areas of Uttar Pradesh are facing acute labor shortages in the agricultural sector. To address this, DSCL has introduced mechanization of key activities on a pilot basis. The company has introduced a tractor-operated trench planter, leased to outgrowers for a nominal rental to reduce capital investment, and supported with training or specialized operators and mechanics to operate the machinery at a subsidized rate. Efforts are also underway to introduce mechanized harvesting of sugarcane.

**Outgrower training and capacity building:** The general awareness level of outgrowers is low, especially on agronomic practices for sugarcane cultivation, mainly because it is a new crop in the area. DSCL has developed 200 extension workers across their command area to interact with the outgrowers and raise awareness of sugarcane cultivation and good management practices. A number of the extension workers have been extensively trained under the IFC advisory project. Outgrower training is carried out both on the farm as well as in the company training facilities. DSCL has established a demonstration farm to which outgrowers are regularly invited to learn about practices and operations.

**Seedcane provision:** A major problem is the lack of suitable high yielding and high sucrose content cultivars available to outgrowers. DSCL has developed foundation seedcane nurseries for appropriate cultivars of sugarcane. Seedcane is developed after trials of approved cultivars and provided to outgrowers at a subsidized rate for further propagation locally. The company has installed the Moist Hot Air Treatment (MHAT) plants in their seedcane nurseries to provide outgrowers with easy and affordable seedcane treatment facilities.

**SOURCE:** DSCL AND IFC DELHI, DECEMBER 2010

5.5.2 Payment mechanisms for extension

The provision of extension services is a costly activity that has to be paid for – by whom is a constant area of discussion. Outgrowers must pay for services that they receive in some form, for them to perceive them to be of value. The way in which services are paid for can vary according to regulatory frameworks and models employed.

**5.5.2.1 Industry levy or cess**
A cess or levy collected by the mill from each grower, on the basis of production, contributes a proportion towards extension services. This charge is usually determined by the industry.

**5.5.2.2 Deduction at source**
Direct deductions from cane payments by the mills paid to associations or management companies, where typically extension costs form part of the management and administration fees, or the mill charges the outgrowers directly for extension. This charge is determined by the service provider.

**5.5.2.3 User pays**
The outgrower pays the service provider directly for any extension services rendered.

**5.5.2.4 Government sponsorship**
Government pays for the extension services at minimal or no cost to the grower.
5.5.2.5 Commercial sponsorship
Commercial supply companies will build in the cost of extension into the price of their product.

5.5.2.6 Development partner support
A development partner will fund the extension program requiring minimum or no payment from the outgrowers.

5.5.3 Monitoring and evaluation of extension

Whilst extension is a key component of successful outgrower schemes and subsequently reliable cane supply, the monitoring and evaluating of extension services remains low, and is often judged by yield and cane supply results. Not many clear examples exist of how extension is monitored in practice and unfortunately few examples exist of outgrowers demanding improved extension services despite them often paying for the service. This may of course be linked to the level of understanding and of expectation of the outgrower as to what extension services should incorporate and provide. It may also be linked to how well the outgrower understands the financial elements of the business, for example, what has been deducted from his/her cane payments.

A regulated industry or institution will develop frameworks and guidelines to evaluate the effectiveness of extension programs. Examples of these are given below.

- Control of pests and diseases
- Adoption of new technology
- Productivity of cane and sugar
- Farming systems
- Soil conservation
- Financial sustainability
- Environmental sustainability
- Adoption of industry regulations.

It is important to ensure that there is good interaction between all stakeholders, with a high level of accountability. It is important to ensure transparency as this leads to trust. A relationship founded on trust is more likely to succeed than a relationship of convenience supported by legal contingencies (Masuku et al. 2003). Outgrowers need to be involved in all stages of development and negotiation. To do this effectively, it is important to ensure that extension officers examine the suitability of the material and the message.

5.6 Supporting services

5.6.1 Management Information Systems (MIS)

Accurate outgrower registration and maintenance of records is essential for the good management of any scheme. Clear, transparent and timely information provided to the outgrowers will build trust and enhance the relationship between the operations management unit, the mill and the outgrower. It will assist with operational planning, facilitate the monitoring and evaluation of problem areas and reduce risk. Many industry regulatory frameworks demand the registration of outgrowers to facilitate the implementation of control measures and to enable monitoring of industry development. Management organizations need to maintain detailed information on all land, crop, personal and financial matters. This information should be held within a comprehensive MIS.
There are a number of MIS in commercial use; however, many outgrower schemes lack the capacity to use them and are too small to warrant one. A simple database provides a similar service and would be more manageable, but as with all systems the effectiveness of the output relies on the accuracy of data collection and input. An MIS will record inputs, activities and outputs related to individual outgrowers. This facilitates accurate payments and, if well maintained, can reduce risk for financial institutions when lending money to the outgrowers.

The key to a successful MIS for outgrower development is that it must be simple to operate. It should provide the information necessary to aid management without placing too much of a burden on the administrative and field staff.

Box 5.10 Overview of the EID Parry Cane Management Information System

EID Parry, Pettavaithalai Mill in Trichy, and all other factory units within the group, operate a comprehensive MIS to manage in excess of 20,000 small scale outgrowers per factory unit, who are dispersed over primarily a 20 km radius but with some delivering from 80 km away. All farmers undertake operations independently with support from EID and deliver as individuals with a range of different transport mechanisms. Farmers are registered in the system on an annual basis and paid an advance for their cane production. The farmers are then provided with a number of services on a cashless basis from the mill and other partners that need to be recorded and deducted from the final cane payments. It is imperative that the system accurately and transparently records this data and that it is accessible from a number of remote field locations for data entering and account viewing purposes. The EID system is web based to facilitate remote access.

For operational management purposes the land within the command area is divided into divisions, sections, villages, groups and outgrower, providing accurate locations and plot details such as size, topography, soil profile, access to water and access to infrastructure. Each outgrower is allocated a grower number which relates to a geographical reference. Personal information about the grower is captured: name, father’s name, physical and postal address, phone number, bank details, employment details and any other pertinent information. There is an extension checklist against each outgrower and plot where every detail about field operations is captured; for example ratoon information, source of seed, plant spacing, fertilizer application, P&D records and control, manure application, irrigation method and scheduling, plant protection methods, drought management methods, and harvesting schedule. This information is captured by EID field staff and entered at the remote location field offices and uploaded to the main system daily.

The depth of this information enables EID to accurately estimate crop yields and manage the harvest plan. The system also improves management and control of the crop, enabling EID to identify patterns of pests and diseases, and to react swiftly to significantly reduce risk. The outgrowers are given three days’ notice to harvest and deliver their cane, based on the age according to the management information system. Upon harvest, they are provided with crop information and financial management information including data by short SMS through mobile phones detailing the services that have been provided and recorded, and deductions to be made, for the outgrowers to view. This enables them to raise any potential discrepancies and improves the transparency of the payment system and thus the partnership.

INFORMATION SOURCE: EID PARRY/K MATHIAS INTERVIEW, NOVEMBER 2010

5.6.2 Aerial imagery and mapping

Mapping of land areas and location provides an important component in producing accurate outgrower and industry records. GPS mapping of individual areas is essential for estimating cane supply, water use, and quota. Mapping assists with the correct ordering and use of inputs. Aerial imagery with mapping annotation on the ground offers a valuable technology to look beyond visible wavelengths of light through near infra-red (NIR) wavelengths which provide indicators for biomass energy and increase the value of the images. Aerial imagery and GPS mapping linked with an MIS enables the development of a ‘point and click’ mapping system. This provides ‘real time user friendly’ visual and topographical information for planning purposes.
5.6.3 Contracted services

Contracted services cover a wide range of mainly mechanized operations. Services include technical support and management, land development, planting, harvesting, loading and haulage to the mill. India, for example, is a country that previously undertook most operations by hand or animal, but has moved on towards mechanization due primarily to labor shortages. Small scale growers are advised to contract machinery services from reputable companies, which have the experience and technical ability to carry out operations on time and to a given standard. It is seldom feasible for small scale growers to own and operate their own machinery. The outgrower organization responsible for using contractors must develop capacity for contract negotiation, monitoring and evaluation. They must have the ability to reject substandard operations and services. Where an individual outgrower does not have this capacity, support should be provided by the extension officer. GMP guidelines will assist in facilitating contract negotiations and evaluation.

In India and Mauritius, outgrower organizations have developed local ‘one stop shops’ to provide the outgrower with easy access to inputs and services. This type of model is extremely beneficial in industries with a large number of outgrowers and provides an opportunity for technology transfer.

5.6.4 Seedcane supply

The provision of hardy cultivars of quality, clean seedcane is a key contributor to the success of an outgrower scheme. However many outgrowers use their own ratoon cane as a source of seedcane because of financial and logistical constraints. This increases the chance of disease, reduced yield and low quality cane. This also can result in yield loss from not using the newer and more pest and disease tolerant cultivars.

Seedcane can be obtained from a number of sources. Seedcane requirements must be planned at least one year in advance. This allows the seedcane producer to provide the seedcane at the right age for planting out. It is important to appreciate that varieties are grown for harvesting at specific times as early, mid or late season.

5.6.4.1 Mill provision

The mill can agree to supply seedcane to the outgrowers at an agreed price, either including or excluding haulage. The advantage of this method is that the quality of the seedcane is more reliable and choice of cultivar is based on sound agronomic expertise. The disadvantages are that the cost of hauling from one centralized point may be high and the most suitable variety may not be available.

5.6.4.2 Seedcane supplier

Specific outgrowers or entrepreneurs produce seedcane to sell directly to the outgrowers. The advantage of localized production is low haulage costs. This increases the number of suppliers of seedcane and benefits the local economy. A disadvantage could be the capacity of these growers to provide clean, quality seedcane at the right age at the right time. Significant initial support will need to be provided to develop this capacity and to develop these individuals as small businesses.

5.6.4.3 Outgrower plant cane supply

Primary seedcane is obtained from the mill nurseries. This is grown by the outgrower to bulk up this material for forward sale after harvest as seedcane. First ratoon cane may be used to supply seedcane, but subsequent ratoons are milled. The advantage of this method is the low cost of production and transportation and the development of rural communities; however, the disadvantage lies in quality and disease control and ensuring that the seed growers are capable of managing the crop to the necessary level.
5.6.4.4 Outgrower organization
Where possible, outgrower organizations develop seedcane farms to supply their members. This is usually from core estate land or land acquired in the area. The advantages of this are low transportation costs and the ability to control development. There is also opportunity to use the seedcane farms as demonstration plots for training purposes and for additional income for the organization. The disadvantages lie in the capacity of the organization to provide clean, quality seedcane at the right age at the right time and to manage the seedcane farm professionally. There can be a higher cost of transport if the seedcane farm is remote from the outgrowers.

5.6.5 Input supply
In many industries the supply of agricultural inputs is undertaken by the mill, particularly where the mill operates an estate. This enables the outgrowers to benefit from bulk pricing and economies of scale. Some mills finance the supply of inputs through a retention fund, where a proportion of outgrower cane payment is retained for the procurement of inputs. This helps in economic climates where cane yield and price fluctuations occur. As access to finance improves for outgrowers, some mills have abolished the retention system, particularly where an operating company is employed. Financing then becomes the responsibility of the individual outgrower, operating company or association. Many mills have retained the option of accessing bulk orders of inputs. This must be pre-financed and often carries a handling fee.

Accurate records are essential where outgrower organizations manage input supply on behalf of the outgrowers. The individual outgrower must be able to verify the deductions made from their cane payments. In some cases, where activities are undertaken by labor, not the outgrower, it may be necessary for outgrowers to witness and verify the application of inputs onto their land to improve transparency and reduce suspicion. Centralized provision of inputs can also result in delays in procurement and supply leading to late application and yield loss.

The mill or outgrower association may be able to facilitate access to finance for inputs for individual growers. This can be done through finance institutions and tripartite agreements to reduce the risk of loan default. The availability of outgrower data from the MIS will support these interventions and reduce risk and possibly the cost of finance.

5.7 Contractual arrangements

5.7.1 Cane Supply Agreement (CSA)

The provision of a CSA is the main link between outgrowers and millers. The CSA defines the roles and responsibilities of each partner. The depth and detail of the CSA depends on the regulatory framework of the industry. It must take cognizance of national policies and guidelines. Examples are varietal use and P&D monitoring and control. In unregulated or poorly regulated industries the CSA should incorporate a wide range of issues to clearly define and regulate sugarcane production and supply. Contract facilitation is a key component involving outgrower organizations’ interests with their members. Historically, many CSAs were loaded in favor of the mill as outgrowers often lacked the necessary capacity. Due to the increased demand for outgrower cane supply and the increased interest of external stakeholders in supporting outgrowers, the contract facilitation has improved and contracts are more equitable.

Outgrower organizations should work in partnership with all stakeholders to design a contract (or agreement) to cater for all parties, ideally, in line with a code of conduct designed and implemented.
by external bodies in partnership with all stakeholders. The code of conduct should promote transparency and protect vulnerable stakeholders. The benefits are considerable when the body implementing the code is professional and impartial. The code requires all parties within the supply chain to undertake to comply. All contracts should be written in accordance with the code.

5.7.1.1 CSA components

Contracts or agreements should include:

- Quality requirements
- Pricing
- Input costs and repayments
- Termination, period of agreement
- Methods of arbitration
- Investment requirements and cost sharing
- Extension and training
- Roles and responsibilities.

CSAs should consider the appropriateness and include the following:

- Clear identification of the outgrower or organization that will be supplying the cane
  - Supplier/outgrower numbers
  - Outgrower name and identification particulars
  - Plot location and authority to use land
  - Associated organization and mandate.
- The mill to which cane will be supplied and CSA
- The cane delivery schedule
  - Water allocation or quota for irrigated cane
  - Cane delivery quota allocation
  - Estimated milling season dates
  - Cane supply estimates
  - Outgrower delivery through the season
  - The process of advising delivery dates/Daily Rateable Delivery
  - Obligation of the mill to crush all cane delivered under the agreed quota
- Harvesting and haulage procedures
  - Contractual obligations
  - Method of cane supply (burning procedures or green cane)
  - Loading and hauling limitations as determined by the mill and local authority (e.g. Roads Act)
- Quality control procedures – responsible body and enforcement
  - Variety control
  - Pest and disease control
  - Seedcane control
  - Restrictions on other crops (for P&D management purposes)
  - Rights to inspect
  - Standards/quality of cane supplied – % trash, roots or tops
  - Age of cane
  - Burn/cut to crush ratio
  - Timely offloading obligations to mill
- Downstream product availability to outgrowers
  - Filter mud
  - Vinasses
  - Bagasse
- Molasses
- Electricity
- Access to and charges for mill services
  - Electricity
  - Water
  - Infrastructure
  - Research
  - Technical assistance
  - Extension
  - Training
  - Data collection and management
- Cane payments
  - Formula on division of proceeds to be used
  - Products to be included in the formula
  - How the price will be reached
  - When payments will be made
  - How the pricing formula will be reviewed
- Force Majeure
- Length of agreement and options to extend
- Arbitration routes enabling both parties to remove themselves from the agreement due to causes beyond their control.

Agreements should be produced in local languages and in simple picture format, where applicable to be accompanied by capacity building and training. Before signing an agreement all parties, having read the agreement, should be clear about how the agreement affects them and their production. There is need for a balanced contract design with risks, incentives and enforcement modalities being fairly applied for all parties.

5.8 Summary of good management practice recommendations

There are a considerable number of GMPs identified in the text above that can be adapted to suit a variety of situations and requirements. Several of the key generic recommendations for the development of community and outgrower initiatives are summarized in the bullet points below.

- Prioritize the social components of a scheme; do not underestimate their influence
- Ensure that development is demand driven and participatory
- Develop the correct model for the social, environmental and political climate
- Promote outgrower engagement and ownership
- Build capacity at all levels
- Develop transparent and clear systems
- Strengthen stakeholder relationships
- Ensure that technology is appropriate for the capacity of the stakeholders
- Develop clear understanding of stakeholder roles and responsibilities
- Develop agreements that reflect the rights of all parties
- Encourage partnerships with key areas of expertise
- Where short term support is implemented ensure a sustainable exit strategy
- Communicate, communicate, communicate.
5.9 Conclusion

The importance of the integration and acceptance of a company into its community and environment is paramount to its sustainability, and this integration and acceptance will only come about if the stakeholders in the industry are treated with dignity and respect. In a speech made in Cape Town, South Africa in March 2011 by Mr Roy Bennett, a prominent politician and member of the Zimbabwean political party ‘Movement for Democratic Change’, he stated that, “The lessons for us all, and for those businesses you invest in, is that widespread social community acceptance is the fundamental prerequisite for sustainable long-term investment in Africa—be it in Egypt, South Africa, Zambia or Zimbabwe—or, for that matter, anywhere in the world.” Companies are, in many countries, the backbone of a society, replacing or improving social and infrastructural services that are lacking from Governments. Companies need to acknowledge this situation and integrate the social and developmental requirements into their business to ensure that the resources and markets for their products remain viable. Inclusion, participation, respect and communication are the recommended good management practices from this manual.

A significant number of investors have learned the importance of the ‘human factor’ the hard way and have struggled to regain economic growth and rebuild reputations. More and more companies are seeing the benefit of investing in the human resource through improved performance and relationships, and now strive to further improve conditions and meet the ever improving codes of conduct and standards. Establishing means of economically, socially and environmentally enhancing the livelihoods of those impacted by the business, involving communities in a value chain, developing fair and transparent supply chain packages, improving workers conditions and promoting a safe environment will encourage the success of a company. Now, however, in addition to economic and productivity benefits, there are increasing numbers of market led initiatives promoting improvements and adding further value to these developments. Codes and standards are important in guiding and measuring developments, and good management practices will facilitate in meeting targets through the best mechanisms, but the true importance lies in the will and desire of the company to develop fair, safe and equitable conditions. The future of the sugar industry lies in the hands of its stakeholders and, with continued support and development; this future will be bright and sustainable.
5.10 References


### APPENDIX 1 - Soil Form Identification Key Used in the South African Sugar Industry

<table>
<thead>
<tr>
<th>Subsoil</th>
<th>Organic</th>
<th>Humic</th>
<th>Vertic</th>
<th>Melanic</th>
<th>Orthic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unspecified Hard rock</td>
<td>Champagne</td>
<td></td>
<td>Arcadia</td>
<td>Inhoek</td>
<td>Mispah</td>
</tr>
<tr>
<td>Soft plinthic B</td>
<td></td>
<td></td>
<td></td>
<td>Milkwood</td>
<td>Westleigh</td>
</tr>
<tr>
<td>Hard plinthic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dresden</td>
</tr>
<tr>
<td>Lithocutanic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neocutanic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neocutanic B/ unspecific wet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedocutanic B/ saprolite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedocutanic B/ unconsolidated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pedocutanic B/ unconsolidated wet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prismacutanic/ unspecified</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red structured</td>
<td>Red apedal B/ unspecified</td>
<td>Inanda</td>
<td></td>
<td></td>
<td>Shortlands</td>
</tr>
<tr>
<td>Red apedal B/ unspecific wet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hutton</td>
</tr>
<tr>
<td>Red apedal B/ soft plinthite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bloemdal</td>
</tr>
<tr>
<td>Red apedal B/ Neocarbonate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bainsvlei</td>
</tr>
<tr>
<td>Yellow-brown apedal B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Augrabies</td>
</tr>
<tr>
<td>Yellow-brown apedal/ red apedal B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow-brown apedal/ soft plinthic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow-brown apedal/ hard plinthic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow-brown apedal/ unspecified wet G horizon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ unspecified</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ soft plinthic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ hard plinthic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ lithocutanic B</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ Neocutanic B</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ Pedocutanic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ Prismacutanic B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E horizon/ yellow-brown apedal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stratified alluvium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: SASRI (1999). Identification and management of the soils of the South African sugar industry

660
Prepared by PGBI Sugar & Bio-Energy (Pty) Ltd.
APPENDIX 2 - Guide To Taking Soil and Leaf Samples

There are essentially four steps to follow when using soil analysis to prepare fertilizer recommendations. These include:

- Step 1 - Sampling soil in the field
- Step 2 - Laboratory analysis of the sample
- Step 3 - Interpretation of the results
- Step 4 - Production of actual fertilizer recommendations

**Step 1 - Soil sampling guidelines**

The accuracy of a recommendation is almost totally reliant on how representative the sample is of the area to be treated. The best way to take samples for fertility testing is with a Mount Edgecombe soil sampler, which is simple and quick to use. If this is not available then an Eykelkamp auger or equivalent turning or tube auger will also suffice.

- At crop establishment: Take 30 cores per composite sample to a depth of 20cm along the diagonals of the field after plough-out and before re-establishment.
- For ratoon cane where fertilizers were broadcast: Take 30 cores across the field from the interrows only (Figure 1).
- For ratoon cane where fertilizers were side dressed or banded along the row: Take one soil core in the row for every eight in the interrow across the field. Take a total of 30 cores.
- Ensure that the area to be sampled is not more than 4 hectares. Where the area is larger than 4ha then prepare a second or third composite sample may be needed.
- Avoid anthills, old roads, and filter cake or fertiliser dumps when sampling.
- If the field consists of two or more distinct soil types, or only parts of the field have received large amounts of filter cake or organic manure in the past, a separate sample should be submitted from each portion, even if the field is to be fertilised as one unit.
- For new areas that have not yet been cultivated, it is best to stratify the area into homogenous landscape or terrain units which should then be sampled separately (See Fig2).
- All the augerings should be collected in a good-quality plastic bag or a clean plastic bucket to produce the single composite sample.
- After collection, all the ‘augerings’ should be mixed thoroughly to ensure a uniform composite sample.
- Prepare a 500 to 1000g subsample for dispatch to a reputable, preferably ISO accredited soil testing lab.
- Provide as many details as possible on a label and on the sample bag to ensure that the sample can be easily identified, and that meaningful interpretation of the results is possible.
- Ensure that the soil test procedures used by the lab are calibrated for determining the fertilizer requirement of sugarcane and that reliable threshold values are available for interpretation of the results.
Figure 1. Suggested soil sampling pattern for a field prior to crop establishment.

Figure 2. New areas should first be stratified according to landscape position.
Step 2 - Soil tests recommended for sugar cane

Once soil samples have been oven or air dried and ground, the following determinations may typically be carried out on soils to determine plant nutrient levels in the laboratory:

- pH in a water extract
- An estimate of N mineralization potential
- Acid extract for P such as 0.02N sulphuric acid extract (or Bray P2)
- Exchangeable K, Ca and Mg in an 1N ammonium acetate extract
- Micronutrients in a weak mixture of ammonium carbonate and EDTA
- P fixation using an overnight incubation
- Acid saturation or Al saturation index
- S in an ammonium acetate
- Organic carbon using the Walkley Black method
- Particle size analysis (clay, silt and sand)

Ensure that the laboratory you select is accredited and at least belongs to an internationally accepted soil and leaf analysis quality control monitoring scheme such as WEPAL based in Holland. In South Africa most labs belong to the Agricultural Laboratory Association of South Africa (AgriALASA). Similar organizations exist in the USA and Australia.

Step 3 - Interpretation of soil analysis

In general in developed industries the amounts of fertilizer recommended are based on soil specific threshold values established from a large number of fertilizer trials conducted on a wide range of soils. An example of soil threshold values used in the South African and Swaziland Sugar Industries is shown in Table 1.

Table 1: Example of soil nutrient threshold values used by SASRI and the Swaziland Sugar Association laboratories (Meyer et al 2004)

<table>
<thead>
<tr>
<th>NUTRIENT</th>
<th>THRESHOLD VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus (P)</td>
<td>31 mg/kg soil for plant cane</td>
</tr>
<tr>
<td></td>
<td>11 mg/kg for ratoons</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>112 mg/kg - clay content 30% or less</td>
</tr>
<tr>
<td></td>
<td>150 mg/kg - clay content 30-40%</td>
</tr>
<tr>
<td></td>
<td>225 mg/kg - &gt;40% clay (Ca+Mg/K&lt;25)</td>
</tr>
<tr>
<td></td>
<td>325 mg/kg - &gt;40% clay (Ca+Mg/K&gt;25)</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>200 mg/kg</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>25 mg/kg</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>1,0 mg/kg - clay content&gt; 15%</td>
</tr>
<tr>
<td></td>
<td>0,5 mg/kg - clay content 15% or less</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>15 mg/kg</td>
</tr>
<tr>
<td>Lime</td>
<td>When Aluminium Saturation Index is &gt;20% (for all varieties except N12)</td>
</tr>
<tr>
<td>(calcitic or dolomitic)</td>
<td>When Aluminium Saturation Index is &gt;40% (for N12 only)</td>
</tr>
</tbody>
</table>
It is extremely important to note that the soil threshold values used to make recommendations in the above instances relate to specific chemical extractants, extractant to soil ratios, extraction times and methods of shaking and in the case of P and K in particular, have been correlated with yield response data from hundreds of trials conducted throughout the sugar industry. For example the P requirement of plant cane and a first ratoon crop is based on a threshold value of 31 mg/kg using the Truog test procedure. The P requirement of a single ratoon sugarcane crop is based on a lower soil threshold value of 11 mg/kg.

This threshold value does not necessarily apply to other soil P extractants and the use of factors to interpret soil P test data from other soil extractants may result in misleading recommendations. (Kingston 2000 and Botha and Meyer 2004. Any change to a new soil extractant for measuring plant available P must be recalibrated using field trial response and soil test P data, representative of soils in the region, in order to establish a new threshold value for determining P requirement of sugarcane (see chapter 5.3.6 p 204).

Leaf analysis

Leaf sampling is used to monitor the uptake of nutrients by the cane crop and it is particularly useful in checking the accuracy of fertilizer recommendations applied to a whole crop cycle covering a plant and four ratoon crops. As leaf analysis is dependent on the age of the crop and climatic conditions at the time of sampling, it is important that the leaf samples are taken according to the recommended guidelines:

- Cane should be actively growing for at least three weeks, and sampled in the early morning at least four weeks after the last fertilizer application. In the case of cane grown under irrigation, sugarcane should be sampled at about three to four months of age.
- Select stalks of average height, avoiding young shoots. Remove the third youngest leaf from the top (see Fig 2)
- Collect about 40 leaves from well spaced intervals throughout the field using a diagonal sampling pattern (20 leaves along each diagonal)
- Hold the leaves together in a bundle, chop off the top and bottom leaving a central portion about 300mm long. Strip and discard the midrib as soon as possible after sampling and spread the leaves out on a clean surface to dry in the sun.
- Once the leaves are dry, bundle the leaves together and send to the laboratory
- Ensure that the label is tightly secured to the sample and that correct information is given on the label.

Leaf nutrient levels should be checked against the optimum range of values shown in Table 2.
Leaf sampling procedure

3rd leaf
mid 30 cm
Bundle, dry
40 leaves
Strip midrib & label

Figure 3. Main steps in taking a leaf sample as adopted in South Africa (SASRI Information sheet 7.9)

Table 2. Optimum range of concentration in the TVD leaf tissue for the macro and micro nutrients (adapted from Anderson 1990).

<table>
<thead>
<tr>
<th>NUTRIENT</th>
<th>UNITS</th>
<th>OPTIMUM RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen* (N)</td>
<td>%</td>
<td>1.8-2.4</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>%</td>
<td>0.19-0.25</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>%</td>
<td>1.05-1.45</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>%</td>
<td>0.15-0.25</td>
</tr>
<tr>
<td>Magnesium Mg)</td>
<td>%</td>
<td>0.08-0.18</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>%</td>
<td>0.12-0.20</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>%</td>
<td>0.75-1.50</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>ppm</td>
<td>13-20</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>ppm</td>
<td>15-75</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>ppm</td>
<td>3-7</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>ppm</td>
<td>75-200</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>ppm</td>
<td>2-7</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>ppm</td>
<td>0.05-0.15</td>
</tr>
</tbody>
</table>

*Depends on age and season of sampling
Further reading

Leaf analysis


SASRI Information Sheet 7.9  Leaf sampling guide. Published by the South African Sugarcane Research Institute, Mount Edgecombe, South Africa.


## APPENDIX 3 – Examples of Selected Soil Specific Crop Management Recommendations

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>DESCRIPTION</th>
<th>WRB</th>
<th>ENVIRONMENTAL RISKS</th>
<th>SLOPE</th>
<th>SEASON</th>
<th>RECOMMENDED STOOL ERADICATION METHOD</th>
<th>OTHER BENEFICIAL PRACTICES BEFORE PLANTING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HUMIC FERRASOLS</strong></td>
<td>Dark brown humic clay loam overlying a deep friable red sandy clay loam</td>
<td></td>
<td>High potential for release of carbon dioxide and nitrous oxide with excessive tillage and liming. Prono to acidification and build up of Al and Mn toxicity which could lead to in imbalance in micro-organism biodiversity</td>
<td>&lt;20%</td>
<td>Winter</td>
<td>Shallow mouldboard plough (100mm)</td>
<td>Use of amendments such as filtercake, liming subject to soil testing, Legume fallow may not be beneficial due to the high N mineralising capacity of these soils</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Combination tillage with fluazifop</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Combination tillage with glyphosate</td>
<td></td>
</tr>
<tr>
<td><strong>VERTISOLS</strong></td>
<td>Dark cracking black to grey cracking clay often self mulching and with slikensides</td>
<td>HUMIC FERRASOLS</td>
<td>With the wrong type of irrigation, very prone to early run off due to surface sealing leading to potential loss of fertilizer and herbicide chemicals</td>
<td>&lt;20%</td>
<td>Winter</td>
<td>Shallow mouldboard plough</td>
<td>Lime not required but filtercake applied in the furrow or slotted in will be beneficial to overcome tilth limitation. Mole drainage, slotted drains need to be considered for wet areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Combination tillage with fluazifop</td>
<td>Land planing essential for furrow irrigation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Combination tillage with glyphosate</td>
<td></td>
</tr>
<tr>
<td><strong>CHROMIC LUVISOL</strong></td>
<td>Fairly deep reddish blocky structured clay</td>
<td></td>
<td>A very stable soil but harvesting under wet conditions can lead to serious compaction. High potential for release of carbon dioxide and nitrous oxide</td>
<td>&lt;15%</td>
<td>Winter</td>
<td>Shallow mouldboard plough</td>
<td>Use of amendments such as filtercake, liming subject to soil testing, Legume fallow should be considered after a long cropping cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Combination tillage with fluazifop</td>
<td>Land planing essential for furrow irrigation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Combination tillage with glyphosate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Winter</td>
<td>Chipping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Chipping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Chipping</td>
<td></td>
</tr>
<tr>
<td><strong>CAMBISOL</strong></td>
<td>Shallow grey loamy sand overlying a lithic horizon with clay tongues into weathering rock in a crest position</td>
<td></td>
<td>Highly erodible and compactible. Very prone to loss of chemicals such as N and K fertilizers and herbicides. Potential loss of N from urea also very high.</td>
<td>&gt;15%</td>
<td>Winter</td>
<td>Chipping or rotary hoe</td>
<td>Lime, Calcium silicate amendments, filter cake high priority.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Chipping or combination tillage</td>
<td>Rate subject to soil tests</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Chipping or glyphosate</td>
<td>Legume fallow highly recommended</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Winter</td>
<td>Chipping or rotary hoe</td>
<td>Strip farming conservation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Chipping or combination tillage</td>
<td>layout essential for slopes&gt;5%?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Chipping or glyphosate</td>
<td></td>
</tr>
<tr>
<td><strong>GLEYSOL</strong></td>
<td>Grey loamy sand to sandy clay loam overlying mottled gley</td>
<td></td>
<td>Typical bottomland soil prone to drainage and salinity build up. High potential for loss of N by denitrification and leaching. Very prone to compaction</td>
<td>&lt;10%</td>
<td>Winter</td>
<td>Shallow mouldboard plough</td>
<td>Mole drainage, slotted drains, open drains</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>Combination tillage with fluazifop</td>
<td>Land planing essential for furrow irrigation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Summer</td>
<td>Combination tillage with glyphosate</td>
<td>Legume fallow highly recommended after each crop cycle</td>
</tr>
</tbody>
</table>
APPENDIX 4 - Land Forming For Sugar Cane

General
Land forming for sugar cane and for farming in general can be conveniently divided into two categories, namely for surface drainage and for surface irrigation. Of the two the latter is more costly and allows less tolerance in design, but common general principles apply in both. Both are most efficiently carried out by scrapers carrying soil from cut to fill, the reason being that in most cases the biggest fill areas are at some distance from the biggest cut areas. In agriculture tractor drawn scrapers, often two in tandem, are more commonly used than self powered scrapers. It is vital that the tractors should have sufficient pulling power to do the work smoothly without having to repeatedly lift the scraper blades in areas of harder soil or deeper cuts, leaving steps that later have to be smoothed out. Scaler suppliers and earth moving contractors can usually recommend the correct power needed for the particular scraper.

Land forming for surface drainage. It has been demonstrated over many years that land forming to ensure good surface drainage in rainfed and overhead irrigated fields pays dividends in increased yields and conservation of the soil. This is especially true in arid and semi arid conditions because of poor leaching of the salts in the soil which are drawn up through capillary action when standing water evaporates. The cost of this type of land forming can be kept quite low with careful design if the main objective is not lost sight of, i.e. simply getting excess water off the field. As long as the slope of the land is always off the field into collector drains, there is no reason why there cannot be a number of plane surfaces in the field and even some shallow in-field valleys, as long as these do not interfere unduly with cultivation, harvesting, haulage and other farming practices. The temptation to aim unnecessarily for a minimum number of planes should be resisted.

Land forming for furrow irrigation. This is by far the most common type of surface irrigation and requires careful attention in design. Water is released into the top end of sloping furrows and irrigates the crop as it flows down the slope. Design is aimed at obtaining optimum contact time and uniformity of application, which are vital in obtaining optimum yields. These are achieved by the right combination of slope, furrow length and flow rate applied to match the infiltration rate and TAM (Total Available Moisture) of the soil. Irrigation design for the required contact time should be completed before land forming design begins.

It is vital that land forming design should take into consideration the depth of the top soil and deep cuts should be avoided as far as possible to avoid exposing subsoil of lower fertility. Many examples of visible patches of poor cane can be seen where the top soil has been scalped off. A simple rule of thumb is that doubling the length of furrow results in four times the depth of cut and four times the quantity of soil moved and a fifty percent increase in furrow length requires 2.25 times the cut and quantity of soil moved.

All land forming design should be aimed at meeting, as far as the topography allows, the optimum combination of line length and slope as derived in the irrigation design. Because the slope in the furrow is largely dictated by the need to avoid heavy cuts, and the infiltration rate is fixed by the soil type, the two main tools for obtaining optimum contact time and uniformity of application are the furrow length and the flow rate of water into the furrow. A typical combination of all these factors in a good sandy clay loam might be a slope of 1:250, with furrow lengths of 100 metres and an application rate of two litres per second. Where steep grades are unavoidable the furrow direction can be angled across the slope to reduce the gradient along the furrow; in other cases the maximum grade available is flatter.

Quantities of cut and fill vary widely depending on the topography of the field. A uniformly sloping field with very few humps and hollows might need 300 cubic metres per hectare or less; undulating topography would need a lot more. Design should be for an excess of cut over fill to allow for settling and compaction of the fill areas. An excess of 20 percent is commonly used.
Land forming design to achieve the right combination of slope, soil type, furrow length, soil depth and application rates can be quite complex and a good awareness of the importance of not scalping the top soil, combined with experience and design skill are essential for obtaining the best results. Where absolutely necessary the top soil can be removed, the ground cut to extra depth, and the top soil returned, but this can be costly and would normally be done only as a last resort.

Selection of scraper systems. There are three main types in common use for land forming:
Open blade Ejector scraper is useful for low amounts to be moved over short distance up to 50 m. Carry-all scraper is the most commonly used, less expensive and used for long distances up to 600 m (two units in tandem). It cuts well on grade but does not fill well and is often used with an ejector scraper for finishing.
Closed-bowl ejector scraper has had a huge impact on Land Forming; it combines the features of the open bowl scraper with the carry-all. This unit both cuts on grade and fills on grade and generally does not need a finishing scraper in sugarcane. The closed-bowl ejector is generally 30% more expensive than a carry-all but in most cases this extra cost is well justified and will result in more economic levelling costs. This ejector can also be used in tandem or singly.
There are numerous options in size of scraper, but a typical system commonly used would be 18 cubic yard scrapers in tandem behind a 450 hp tractor

Land Planing is a cheap operation which is sometimes used as a final smoothing operation.

Precision Land Forming systems
Modern technology in the form of laser levellers and GPS controlled scrapers has made the whole land forming operation much faster, more efficient, more accurate and more cost effective than in the past. After ploughing and harrowing the field is surveyed, levels being taken on a 10 x 10 or 15 x 15 metre grid. This is very quickly and accurately carried out using a GPS on a tractor driven up and down the field at the required intervals; surveyors’ GPS equipment giving the required accuracy is costly, and traditional survey methods while taking longer can give equally accurate results. Grids with wider intervals can be used but the accuracy of the design and the efficiency of the scrapers falls away rapidly as the grid spacing increases above 15 metres. Advantages and disadvantages of the two systems are:
Laser systems are easy to use, less expensive than GPS and are accurate to within 30mm in 30 m and can give grade changes. However they are vulnerable to wind, machine vibration, dust, fog and rainfall.
GPS systems have more functions (ability to change grades) and have a greater range; they are not as vulnerable to the above problems. However they are more expensive, require a base station and are susceptible to satellite availability and signal loss.

Quantities and costs of earth moving for land forming. It has been found that in many areas where levelling is being done for sugarcane, the average movement of soil is 550 m$^3$ per ha, ranging from 250 to 900 m$^3$ per ha. The cost is an average of $2.5 per m$^3$ but the price varies with the quantity to be moved, the price being higher for smaller quantities per ha and lower for bigger volumes.
APPENDIX 5 – Relevant Chapter Cross Reference Index to IFC and Bonsucro Standards

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Note: This table provides guidance on how chapters in the manual can be used to support the adoption of industry (Bonsucro) or IFC standards (see Box 2.1 p 593 and Box 2.4 p 597). However, this table is merely a reference document not a guidance note for either IFC or Bonsucro.

IFC Performance Standards can be found at [www.ifc.org](http://www.ifc.org) and Bonsucro Production Standards can be can be found at [www.bonsucro.org](http://www.bonsucro.org).
WHO  World Health Organization
WWF  World Wildlife Fund

SYMBOLS

°C  degrees Celsius
cm  centimeter
d  day
g  gram
h  hour
ha  hectare
kg  kilogram
kJ  kilojoule
km  kilometer
kW  kilowatt
L  litre
mg  milligram
MJ  megajoule
mm  millimeter
m  meter
MPa  megapascal
MW  megawatt
%  percentage
s  second
t  tonne
μg  microgram
TECHNICAL GLOSSARY

**A**

**ABIOTIC:** Not biotic; not formed by biologic processes.

**ACTINOMYCETES:** Any of numerous, generally filamentous, and often pathogenic, microorganisms resembling both bacteria and fungi.

**ACTIVATED SLUDGE:** Microorganisms that form a sludge that is active in the digestion of effluent under aerobic conditions

**ADSORPTION:** The retention of atoms, ions, or molecules onto the surface of another substance.

**AEROBIC DIGESTION:** Digestion of effluent under aerobic conditions requiring equipment and energy for dissolving oxygen into the water.

**AERObIC:** Able to live, grow, or take place only when free oxygen is present.

**AGGREGATE:** A single cluster of soil particles such as a ped, crumb, block or granule

**ALGAE:** Chlorophyll-bearing nonvascular, primarily aquatic species that have no true roots, stems, or leaves; most algae are microscopic, but some species can be as large as vascular plants.

**ALKALINE SOIL:** Soil with a pH higher than 7.0.

**ALLUVIUM:** Deposits of clay, silt, sand, gravel or other particulate rock material left by a river in a streambed, on a flood plain, delta, or at the base of a mountain.

**ALUMINIUM TOXICITY:** Aluminium in many soils occurs in quantities sufficient to harm plant growth, below pH 5.3 (water).

**AMENDMENT:** Any substance used to alter the properties of (ameliorant) soil to make it more suitable for plant growth, e.g. lime, gypsum, fertilisers.

**AMMONIFICATION:** The biochemical process whereby (ammoniacal?) nitrogen is released from nitrogen containing organic compounds in the soil.

**ANAEROBIC DIGESTION:** Digestion of liquid effluent in the absence of oxygen.

**ANAEROBIC:** An organism or a process that does not utilise, or cannot exist in the presence of gaseous oxygen.

**ANIONS:** Negatively charged ions.

**ASH CONTENT:** Solid residue determined gravimetrically after incineration in the presence of oxygen. In analysis of sugar products, sulfuric acid is added to the sample, and this residue as sulfated ash heated to 800°C is taken to be a measure of the inorganic constituents. Sometimes determined indirectly by measurement of electrical conductivity of the product in solution (see Conductivity ash).

**ATTERBERG LIMITS:** The moisture contents which define a soil's liquid limit, plastic limit, and sticky limit.

**AUGMENTATIVE OR INUNDATIVE RELEASE:** Refers to the release of laboratory reared parasitoids or predatory insects, to supplement (augment) existing populations or to flood the environment with such insects (inundate).

**AUXINS:** Plant Growth Hormone.

**AVAILABLE WATER CAPACITY (AWC):** A soil characteristic which is reflected by the depth of soil water in mm per meter of soil depth between the limits of field capacity (FC) and the permanent wilting point (PWP) of a given crop. (This is normally at soil water tensions between 10 kPa and 1500 kPa.) \(\text{AWC} = \text{FC} - \text{PWP}\)
B

**BACTERIA:** Unicellular microorganisms that exist either as free-living organisms or as parasites and have a broad range of biochemical, and often pathogenic, properties.

**BAGACILLO:** Fine fraction of bagasse obtained by screening, generally used as a filter aid in filtration.

**BAGASSE:** Cane residue leaving mills after extraction of juice.

**BASIC ROCK:** A general geological term for igneous rock with more than 45% and less than 66% SiO₂.

**BENTHIC INVERTEBRATES:** Insects, mollusks, crustaceans, worms, and other organisms without a backbone that live in, on, or near the bottom of lakes, streams, or oceans.

**BENTONITE:** A colloidal clay, largely made up of the mineral sodium montmorillonite, a hydrated aluminum silicate. Because of its expansive property, bentonite is commonly used to provide a tight seal around a well casing.

**BIOACCUMULATION:** The biological sequestering of a substance at a higher concentration than that at which it occurs in the surrounding environment or medium. Also, the process whereby a substance enters organisms through the gills, epithelial tissues, dietary, or other sources.

**BIOASSAY:** A method used to determine the toxicity of specific chemical contaminants. A number of individuals of a sensitive species are placed in water containing specific concentrations of the contaminant for a specified period of time.

**BIOAUGMENTATION:** The introduction of cultured microorganisms into the subsurface environment for the purpose of enhancing bioremediation of organic contaminants.

**BIOCHEMICAL OXYGEN DEMAND (BOD):** The amount of oxygen, measured in milligrams per liter, that is removed from aquatic environments by the life processes of microorganisms.

**BIOCIDE:** A substance capable of destroying (killing) living organisms.

**BIODEGRADATION:** Transformation of a substance into new compounds through biochemical reactions or the actions of microorganisms such as bacteria.

**BIOGAS:** Gas produced during anaerobic digestion of organic matter. The gas contains approximately 60% methane and 40% carbon dioxide (v/v).

**BIOMASS:** The amount of living matter, in the form of organisms, present in a particular habitat, usually expressed as weight per unit area or volume.

**BIOTA:** Living organisms.

**BLEACHED HORIZON:** A light coloured and highly leached horizon.

**BIOLOGICAL OXYGEN DEMAND (BOD):** A common measure of pollutant organic material in water. The test indicates the amount of water-dissolved oxygen (expressed as mg/L of water) consumed by microbes incubated in darkness for five days at an ambient temperature of 20°C.

**BORON:** An essential element which may be involved in carbohydrate transport.

**BREAK CROP:** An annual crop, often a legume such as sunn hemp (Crotalaria juncea) and soya beans, planted between sugarcane plantings as part of a crop rotation to aid in disease and pest control and to improve soil quality.

**BRIX:** Measurement of dissolved solids in sugar liquor or syrup using a refractometer, otherwise referred to as refractometric dry solids. For solutions containing only sugar and water, Brix = % sugar by mass.

**BROWN RUST:** A widely distributed foliar disease of sugarcane caused by the fungus *Puccinia melanocephala*; spread by wind blown and rain splashed spores.
BUFFER CAPACITY: The capacity of a soil to resist an induced change in soil pH.

BULK DENSITY: The amount of mass of a soil per unit volume of soil; where mass is measured after all water has been extracted and total volume includes the volume of the soil itself and the volume of air space (voids) between the soil grains.

C

C HORIZON: A mineral horizon of weathered rock or other

C₄ PLANTS: C₄ carbon fixation is a biochemical mechanism used in carbon fixation, named for the 4 carbon atoms present in the first product of C fixation in these plants. C₄ plants have a competitive advantage over plants possessing the more common C₃ carbon fixation pathway under conditions of drought, high temperatures, and nitrogen or CO₂ limitation.

CALCIUM: An essential element which is a constituent of the plant cell wall. And acts in metabolic regulation.

CARBONATION: Introduction of carbon dioxide gas into limed juice or syrup to remove color and nonsugar solids.

CATENA: See toposequence.

CATION EXCHANGE CAPACITY (CEC): The sum total exchangeable cations that soil colloids or clay can adsorb.

CATIONS: An atom, a group of atoms, or compounds that are positively charged electrically as the result of the loss of electrons.

CHEMICAL OXYGEN DEMAND (COD): Is a test commonly used to indirectly measure the amount of organic compounds in water. Organic compounds can be oxidized to CO₂ with a strong oxidizing agent under acidic conditions. It is expressed in mg/L, which indicates the mass of oxygen consumed per liter of solution

CHLOROPHYLL: Green pigment in leaves, traps light for photosynthesis in plants, algae and some bacteria.

CLARIFIER: Apparatus for the separation by sedimentation of suspended solids from a turbid sugar solution.

CLAY MINERALS: Very small, naturally occurring crystalline compounds of iron, aluminium and silica, e.g. kaolinite, montmorillonite, illite

CLAY: A soil separate consisting of particles of less than 0,002 mm in diameter (see soil texture)

COGENERATION: The use of a power station to simultaneously generate both electricity and useful heat.

COLLOID: Very fine mineral or organic substances.

COLLUVIIUM: A deposit of soil and or rock fragments accumulated at the base of steep slopes and transported by gravity.

COLOR: Attenuation index, determined by absorption of light under defined conditions. Generally measured using the ICUMSA method at 420nm, and referred to as ICUMSA units or IU.

COMBINATION TILLAGES: Use of chemical and mechanical eradication methods in sequence to eradicate the crop

CONDENSATE: The liquid that separates from a vapor during condensation.
CONDENSED MOLASSES SOLUBLES (CMS): Is produced by evaporating vinasse; it saves transport costs for application to fields distant from the distillery. As a valuable fertilizer it can be augmented with N or P.

CONFINING LAYER: A layer of sediment or lithologic unit of low permeability that bounds an aquifer,

CONSISTENCY: The resistance of a soil to deformation or rupture

CONSUMPTIVE USE: The quantity of water that is not available for immediate reuse because it has been evaporated, transpired, or incorporated into plant tissue. Also referred to as "water consumption".

CONTROLLED TRAFFIC: use of the same tracks for all infield machinery facilitated by the use of GPS recording of original track positions

COPPER: An essential element which is a component of several enzymes in plants. Necessary for chlorophyll formation in plants.

CO-PRODUCTS: are items produced in addition to the main (or original) product.

CROP COEFFICIENT (KC): The ratio of evapotranspiration (ET) to reference evapotranspiration (ETo) for a given crop when growing in large fields under optimum growing conditions.

CROP FACTOR: The ratio of evapotranspiration (ET) to pan evaporation (Eo) for a crop of a given age, in a certain growth phase, with a certain canopy size, in a certain climatic zone.

CROP ROTATION: Planting a succession of different crops, such as sugarcane and a break crop, to aid in disease and pest control and to improve soil quality.

CROP WATER REQUIREMENT (CWR): The depth of water in mm required for evapotranspiration (ET) by a given crop over a specific period. Equal to Nett irrigation requirement (NIR) of a given crop plus effective rainfall (Re).

CRUMB: See soil structure.

CRUST: A compacted, brittle, surface layer of the soil, a few millimetres thick.

CRYSTALLINE ROCKS: Rocks (igneous or metamorphic) consisting wholly of crystals or fragments of crystals.

D

DARCY’S LAW: An empirical relationship between hydraulic gradient and the viscous flow of water in the saturated zone of a porous medium under conditions of laminar flow.

DENITRIFICATION: The biochemical reduction of nitrate or nitrite nitrogen to gaseous nitrogen in waterlogged soils.

DIAPAUSE: A period of suspended development in certain insects.

DIATOMS: Single-celled, colonial, or filamentous algae with siliceous cell walls constructed of two overlapping parts.

DIELDRIN: An organochlorine insecticide no longer registered for use in the United States. Also a degradation product of the insecticide aldrin.

DRAINAGE: That part of irrigation and rainfall that percolates past the effective rooting depth (through the root zone of the crop) before it can be utilised by the crop.

DRAWDOWN: Lowering the water table due to withdrawal of groundwater as from a well.

DYSTROPHIC SOIL: A soil that has a low base status and has usually undergone marked leaching.

E
ECOREGION: An area of similar climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

ECOSYSTEM: The interacting populations of plants, animals, and microorganisms occupying an area, plus their physical environment.

EFFECTIVE POROSITY: The amount of interconnected pore space in a soil or rock through which fluids can pass, expressed as a percent of bulk volume. Some of the voids and pores in a rock or soil will be filled with static fluid or other material, so that effective porosity is always less than total porosity.

EFFECTIVE RAINFALL (RE): The rain that falls during a given period which can be used beneficially by the crop and that partially or completely replaces scheduled irrigation. (This excludes surface run-off, deep percolation and a portion of interception).

EFFECTIVE ROOT DEPTH (ERD): The soil depth in mm to a level at which the growth of the nutritive roots of the plant is restricted by soil-related conditions. Generally 85% - 90% of the roots occur within this depth of soil.

ELUVIATION: The removal of soil in suspension (or in solution) from any part of, or from the whole soil profile.

ENDOPHYTE: Usually a bacterium or fungus living within a plant.

ENZYME: (a) Any of numerous proteins or conjugated proteins produced by living organisms and functioning as biochemical catalysts. (b) A protein that a living organism uses in the process of degrading a specific compound. The protein serves as a catalyst in the compound's biochemical transformation.

EQUIVALENT: The weight in grams of an ion or compound that replaces 1 gram of hydrogen. Numerically the atomic weight of the element or compound divided by its valence equates to the equivalent.

EUTROPHICATION: The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

EVAPORATION (E): The loss of water from the soil surface and the top layer of soil into the atmosphere in mm/day.

EVAPORATION PAN: A device (The American class A pan) used for the measurement of the amount of water lost through evaporation from an open water surface during a specific period.

EVAPORATOR EFFECT: One of a system of evaporators operating in series as a multiple effect system (e.g., first effect, second effect).

EVAPOTRANSPIRATION (ET): The loss of water through transpiration (T) by the growing plant plus evaporation (E) from the soil surface in mm/day.

FERRICRETE: A hardened subsurface layer which may be caused by the strong cementation of soil particles and organic matter, by materials such as sesquioxides (mainly iron), calcium

FERTIGATION: Application of fertilizer in irrigation water.

FERTILIZER USE EFFICIENCY (FUE): An expression of the units of yield obtained per unit of nutrient input for the crop. In the case of sugarcane kg N/ton cane yield a value in the range 1.2 to 1.4 kg N per ton cane may be regarded as good.

FIELD CAPACITY: The maximum amount of water that a soil can retain after excess water from saturated conditions has been drained by the force of gravity.
FIJI DISEASE VIRUS (FDV): A systemic disease of sugarcane caused by a virus and spread by the leafhopper *Perkinsiella saccharicida*; largely restricted to Australia and formerly widespread and damaging there.

FILTER CAKE: Material retained on the screens of the filters after filtering clarifier muds.

FINE SAND: Soil separates consisting of particles 0.05 (very fine sand) to 0.25 mm in diameter (see soil texture).

FIXATION: The process of converting a plant nutrient in the soil, from a readily available form to a less available form.

FLEX FUEL VEHICLE (FFV): Are able to run on gasoline (petrol), ethanol or any mixture of the two.

FLOCCULANT: Polyelectrolyte solution added to juice to assist clarification.

FLOCCULATION: The joining together of colloidal particles to form clusters.

FLUVIAL DEPOSIT: A sedimentary deposit consisting of material transported by suspension or laid down by a river or stream.

FLY ASH: Particles of ash and partly burnt bagasse that “fly” with the furnace gases but are usually recovered by wet scrubbing before the gases leave the stack.

FOLIAR DIAGNOSIS: Estimation of the nutrient status of a plant or the nutrient requirements of the soils, through chemical analysis or color measurements of plant leaves.

FREELY AVAILABLE WATER (FAW): Depth of soil water in mm available for continuous optimum crop growth within the effective root ing depth of the crop. Stress will set in at below this moisture level.

FUNGI: aerobic, multicellular, nonphotosynthetic, heterotrophic microorganisms. The fungi include mushrooms, yeast, molds, and smuts. Most fungi are saprophytes, obtaining their nourishment from dead organic matter. Along with bacteria, fungi are the principal organisms responsible for the decomposition of carbon in the biosphere.

FUZZ: The ‘true’ seed of sugarcane produced by intercrossing male and female parent varieties.

G

GEOREFERENCED: To georeference something means to define its existence in physical space. That is, establishing its location in terms of map projections or coordinate systems.

GHG-GREENHOUSE GAS EMISSIONS: are those generated during, combustion or decomposition of biologically-based material and trap heat in the atmosphere. The most important are water vapor, CO₂, methane, nitrous oxide and fluorinated gases.

GLEY: A soil material developed under prolonged waterlogging.

GLUCOSE: A common sugar with six carbon atoms per molecule. Present in all cells. A constituent of cellulose, starch and other polysaccharides.

GLYPHOSATE: Is a broad-spectrum systemic herbicide used to kill weeds.

GRANITIC ROCK: A coarse-grained igneous rock.

GRAVEL: Rock fragments more than 2 mm in size and less than about 7 mm in cross-section.

GREEN GRASSY SHOOT DISEASE (GGSD): A systemic disease of sugarcane caused by a phytoplasma and spread by leafhoppers; widespread and often serious in sugar industries in the Far East. Infected plants produce a large number of stunted, grass-like shoots.
GREENMANURE: Mainly legume plants grown to be incorporated into soil to improve fertility.

GROUND TRUTHING: Confirming on the ground what satellites and aerial photography indicate

GYPSUM: A mineral or rock composed of calcium sulfate

H

HENRY’S LAW: The relationship between the partial pressure of a compound and the equilibrium concentration in the liquid through a proportionality constant known as the Henry's law constant.

HORIZON, SOIL: A soil layer, bounded by air, hard rock or soil material that has different characteristics.

HOT WATER TREATMENT (HWT): The treatment of sugarcane setts (seedcane) by soaking in hot water, usually for 2 h at 50 °C, to eliminate RSD and certain other sugarcane pathogens.

HUMUS: The stable, dark-colored fraction of the soil organic matter remaining after most added plant and animal residues have decomposed.

HYDRAULIC CONDUCTIVITY: A coefficient of proportionality describing the rate at which water can move through a permeable medium. Hydraulic conductivity is a function of both the intrinsic permeability of the porous medium and the kinematic viscosity of the water which flows through it. Also referred to as the coefficient of permeability.

HYDRAULIC GRADIENT: The change in total potentiometric (or piezometric) head between two points divided by the horizontal distance separating the two points.

HYDROLOGIC CYCLE: The circulation of water from the sea, through the atmosphere, to the land, and thence back to the sea by overland and subterranean routes.

HYDROMORPHIC SOILS: Soils with features such as gleying, mottling, or concretionary horizons, resulting from permanent or intermittent water tables, e.g. Gleysols.

HYDROPHILIC: Having an affinity for water, or capable of dissolving in water; soluble or miscible in water.

HYDROPHOBIC: Tending not to combine with water, or incapable of dissolving in water; insoluble or immiscible in water. A property exhibited by non-polar organic compounds, including the petroleum hydrocarbons.

ILLUVIATION: Deposition of soil material, removed by percolating water, from one horizon to another; usually from an upper to a lower horizon in the soil profile.

IMBIBITION: The process of adding imbition water to the extraction plant to increase extraction.

INDURATED: Hardened consistency caused by cementing.

INfiltration or Intake Rate: The rate of infiltration of water into a moist soil is known as steady infiltration rate (expressed as mm/hr).

INITIAL INFILTRATION RATE: The initial rate of infiltration of water into soil at the onset of the application of water (normally when the soil is dry). Steady Infiltration rate on the other hand refers to practically constant or continuous rate of infiltration of water into wetted soil after a time. Also referred to as terminal infiltration rate.

INOCULATE: To implant microorganisms onto or into a culture medium.

INSTAR: Larval or nymphal stage.
INTEGRATED CONTROL SYSTEM: The application of various control methods, such as variety resistance, seedcane health, efficient crop eradication and possibly pesticides, in an integrated program to control pests and diseases.

IRON (Fe): an essential trace element which is absorbed by plants as ferrous iron. Functions as catalyst in chlorophyll formation and acts as an oxygen carrier.

KAOLINITE: A non-swelling clay mineral with a 1:1 crystal structure.

LABILE CARBON: Available fraction of organic carbon, a vital component of soil organic matter.

LEACHING: The removal of materials in solution from soil or rock to ground water; refers to movement of pesticides or nutrients from land surface to ground water.

LEAF SCALD: An infectious, systemic disease of sugarcane caused by the bacterium Xanthomonas albilineans.

LIDAR: (Light Detection And Ranging, also LADAR) is an optical remote sensing technology that can measure the distance to, or other properties of a target by illuminating the target with light, often using pulses from a laser.

LIME: The term lime, or agricultural lime is applied to ground limestone containing calcium carbonate and magnesium carbonate, hydrated lime (calcium hydroxide) or burnt lime (calcium oxide). Lime is used to reduce soil acidity and to provide calcium and magnesium as essential elements.

MACRONUTRIENTS: The essential plant nutrients required in the largest amount by plants.

MAGNESIUM (Mg): An essential element which is classed as a secondary nutrient with calcium and sulphur. It is a constituent of chlorophyll and is actively involved in photosynthesis. Mg aids in phosphorus metabolism, plant utilization of sugars, and the activation of several enzymes.

MAJOR IONS: Constituents commonly present in concentrations exceeding 1.0 milligram per liter. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulfate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.

MANGANESE (Mn): An essential metallic trace element functioning as a part of enzyme systems in plants. It also activates several important metabolic reactions and plays a direct role in photosynthesis by aiding chlorophyll synthesis.

MASS FLOW: Movement of fluid in responses to pressure. Movement of heat, gases or solutes together with the flowing fluid in which they are contained.

MASSECUITE: The mixture of crystals and mother liquor resulting from the crystallization process.

MEDIAN: The middle or central value in a distribution of data ranked in order of magnitude. The median is also known as the 50th percentile.

MERISTEM: The area of rapidly dividing cells at the growing point of a shoot.

MICROGRAMS PER LITER (µg/L): A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion.

MICRONUTRIENTS: Nutrients that plants need in only small or trace amounts. Essential micronutrients are zinc, copper, iron, manganese, boron, molybdenum and chloride.
MICROORGANISMS: Microscopic organisms including bacteria, protozoans, yeast, fungi, mould, viruses, and algae.

MILLIGRAMS PER LITER (mg/L): A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million

MINERALIZATION: The release of inorganic chemicals from organic matter in the process of aerobic or anaerobic decay.

MINIMUM TILLAGE: reduced tillage compared with conventional crop establishment tillage (or soil disturbance). In cane usually refers to the use of chemical to eradicate the previous crop and tillage only on the old interrow where new planting takes place.

MOLASSES: The mother liquor separated from the crystals by centrifuging. A, B or C molasses is derived from the corresponding massecuities.

MOLYBDENUM (Mo): This micronutrient is required in the smallest quantities of all essential elements. Is mainly required in the synthesis and activity of the enzyme nitrate reductase. Also vital in symbiotic nitrogen fixation, by Rhizobia bacteria in legume root nodules.

MONOCULTURE: The practice of repeated cultivation of one crop plant species on the same land.

MONTMORILLONITIC CLAY: 2:1 lattice clay type dominates and has greater potential to bind (adsorb) chemicals e.g. herbicides.

MULCH: In sugarcane agriculture this refers to the protective layer of cane tops and leaves on the surface of the soil that reduces evaporation of water, reduces soil erosion, suppresses weeds and enhances favorable biological processes within the soil.

NEONATE: Recently hatched larval stage.

NER: NET ENERGY RATIO: The ratio of renewable energy output of biofuel to the fossil energy input in the whole production chain.

NITRIFICATION: The formation in soils of nitrite and nitrate from ammonium ions through the activities of certain soil bacteria; the biochemical oxidation of ammonium to nitrate.

NITROGEN: An essential macronutrient which is a constituent of every living cell, plant or animal. In plants, N forms part of the chlorophyll molecule, amino acids, proteins, and many other compounds.

NITROGEN CYCLE: The pathways taken by nitrogen from the atmosphere through soils, plants, animals and man back to the atmosphere.

NITROGEN FIXATION: The conversion of elemental atmospheric nitrogen into organic or inorganic forms by soil organisms. The nitrogen fixing process associated with legume root nodules is known as symbiotic nitrogen fixation.

NOMOGRAPH: A nomogram, nomograph, or abac is a graphical calculating device, a two-dimensional diagram designed to allow the approximate graphical computation of a function.

NONSUGAR: Common overall term for dissolved solids contained in any process stream other than sugar.

NURSERY: A carefully managed plot of sugarcane, established by planting healthy seedcane, and used to produce high quality seedcane for further propagation.

NUTRIENTS: Nutrients are chemical elements that are essential for optimum plant and animal growth. The major nutrients include nitrogen, phosphorus and potassium, secondary nutrients
include calcium, magnesium and sulphur and the minor or trace nutrients are zinc, copper, iron, manganese, boron and molybdenum.

ORANGE RUST: A widely distributed foliar disease of sugarcane caused by the fungus *Puccinia kuehnii*; spread by wind blown and rain splashed spores.

ORGANIC FERTILIZER: Organic material that releases or supplies useful amounts of plant nutrient when added to soil.

ORGANOCHLORINE INSECTICIDE: A class of organic insecticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodiienes (such as chlordane), and chlorinated benzenes (such as lindane). Most organochlorine insecticides were banned because of their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.

ORGANOPHOSPHORUS INSECTICIDES: Insecticides derived from phosphoric acid and are generally the most toxic of all pesticides to vertebrate animals.

ORTHOPHOTO:: An orthophoto, orthophotograph or orthoimage is an aerial photograph geometrically corrected ("orthorectified") such that the scale is uniform: the photo has the same lack of distortion as a map. Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances, because it is an accurate representation of the Earth's surface, having been adjusted for topographic relief,[1] lens distortion, and camera tilt.

OXIDATION-REDUCTION (REDOX): A chemical reaction consisting of an oxidation reaction in which a substance loses or donates electrons, and a reduction reaction in which a substance gains or accepts electrons. Redox reactions are always coupled because free electrons cannot exist in solution and electrons must be conserved.

PACHYMETRA ROOT ROT: A disease of sugarcane caused by the soil-inhabiting fungus *Pachymetra chaunnorhiza*; common and serious in the wet topics of the Australian sugar industry.

PAN COEFFICIENT ($k_p$): The ratio of reference evapotranspiration ($ET_o$) to pan evaporation ($E_o$) for the same period.

PAN EVAPORATION ($E_o$): The depth of water that evaporates from an evaporation pan during a certain period in mm/day or mm/month.

PAN OR VACUUM PAN: Vacuum evaporative crystallizer used in the sugar industry to crystallize sugar from liquor, syrup or molasses.

PARASITOID: Parasitic insect (often a dipteran or hymenopteran) that feeds and lives (usually) internally within the egg, larva or pupa of another insect, eventually killing it.

PARENT MATERIAL: The unconsolidated geological material from which soil develops.

PART PER MILLION (ppm): Unit of concentration equal to one milligram per kilogram or one milligram per liter.

PATHOGEN: An infectious microorganism that causes disease. Sugarcane diseases are caused by viruses, bacteria, phytoplasmas and fungi.

PERMANENT WILTING POINT (PWP): The moisture level of a soil at which plants wilt and fail to recover turgidity.

PERMEABILITY: A qualitative description of the relative ease with which rock, soil, or sediment will transmit a fluid (liquid or gas). Often used as a synonym for hydraulic conductivity or coefficient of permeability.
PESTICIDE: A chemical applied to crops, rights of way, lawns, or residences to control weeds, insects, fungi, nematodes, rodents or other "pests."

pH: The logarithm of the reciprocal of the hydrogen ion concentration (activity) of a solution; a measure of the acidity (pH less than 7) or alkalinity (pH greater than 7) of a solution; a pH of 7 is neutral.

PHENOLS: A class of organic compounds containing phenol (C₆H₅OH) and its derivatives. Used to make resins, weed killers, and as a solvent, disinfectant, and chemical intermediate. Some phenols occur naturally in the environment.

PHOSPHATATION: Clarification using phosphoric acid and lime, in which certain nonsugar components are removed by flotation.

PHOSPHORUS: A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

PHOTOSYNTHESIS: Synthesis of chemical compounds by organisms with the aid of light. Carbon dioxide is used as raw material for photosynthesis and oxygen is a product.

PHYTOPLASMA: An infectious microorganism, related to but distinct from bacteria; usually spread by leafhoppers.

PLASTIC LIMIT (PL): The lower limit of the plastic state of a soil.

PLASTIC SOIL: One that will deform without shearing (typically silts or clays). Plasticity characteristics are measured using a set of parameters known as Atterberg Limits.

POLARIZATION (or pol): The apparent sucrose content expressed as a mass percent measured by the optical rotation of polarized light passing through a sugar solution. This is accurate only for pure sucrose solutions.

POLYAROMATIC HYDROCARBON: Aromatic hydrocarbons containing more than one fused benzene ring. Polyaromatic hydrocarbons are commonly designated PAH.

PORE VOLUME: The total volume of pore space in a given volume of soil or sediment. Pore volume usually relates to the volume of water (or air) that will completely fill all of the void space in a given volume of porous matrix. Pore volume is equivalent to the total porosity.

POROSITY: The volume fraction of soil not occupied by solid material but usually occupied by water and/or air.

POSTEMERGENCE HERBICIDE: Herbicide applied to foliage after the crop has sprouted to kill or significantly retard the growth of weeds.

POTASSIUM: One of the big three essential macronutrients. It has important roles in the activation of enzyme systems, is vital to photosynthesis and in the formation and translocation of sucrose in the phloem within the sugarcane stalk.

POTYVIRUS: A member of an important group of plant-infecting viruses that includes sugarcane mosaic virus; transmitted by various species of aphids.

PRE-EMERGENCE HERBICIDE: Herbicide applied to bare ground after planting the crop but prior to the crop sprouting above ground to kill or significantly retard the growth of weed seedlings.

PRETRASH: The act of remove the dead leaves from standing sugarcane stalks.

PROTOZOA: Single-celled, eucaryotic microorganisms without cell walls. Most protozoa are free-living although many are parasitic. The majority of protozoa are aerobic or facultatively anaerobic heterotrophs.
PURITY: The true purity is the sucrose content as a percent of the dry substance or dissolved solids content. The solids consist of sugar plus non-sucrose components such as invert, ash, and colorants. Apparent purity is expressed as polarization divided by refractometer Brix, multiplied by 100.

R

RATTOON STUNTING DISEASE (RSD): One of the most important diseases of sugarcane; caused by the bacterium *Leifsonia xyli* subsp. *xyli* and found in most countries where sugarcane is grown.

REFERENCE EVAPOTRANSPIRATION (*ET*<sub>0</sub>): The evapotranspiration (ET) in [mm/day] of a reference crop: normally green grass of uniform height (80 to 150 mm tall) growing actively, completely shading the ground and not short of water, or where specified full canopy sugarcane 3m tall.

REFINING: Purification of sugar through chemical and physical methods, generally including some or all of clarification, filtration, decolorization and recrystallization.

RIPARIAN ZONE: Pertaining to or located on the bank of a body of water, especially a stream.

ROGUING: The inspection of seedcane and commercial fields to identify unwanted stalks and plants (stools) and the removal of these from the field.

ROOT ZONE: The area around the plant below the soil surface delimited downwards by the effective root depth (ERD) sideways by the lateral extension of most of the plant’s nutritive roots.

RUNOFF: Excess rainwater or snowmelt that is transported to streams by overland flow, tile drains, or ground water.

S

SALINE SOIL: A non-alkali soil containing soluble salt in such quantities to interfere with the growth of most plants.

SALINE-ALKALI SOIL: A soil containing a high proportion of soluble salts with either a high degree of alkalinity or high amount of exchangeable sodium or both.

SEEDCANE: Sugarcane stalks grown in specially managed plots that are used to propagate the crop.

SETT: A section of stalk having from one to several buds that is used to propagate sugarcane vegetatively in commercial practice.

SLAGGING: The molten or partial melting pasty ash deposited in radiant heat transfer surface like boiler furnaces caused by metallic ions, in this case from sugarcane trash.

SMUT WHIP: The long, curved, spore-bearing fungal structure that develops from the tip of a smut-infected stalk, tiller or sideshoot and superficially has a whip-like appearance.

SMUT: One of the most important diseases of sugarcane internationally, caused by the fungus *Ustilago scitaminea*. Spread by wind-blown spores and in infected seedcane.

SOIL DEGRADATION POTENTIAL: the degree to which a soil is likely to lose its fertility due to a loss of organic matter, compaction, acidification, salinization or sodification.

SOIL MOISTURE: the water contained in the pore spaces in the unsaturated zone.

SOIL SPECIFIC MANAGEMENT: Management of sugarcane cultivars, land preparation, nutrient inputs, herbicide and pesticide applications, irrigation scheduling, cane harvesting and haulage practices according to changes in soil characteristics and composition or soil type.

SOLUTION: Formed when a solid, gas, or another liquid in contact with a liquid becomes dispersed homogeneously throughout the liquid. The substance, called a solute, is said to dissolve. The liquid is called the solvent.
SORPTION: General term for the interaction (binding or association) of a solute ion or molecule with a solid.

SPECIFIC GRAVITY (SG): The dimensionless ratio of the density of a substance with respect to the density of water. By definition the specific gravity of water is equal to 1.0

STRUCTURE: The arrangement of primary particles into secondary units or peds with a particular size and shape.

SUBSURFACE DRAIN: A shallow drain installed in an irrigated field to intercept the rising groundwater level and maintain the water table at an acceptable depth below the land surface.

SUCROSE: Pure chemical compound we know as white sugar, generally measured by polarization in pure solution or by GC or HPLC in impure solution. The chemical term is β-D-Fructofuranosyl α-D-glucopyranoside.

SUGAR: Term for the disaccharide sucrose and products of the sugar industry, essentially composed of sucrose.

SUGARCANE MOSAIC VIRUS (SCMV): An important, systemic disease of sugarcane that occurs in many countries; caused by various strains of potyviruses and spread by a number of species of aphids as well as in seedcane.

SUGARCANE YELLOW LEAF VIRUS (SCYLV): A systemic disease of sugarcane caused by a member of the viral group luteoviridae; spread by aphids.

SULFITATION: Introduction of sulfur dioxide to juice or liquor.

SULFUR: An essential secondary nutrient, important in forming plant protein as part of amino acids.

SURFACE RUN-OFF: That portion of rainfall or irrigation, which runs off without infiltrating the soil.

SWEET WATER: Wash water or water containing a small amount of sugar.

SYRUP: The concentrated juice from the evaporators.

SYSTEMIC PATHOGEN: A disease-causing pathogen of sugarcane that occurs within the internal vascular tissues of the plant. Systemic diseases can be spread by the planting of infected seedcane and also develop from the stubble of an old crop to reappear in the subsequent ratoon crop after harvest.

THERMOTHERAPY: The treatment of sugarcane setts with heat, usually in the form of hot water, to eliminate certain pathogens and pests from seedcane. The most commonly used treatment is a soak in water at 50 °C for 2 hours.

TILLERING: Emergence, growth and development of lateral buds on the sugarcane stalk to form tillers or shoots.

TISSUE CULTURE: The process of generating new individual plants by the induction of cell proliferation from meristematic (re-generative) tissue in artificial growth media under aseptic conditions. Used for rapid propagation of sugarcane and the elimination of pathogens.

TOTAL AVAILABLE WATER (TAW): The depth of soil water available within the effective root depth (m) of a given crop between the limits of field capacity (FC) and the permanent wilting pint (PWP). (This is normally at soil water tensions between:10 kPa and: 1 500 kPa. (TAW = AWC * ERD).

TOTAL FERMENTABLE SUGARS (TFS): In sugarcane are primarily sucrose, glucose and fructose with smaller quantities of other fermentable carbohydrates.
**TRACE ELEMENT**: An element found in only minor amounts (concentrations less than 1.0 milligram per liter) in plant, soil, water or sediment. In plant nutrition includes copper, zinc, iron, manganese, boron and molybdenum while pollution studies also focus on arsenic, cadmium, chromium, lead, mercury and nickel.

**TRACER**: A stable, easily detected substance or a radioisotope added to a material to follow the location of the substance in the environment or to detect any physical or chemical changes it undergoes.

**TRANSPIRATION (T)**: Water that is lost from soil storage into the atmosphere and utilised by the crop in mm/day.

**TRIAZINE HERBICIDE**: A class of herbicides containing a symmetrical triazine ring (a nitrogen-heterocyclic ring composed of three nitrogens and three carbons in an alternating sequence). Examples include atrazine, propazine, and simazine.

**U**

**Unconsolidated deposit**: Deposit of loosely bound sediment that typically fills topographically low areas.

**Unsaturated zone**: the zone between land surface and the capillary fringe within which the moisture content is less than saturation and pressure is less than atmospheric. Soil pore spaces also typically contain air or other gases.

**Upland**: Elevated land above low areas along a stream or between hills; elevated region from which.

**V**

**VAPOR PRESSURE**: the force per unit area exerted by a vapor in an equilibrium state with its pure solid, liquid, or solution at a given temperature. Vapor pressure is a measure of a substance's propensity to evaporate. Vapor pressure increases exponentially with an increase in temperature.

**VASCULAR BUNDLES**: The conducting vessels of a plant, mainly comprised of the phloem and xylem tissues. Systemic pathogens often inhabit these tissues.

**VINASSE**: Also known as stillage, is a residual liquid/byproduct of the distillation process used to make ethanol from molasses or sugarcane juice and is a valuable fertilizer containing high levels of K, other nutrients and organic matter.

**VOLATILIZATION**: The process of transfer of a chemical from the aqueous or liquid phase to the gas phase. Solubility, molecular weight, and vapor pressure of the liquid and the nature of the gas-liquid interface affect the rate of volatilization.

**VOLUNTEERS**: Regrowth of sugarcane plants from previous plantings with varying amounts of moisture.

**W**

**WATER TABLE**: The point below the land surface where ground water is first encountered and below.

**WATER-QUALITY GUIDELINES**: Specific levels of water quality which, if reached, may with irrigation adversely affect soil quality through the build saline and/or sodic salt levels or for domestic use various pollutants may affect human health or aquatic life.

**WEATHERING**: The process during which a complex compound is reduced to its simpler component parts, transported via physical processes, or biodegraded over time.
**WETLANDS**: Ecosystems whose soil is saturated for long periods seasonally or continuously, including marshes, swamps, and ephemeral ponds.

**WHITE LEAF DISEASE**: A systemic disease of sugarcane caused by a phytoplasma and spread by leafhoppers; widespread and often serious in some sugar industries in Asia. Easily recognised by the characteristic white stripes and chlorosis (white coloration) of the leaves of infected plants.

**WINDROW**: A low, elongated row of material such as trash, left uncovered to dry. Windrows are typically arranged in parallel.

**Z**

**ZINC**(Zn): One of the first recognized metallic micronutrients as essential for sugarcane. Aids in the synthesis of plant growth substances and enzyme systems.

**ZONAL TILLAGE**: soil disturbance in restricted area.
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boilers

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ammonium nitrate (CAN)

carbonate

chloride

cyanamide

deficiency

nitrate

pedocals

salts

tri-phosphate

cane supply agreements

capillary fringe

carbonation

cation exchange capacity

cations

divalent

centrifugal

batch

continuous

non

chemical oxygen demand

child labor

chlorophyll

civic education

clarifier

clay

clay minerals

climate

change

coupled

cogeneration

colloid

color

cultivar

formation

ICUMSA

juice

leaf

pedological properties

soil

sugar

sugar clarification

vinasse

combination tillage

community

carbon dioxide

cation

chemical ripener

COD

dust

emission

factor

herbicide

potassium

silicon

sludge

sucrose

sugar dust

vinasse

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