Cropping Systems Simulation Model
User's Manual

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CropSyst

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Abstract

CropSyst is a user-friendly, conceptually simple but sound multi-year multi-crop daily time step simulation model. The model has been developed to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion. Management options include: cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations (over 80 options), and residue management. The model is currently written in Turbo Pascal 6.0 for MS-DOS using an object oriented programming approach.

For more information about this model, comments or help in using the material presented here or the software package, contact Claudio O. Stöckle or Roger L. Nelson at the Biological Systems Engineering Dept., Washington State University, Pullman WA 99164-6120. Phone: (509)335-1578, FAX: (509)335-2722.
Preface

This release of CropSyst is made available for testing purposes. Although a reasonable amount of model testing has been done through work with several scientists possessing relevant data, we feel that a period of model use by independent users will provide us with valuable feedback. CropSyst is made available at no cost to you. In return, we would sincerely hope that you will provide us with any suggestions that you may have on either the technical aspects of the simulation, or the usability of the software package. Our mail and Email addresses, and phone and FAX numbers, are listed in the manual and in the software. If you are utilizing the international language capabilities of CropSyst, comments regarding the correctness of the translations would be highly appreciated. We will endeavor to provide expeditious replies to recommended modifications to the model or user interface.

We are convinced that great progress for both model developers and users can be obtained by working together in specific projects. To this end, CropSyst was designed to function as a module which can be integrated with other software packages (such as the Geographic Information System Arc/Info). We would like to know of your efforts in using CropSyst for specific applications.

When using simulation models, it is important to understand how the model represents the physical, chemical, and biological processes involved in cropping system response to the environment and management. We suggest that you try experimenting with different input parameter values to get a feeling for which parameters are sensitive to your specific application (whether it be crop production, soil physics or management practices). Discrepancies between observed data and values estimated by the model can only be corrected by identifying which results are not being satisfactorily represented by the model.

As a general rule, if simulation outputs do not seem to conform to the observed data, the technical structure of the model should be the last factor to suspect. Discrepancies often result from incorrectly chosen parameter values. Make sure that all your input data is correct. Watch for typing errors or errors in the units of the parameters. Do not analyze the output in terms of the final yield predicted; rather, check the crop growth in terms of phenology, leaf and root development, water use, nitrogen use, etc.. These elements should conform to empirical observations; if they don't, check the input parameters which are sensitive to your application in order to obtain better representations. Also be very critical of the field data you are using to calibrate or verify the model. It has been our experience that it is not unusual to find errors in tabulating or graphing data, or reducing raw data to a publishable form. We have encountered a number of situations where CropSyst has helped to identify problems with field data. If you find that input parameters need to be assigned unrealistic values to obtain expected results, let us know of your problems.

Model validation is a necessary requirement before model application. In addition, to represent cultivar specific characteristics, fine tuning of selected crop input parameters via calibration is desirable, provided that suitable experimental data is available. This is done by adjusting these parameters within a narrow range of fluctuation of typical values given in the users' manual. There is no such thing as a universal model that will work with an unaltered set of parameters for all conditions: The curious and patient researcher should be able to successfully calibrate the model to specific species and cultivars and obtain satisfactory results. An individual with less background in crop growth may experience more difficulty.

We would like to reiterate that we are interested in your comments and in working with you. Let us know of your problems and successes with CropSyst as we are always interested in improving the model.

Claudio Stöckle
Roger Nelson
Parameter editor

Simulation parameter organization is based on separate component input files for location, soil, crop and management data. The simulation control file is built up by combining these component files. This allows the user to quickly build simulation conditions from a database of existing location, soil, crop and management data.

In order to run CropSyst simulations, input files containing information about driving variables (weather) and input parameters required by the many processes simulated by the model, must be created by the user.

Weather files are simple text files which can be created and manipulated using any text editor of the user's preference. Other input files include: location, soils, crops, and management. These files are created and manipulated CropSyst parameter editor.

Both a DOS and a Windows version of the CropSyst parameter are provided in the current distribution. The DOS version is no longer actively maintained and generally parameters for new features in CropSyst and the CropSyst support utilities will only be added to the Windows version.

Both versions have very similar functionality although the organization of each parameter editor window are slightly different. The Windows version will be documented here. If the DOS version differs significantly, this will be noted.

If you have problems running simulations refer to the hints and trouble shooting.

Main menu and tool buttons

The menu bar across the top of the window has the following organization. A number of menu operations are provided as tool buttons for quick access.

File

This menu works like any other Windows application File menu. The following are specific notes for CropSyst.

New

This allows new parameter files to be creates. Simply select the type of parameter file to be created.

Open

This allows editing new parameter files. A file requestor will be displayed. Select the type of file to be edited, and select the file to be edited.

Save
This will save the currently edited parameter file. This is similar to pressing the button but will save the file without closing the parameter window.

Save as
This will first display a file requestor giving the user the opportunity to save the file with a different name and/or in a different directory.

Print
This will dump the current parameter editor window to the printer.

Print preview
This will dump the current parameter editor window to the printer.

Text edit

This menu provides operations available to edit fields and text editors used in the parameter editor. These functions are the same as in other windows applications.

<table>
<thead>
<tr>
<th>Undo</th>
<th>Alt+BksSp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut</td>
<td>Shift+Del</td>
</tr>
<tr>
<td>Copy</td>
<td>Ctrl+Ins</td>
</tr>
<tr>
<td>Paste</td>
<td>Shift+Ins</td>
</tr>
<tr>
<td>Clear All</td>
<td>Ctrl+Del</td>
</tr>
<tr>
<td>Delete</td>
<td>Del</td>
</tr>
</tbody>
</table>

Window

This menu provides operations for arranging windows. These functions are the same as in other windows applications.

Simulation
This menu allows selection of simulation environment options, running simulations, creating batch simulation runs, report formats, and advanced simulation modules.

Parameter files

These menu operations edit the parameter files:

- Simulation control
- Management
- Soil
- Crop
- Location
- Batch run

Help

The help menu provides access to the online Manual, the CropSyst Wizard and version information in the about option.

Note that the DOS version has a completely different menu organization.

Simulation directory

CropSyst places no constraint on the organization of parameter files. Indeed the user may find different directory and files organizations may be suitable for the creation of different simulation scenarios.

The directory which contains a simulation control (.SIM) file is referred to as a simulation directory. Generally it is best to create a separate simulation directory for each simulation scenario; however you may find it convenient to have a single directory for a group of related simulation scenarios.
The simulation will create a subdirectory in the simulation directory containing files output by the simulation. This subdirectory will have the same name as the simulation control file (without the filename extension). This subdirectory may also contain some input parameter files for certain CropSyst simulation modes (i.e. specific annual management files).

**Simulation support files**

Additional input and output files may be associated with a simulation. These files will have the same name as the simulation file but with the following extensions:

<table>
<thead>
<tr>
<th>Extension</th>
<th>Input/Output</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.RCL</td>
<td>Input</td>
<td>Recalibration file</td>
</tr>
<tr>
<td>.XLH</td>
<td>Output</td>
<td>Harvest report Excel spreadsheet</td>
</tr>
<tr>
<td>.XLD</td>
<td>Output</td>
<td>Daily report Excel spreadsheet</td>
</tr>
<tr>
<td>.XLY</td>
<td>Output</td>
<td>Yearly report Excel spreadsheet</td>
</tr>
<tr>
<td>.XLS</td>
<td>Output</td>
<td>Soil profile Excel spreadsheet</td>
</tr>
<tr>
<td>.WKH</td>
<td>Output</td>
<td>Harvest report Lotus 1-2-3 spreadsheet</td>
</tr>
<tr>
<td>.WKD</td>
<td>Output</td>
<td>Daily report Lotus 1-2-3 spreadsheet</td>
</tr>
<tr>
<td>.WKY</td>
<td>Output</td>
<td>Yearly report Lotus 1-2-3 spreadsheet</td>
</tr>
<tr>
<td>.WKS</td>
<td>Output</td>
<td>Soil profile Lotus 1-2-3 spreadsheet</td>
</tr>
<tr>
<td>.HRV</td>
<td>Output</td>
<td>Harvest report text</td>
</tr>
<tr>
<td>.DLY</td>
<td>Output</td>
<td>Daily report text</td>
</tr>
<tr>
<td>.YLY</td>
<td>Output</td>
<td>Yearly report text</td>
</tr>
<tr>
<td>.PRF</td>
<td>Output</td>
<td>Soil profile text</td>
</tr>
</tbody>
</table>

**Simulation environment preferences initialization file**

An initialization file (CROPSYST.INI) is kept in the simulation directory. The current preferences and memory of the last modified files worked is updated when a simulation file is saved.

When a simulation file is opened, the initialization file is the corresponding simulation directory will be loaded, effectively loading a simulation environment customized for the simulation directory.
Simulation menu

Options

This dialog box allows selection of the simulation model, and language translation.

Simulation model

Run simulation

The 'Run simulation' option allows the user to select a simulation and a report format to run. In the DOS parameter editor, the option is located in the 'File' menu. To run DOS CropSyst without generating any output reports, select the [Cancel] button when prompted for the report format.

Rerun simulation

The Rerun simulation' option invokes the currently selected simulation model program. The last simulation control parameter input file, and the last report format file edited or selected will be used for the simulation run.

In the DOS parameter editor, the option is located in the 'File' menu. Also, if a DOS batch run was created, selected or edited with the batch run generator, the batch run will be executed instead.

Report format

The Report format editor option allows the user to develop custom formats for output.

Batch editor

The Batch file editor option allows the user to construct a set of simulations to be run in sequence. Both individual crop system simulations and advanced simulation modules may be selected.

In the DOS parameter editor, the option is located in the 'File' menu.

Arc/CropSyst Cooperator

Simulation output directory

CropSyst uses Windows Explorer to display the simulation output directory. Most CropSyst reports are available either as Excel spreadsheet files and some as text files. Normally double clicking on these files will open the file using Excel or a text editor.
DOS parameter editor

To run CropSyst enter the command CS from the DOS command line. When CropSyst is initially started, the title screen is displayed with the menu of operations across the top of the screen.

Windowing user interface

CropSyst uses the Borland Turbo Pascal TurboVision library for windows, pull-down menus, file requesters and data entry. All options are accessible with the use of either the keyboard or a mouse.

Input screens consists of a menu strip, a status line and an area in which input windows are displayed.

Windows and Dialog boxes

CropSyst data entry screens consist of one or more dialog boxes. The input dialog boxes use input fields, list selectors and push buttons to simplify data entry. Input fields, selectors, buttons and boxes are called gadgets. When using a mouse, a gadget is activated by pressing the left mouse button while the mouse cursor is over the gadget. If no mouse is available, the gadget is activated by pressing the [Tab] or [Shift] [Tab] key until the gadget is highlighted. Text input fields allow the user to enter text strings. The mouse and editing function keys can be used to position the cursor and insert, delete and edit text in the input field. Numeric input fields allow the user to enter numeric values (integer or float). The value entered will be checked for range violation warnings or error. Use the [Del] key to clear the value to 0. List selectors allow the user to select an item from a list of options. An option is selected by highlighting the item using the mouse or cursor keys and pressing the appropriate accept push button. Check boxes and radio buttons are used to select parameter options. Check boxes are used when multiple options can be selected, and radio buttons are used when only one option can be selected. An option is selected with the mouse, or by using the cursor keys and pressing [Space] or [Return].

Window Management

Under CropSyst, multiple windows may be displayed on the screen. Generally windows are opened when a menu option is selected. A window may be closed by selecting the [. ] box located in the upper left corner of the window frame, or by selecting the appropriate close button usually labelled [Close] [Accept] [Exit] etc. using the mouse. If a mouse is not used, the window may be closed using the Close option in the Windows menu (Pressing [Esc] may also close a window). Windows that don't have the [. ] box in the upper left corner can only be closed by selecting the appropriate button in the dialog box.

Windows can be moved around the screen by selecting the window with the mouse on the top border of the window and dragging it while holding down the left mouse button. If no mouse is available, the window can be move by selecting the "Size/Move" Window menu option and the cursor keys.
The user interface allows multiple input windows to be displayed on the screen simultaneously and windows may cover other windows. When more than one window is on the screen, the top window is the active one. To make another window active, select it by double clicking on the window with the mouse, or press [F6] or [Shift] [F6] to cycle through the windows displayed on the screen.

2.4 Help

The CropSyst help is provided for all input parameters and most menus. To get help on a parameter, highlight the parameter and press [F1]. A window will be displayed on the screen showing the respective section of the manual.

2.4.1 How to Use CropSyst Without a Mouse

All active areas on the input screen (input fields, buttons and other gadgets) should be available via keyboard control. Most active areas in the data entry form window can be reached by pressing the [Tab] key on the keyboard (also [Shift] [Tab]). The [Tab] moves the cursor to the next active area which becomes highlighted.

For numbers and text input areas, simply enter the number/text using the alpha-numeric keys. These text fields can be edited using the normal text editing functions key ([Insert],[Delete] etc.). For button active areas, pressing [Space] or [Enter] on a highlighted button will correspond to clicking on the button with the mouse.

A few active areas on the screen have been bound to either a function key or an [Alt] key sequence. These active areas are denoted by having a highlighted character in the input area label (either yellow or red). For example, pressing [Alt][F] will activate the File menu, [Alt][S] will activate the Soil menu.

Main Menu

A menu strip is displayed across the top of the screen. Menu and submenu options may be selected with the mouse, or by pressing the [Alt] key followed by the highlighted character in the menu option. Additional functions displayed in the status line at the bottom of the screen are often available by pressing the respective function key or key sequence or by selection with the mouse.

Several menu options can be activated directly from the keyboard. The menu option will show what key sequence can be pressed to activate the option. Additional operations which can be activated from the keyboard may be displayed in the status line.

The main menu gives the following options:

- File
- Window
- Control
- Management
- Soil
- Crop
The remaining main menu options: Control, Management, Soil, Crop, and Location, allow the user to create and edit the database of crops, soils, locations and management practices.

**Viewing output**

Output from CropSyst can be viewed, or printed in report form using the View report' menu option. Reports generated by CropSyst can also be imported into databases and spreadsheets.

Output may also be viewed with the included graphing utility accessed via the Graph report' menu option.

The Window main menu option provides facilites for moving CropSyst parameter windows if the computer has no mouse.
Simulation parameter editor

Simulation files contain information allowing the user to build simulation conditions from a database of existing location, soil, crop, and management files. Simulation files also contain information regarding the period of simulation and initial values for model variables that require initialization.

Simulation files are created and modified using the simulation control parameter editor. This editor allows the user to combine component parameter files (e.g., location, soils, crops, management) to build the simulation run and to edit initialization parameters.

![Simulation control parameter window](image)

**Simulation control parameter window**

The primary elements to build a simulation control file consist of the period of the simulation (starting and ending dates), and specification of soil, location, crop rotation and management practices.

Component files are selected by pressing the filename button and using the file requestor to choose the respective files. The [Edit] buttons next to the filename button will allow the currently selected file to be
Simulation description

A description of the simulation (limited to 80 characters in the DOS version) may be entered in the input field at the top of the dialog box. This description will be printed at the top the reports when the report header option is selected in the report format. The description will also be used to compose simulation labels when using the Arc/CropSyst Coöperator or the Rural Watershed modelling modules.

Simulation period

The starting and ending dates specify the period of the simulation. The simulation starts and stops on these dates. Therefore:

1. The starting date must be less than the ending date.
2. The starting date should be before the anticipated planting date of the crop.
3. The ending date should be after any anticipated harvest date.

The year must have four digits, and the day of the month (DOM) must be a valid date for the selected month (CropSyst does handle leap year). To select the month, activate the date button using the mouse (or press return when the date button is highlighted). A date requester is displayed where the year, month and DOM may be selected.

In previous version of CropSyst detail lines in the annual report were produced on January first, so inorder to output all years, it was often necessary to select January 1 of an additional year to get a complete annual report. This is no longer the case, annual report detail lines are now produced on December 31.

Soil and location files

These files are selected from a database of previously created soil and location files.

The user must select a soil and a location in order to run the simulation.

Simulation options

The following simulation options may be selected for the simulation run. Some of the options are selected under the corresponding tab.
**Infiltration model**

There are currently two infiltration models for water transport. **Cascading method** is a simple transport model which only moves water downward. The **finite difference method** is more detailed and can transport both up and down. Using the finite difference method often increases the simulation time. With the finite difference model, additional options are available for the **numerical runoff model** as well as simulation at **30 precipitation intervals and storms**.

**Runtime graph**

It may be desirable to disable the **runtime graphic display** when running **CropSyst** in a non-interactive mode, or for running under some other application, or for long simulation periods (the simulation can run significantly faster without the display).

*Note that some of the CropSyst simulation modules will always disable the runtime graphics in order to allow the intensive simulations to run as fast as possible.*

**Salinity simulation**

The user can select the simulation of salinity. When enabled, both **salt movement** and **salinity effects on crop growth** are enabled.

**Nitrogen simulation**

When nitrogen is turned off, the nitrogen components of are totally deactivated: **nitrogen crop limitations** are disabled, **nitrogen application events** are not used, and all **nitrogen output reports** and variables will have null values.

**Erosion simulation**

When enabled, erosion is simulated using the **Revised Universal Soil Loss Equation**. When erosion is turned off, the erosion model is completely deactivated. All erosion output variables will have null values.

Note that soil erosion is an annual computation, and erosion output is available only in the annual report.

**Remove eroded soil**

This option will remove the computed soil erosion from the soil profile. Because erosion is only computed annually, you will observe a reduction in the soil profile only on January 1st.
Chemical simulation

When enabled, chemical fate (such as pesticides) is simulated. This does not include nitrogen.

Validating the simulation

The [Validation] button will perform a validation check of the parameters in the parameter files selected for the simulation. These will be output to a text file that will be displayed in a window.

Running the simulation

The [Simulation] button will run the simulation using the currently edited simulation file. The parameters will be saved before the simulation is run, so it is not necessary to use the File/Save menu or close the simulation before pressing the running the [Simulation] button.

Initial values

Initial values and parameters for optional submodel specific to each simulation are entered on the dialog box page under the corresponding tab. They are:

Soil profile

The initial soil profile always needs to be set. Nitrogen, organic matter and salinity may be ignored if not running those simulation submodels.

Rotation

A rotation will be need if you intend to run CropSyst with any cropping system. The rotation can be omitted to simulate fallow conditions. If you want to run fallow conditions with management events, you can create the optional Annual management with specific events and/or a corresponding simulation management file.

Residue

It is often the case that there will be some biomass residue at the time the simulation starts. A existing residue pool can be created by enter the residue parameters. If no existiting residue pool is to be created, enter 0.0 for the residue biomass parameters.

Nitrogen

When nitrogen simulation is enabled nitrogen transformation rates can be adjusted for local conditions. These parameters may be omitted when nitrogen simulation is not enabled.

Remember to enter intial nitrogen contents on the soil profile page when nitrogen simulation is enabled.

CO₂

The long term atmospheric Carbon Dioxide concentration simulation is a special global
atmospheric change simulation scenario.

Projects

These are special simulation generation and analysis methods.

Additional simulation specific parameter files

For some special simulation situations, it may be convenient to reset some select state variables. To accomplish this, a recalibration file can be created. This file should be placed in the same directory as the simulation file and must have the same filename with the extension .RCL.

The file may consist of records of the following format:

year doy keyword amount1 ... amountn Year and DOY is the date (Day Of Year) the recalibration is to occur. This may often be the date of a field data measurement. The year may be 0 indicating that the recalibration values are to be used every year on the specified day. amount1...amountn are the values to be used in the first n soil layers.

The following variables can be recalibrated:

**WT - Water table depth (m)**

The recalibration file with water table entries will be used by the finite difference infiltration model to implement water table boundary conditions. In the case of WT, only one value is provided for the depth.

The water table is not used by the Cascade infiltration model and will be ignored when the simulation is run with the Cascade infiltration mode.

**WC - Water content (m³/m³)**

Occasionally, for certain abnormal soil conditions, CropSyst may not be able to simulate certain physical phenomena such as water tables that rise into the root zone, or very deep mud cracks causing deeper evaporation, etc.. This water content can be reset to measured values. This could also be used to specify periods of inundation or the effects of unnatural phenomena outside the scope of CropSyst.

**SNOW - Snow depth (m)**

add the new SNOW depth in snow pack depth CropSyst current converts this to melted liquid water equivalent by dividing this depth by 5.

You need not include dates for 0 depths, 0 depth will be used for dates with no specified depth.
NH4 - Ammonium (kg N/ha initial N)
Not yet implemented

NO3 - Nitrate (kg N/ha initial N)
Not yet implemented

%OM - Percent organic matter (0-10 in a scale of 0-100)
Not yet implemented

Auxillary parameters

In addition to the parameters that can be edited with the parameter editor. There are a few additional parameters that may be useful in certain simulation situations. These parameters can be modified using a text editor.

Hydrologic curve number override

In the soil file, under the section [soil], the entry: hydrologic_curve_number=99 If specified (a value between 1 and 100) will override any curve number selection based on crop type, land treatment, hydrologic condition and hydrologic curve.

This parameter is often used in simulating soil conditions (usually outside the United States) where experience has shown that the curve number look up tables are not useful for the soil type.

ID

This is used by simulation modules to identify GIS polygons or cells.
Runoff models

CropSyst provides three options for determining runoff.

- **No runoff simulation**
- **SCS curve number method**
- **Numerical solution**

**No runoff simulation**

In this mode, CropSyst will try to infiltrate all non-intercepted precipitation and irrigation.

**SCS curve number method**

Runoff will be determined as a function of current soil moisture content, static soil conditions, and management practices.

Runoff is deducted from the water available to enter the soil prior to infiltration.

This method requires selection of land management practices and soil hydrologic characteristics and management, crop and soil parameter files:

- Land treatment in the management file (xxx is assumed default in fallow conditions).
- Land use in the crop file.
- Hydrologic group and hydrologic condition in the soil file.

**Numerical solution**

This method is available only with the Finite Difference infiltration model.

Runoff will be determined as a result of the Finite Difference infiltration model and is deducted after infiltration. The numerical solution method requires the soil surface storage parameter to be specified in the corresponding soil file.
Soil profile initialization

**CropSyst** requires only minimal initialization parameters to provide initial soil water, nitrogen, and organic matter profiles.

![Simulation initialization parameter window](image)

**Soil water profile initialization**

The initial water content of each soil layer at the beginning of the simulation is specified here. This value is expressed in m³ water/m³ soil as shown in the Soil profile initialization parameters table.

**Information Source:**
- Experimental data
- Local experience.
Uses:

- Thermal conductivity in soil layers.
- Soil air volume.
- Soil ice content.
- Soil water potential.
- Leaf water potential (equation 14.8).
- Soil water loss and water content.
- Automatic irrigation
- Plant available water (PAW).

**Soil nitrogen and organic matter profile initialization**

The initial nitrogen content, in the form of nitrate and ammonium, and the organic matter content of each soil layer at the beginning of the simulation is specified here. These values are parameters are used only when [nitrogen simulation](#) is enabled.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric water content</td>
<td>m³/m³</td>
</tr>
<tr>
<td>Nitrate content</td>
<td>kg N/ha</td>
</tr>
<tr>
<td>Ammonium content</td>
<td>kg N/ha</td>
</tr>
<tr>
<td>Organic matter</td>
<td>(0-100)%</td>
</tr>
</tbody>
</table>
Crop and management rotation table

CropSyst incorporates a new versatile crop rotation table which allows simulation of multiple year crop rotations.

Entering a crop in the rotation

1. Click on the [Planting] date button and select the year, month and day of planting. For computed planting date crops, this date specifies the date to start looking for good planting conditions.

2. Click on the [Crop] button and select the crop file to be planted. The [Edit] button can be used to edit the currently selected crop file.

3. Click on the [Management] button and select the management file to be used with the crop. The [Edit] button can be used to edit the currently management crop file. Click on [<-None] if no management file is to be used. A '-' will be displayed when no management file is selected.
4. Click on [Insert] to enter the selected planting date/crop/management (displayed in the line below the rotation table) into the rotation table. The table is sorted by planting date. If the word 'crop' is displayed in an entry, then the entry should be deleted, and a new entry with a crop and (optionally) a management selection must be made.

Deleting an entry in the rotation

1. Click on one or more entries in the table to be removed. The scroll bar on the left side of the table can be used to view long tables.
2. Click on the [Delete] button.

Two crops with the same planting date cannot appear in the table simultaneously.

Repeating a rotation for the simulation period

1. Make sure the simulation run starting and ending dates are set for the correct period.
2. Enter the number of years in the rotation.
   - In the DOS version, the years in the rotation is specified after pressing the [Build] button.
3. Create entries for the first rotation cycle. Highlight the entries to be repeated. These entries will be used as the template for the remainder of the simulation period.
   - In the DOS version, multiple entries cannot be selected. Make sure that there are only the entries to be repeated in the rotation list.
4. Click on the [Build] button.
5. The table will be filled in using the template entries. Fallow periods specified by skipping year numbers in table entries will be preserved.

Additional notes about fallow periods

If the simulation is to be run on fallow conditions only, the rotation table can be left blank.

Since CropSyst runs fallow conditions between harvest and the planting of the next crop, one or more years of fallow growth can be accounted for in the rotation by simply skipping years when entering planting dates and/or increasing the number of years in the rotation.

If you need to run fallow with some management operations, Click on the [Fallow] button to clear the crop entry to fallow and select the management file.

Additional notes about management files

Some times it is desirable to perform management operations irregardless of the crop specified or in addition to the scheduled managements. In order to perform this type of operation, create a subdirectory in the same directory as the simulation file with the same name as the simulation file (Without the .SIM
extension). Create the management file having the same name as the year the management events are to occur in. CropSyst will load management files in this subdirectory when the corresponding year comes to pass.
Residue initialization

The user should provide initial residue cover conditions for the simulation of residue decomposition of residues that may be existing at the time of the start of the simulation.

Simulation residue window

Surface residue (kg/m²)

refers to the amount of initial surface residue matter on the ground.

Incorporated residue (kg/m²)

refers to the amount of initial plant residue incorporated into the first 5 to 8 centimeters of soil.
Residue water content (m³/kg) refers to the amount of water initially stored in the residue matter on the ground.

Residue decomposition time constant (1-300 days)
The approximate number of days required for the residue to decompose 63% of the initial residue mass under ideal moisture and temperature conditions.

Information source:
- Field study data.
- Output from another simulation run (CropSyst or another) such as the residue conditions on the last day of the simulation run.
- Some residue decomposition time coefficients are given in the crop residue constants table.
- Any reasonable values may be used when actual data is not known.

Usage:
The residue values are used to create a residue pool which is maintained throughout the simulation until fully decomposed. The residue pool (as well as residue pools create as a result of management, harvest events and crop failure) affects the following:
- water storage and infiltration.
- potential soil evaporation.
- potential residue evaporation.
- soil residue incorporation.
- residue decomposition.
- runoff.

Residue initialization parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Usual range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface residue</td>
<td>0.0-1.5</td>
<td>kg/m²</td>
</tr>
<tr>
<td>Shallow residue</td>
<td>0.0-0.1</td>
<td>kg/m²</td>
</tr>
<tr>
<td>Residue water content</td>
<td>0.0-0.004</td>
<td>m³/kg</td>
</tr>
<tr>
<td>Residue depomp. coef.</td>
<td>1-300</td>
<td>days</td>
</tr>
</tbody>
</table>
Nitrogen simulation options

Constant organic matter

When this option is selected, organic matter is reset to initial soil profile values at the beginning of each year.

The initial organic constant is the same year after year of a long sequence of simulation years. Organic matter does change daily during the year. Thus, organic matter does not significantly build up or get reduced with time (in the long runs).

This option would be used for situations where a large number of simulations with different weather files are wanted using the same initial conditions.

This is useful to determine the probability (risk) of obtaining given simulation results for a specified management scenario under a variety of possible weather conditions, but under a constant (today's) soil condition.
This is different than long term scenarios where we simulate change as a function of time for a period of 30 or more years. In this case we allow organic matter to continuously fluctuate as estimated by the model throughout the simulation period.
Atmospheric CO$_2$

This checkbox enables atmospheric CO$_2$ modelling.

Initial CO$_2$ concentration
description needed parts per million (ppm)

Annual rate of CO$_2$ concentration increase
description needed
Additional requirements

In order for CO$_2$ modelling to show the crop response to increasing CO$_2$ levels, CO$_2$ parameters in the corresponding crop files should to be specified.

You will also need use a long simulation period (on the order or 30 years) to observe the long time results.
Validation

Parameters for a simulation may be validated either by clicking of the [Validation] button in the simulation control screen of the parameter editor.

Input parameters will be checked to insure that they either fall within valid ranges, or are otherwise reasonable. In addition to range validation, the following errors and warnings will be checked:

- **Simulation control and initialization**
  - Weather files are checked for valid format.
  - Initial water contents must be provided for all soil layers present in the soil profile.

- **Management**
  - A number of days after maturity for harvest must be provided.

- **Crop parameters**
  - Growing degree days at maturity must not equal growing degree days at emergence.
  - Growing degree days must be in assending order: Emergence, Flowering, Grain filling, Senescence, Maturity.
  - Soil horizon sublayer division must not exceed memory limitation imposed by MS-DOS.

- **Soil parameters**
  - $0 < \text{PWP} < \text{Init WC} < \text{FC}$
  - $\text{FC} < 1 - \frac{\text{BulkDensity}}{2.65}$. If false, then decrease FC or bulk density.
  - Value must be given for all residue parameters (both in the crop and simulation initialization).
  - The combination of soil hydrologic group and condition and the crop land use and treatment must exist in the runoff curve number table of the *USDA/SCS National Engineering Handbook* (USDA-SCS, 1988a).
Running CropSyst from the DOS command line

In addition to running CropSyst from the Windows parameter editor, there are several options for running CropSyst from the DOS command shell. This may be useful for creating batch runs: for example, to create new simulation models that use CropSyst to prepare data for further analysis.

From the DOS command line, CropSyst may be run in either an interactive or non-interactive mode. In the interactive mode, CropSyst will prompt for the name of the simulation parameter file and, if the runtime graphics are selected in the parameter file, the user may select the graphs to be displayed as the simulation runs. In the non-interactive mode, the user supplies the names of the simulation parameter file and the report format file on the command line, i.e. the command line:

CROPSYST PARAMA.SIM REPORTQ.FMT NOGRAPH

This will run CropSyst using parameter file PARAMA.SIM and generate output files as specified in the file REPORTQ.FMT.

NOGRAPH is an optional keyword that will disable any runtime graphic option selected in the simulation control file allowing CropSyst to run in the faster text only mode.

The DOS CropSyst has several runtime display options:

1. Runtime graphic display (Color EGA or VGA monitor recommended)
2. Text display showing date, crop and growth stage and some harvest totals.
3. Text display which also shows the daily soil profile

The runtime display can be changed with the simulation is running by pressing [Return].

Runtime soil profile text display

The soil profile text display shows daily values for key variables by soil horizon sublayers.

During the growing season, a bar is displayed next to the soil depth column which represents the respective root depth for the day.

To accommodate soil profiles with many sublayers, the screen will be placed in 80x50 (VGA) or 80x43 (EGA) text display mode if supported by your video graphics card.

Runtime graphic display

The runtime graphics display will graph specified daily computed variables. The graphs displayed here are intended to be used only for general evaluation of the simulation run. Daily variables may be selected for output to a file in a format suitable for importation to a spreadsheet or charting program using the report generator.

While the simulation is running, the graphed variables can be turned on or off by pressing the respective keys on the keyboard as shown on the screen. A check mark indicates the active graphs. The following keys are also active during the simulation run:
Return Toggle the graphics display on/off.
Esc Abort the simulation run and exit the program.
Pause Pause the simulation display.
Space Pause the simulation run.

While the simulation is paused, graphs may be toggled on/off.

The current graph selections are saved and automatically loaded the next time the simulation is run.

The graphed variables are displayed on three viewport graphs on the screen: one for atmospheric conditions, one for biophysics, and a special graph showing plant available water distribution throughout the soil layer. Each pixel along the horizontal axis marks a daily time step. Between the atmospheric and crop status graphs is a bar with alternating shades of gray indicating the months of the year. The start of phenologic growth stages will be marked in the month bar with colored vertical lines that will appear in the following order:

- [P] Planting
- [E] Emergence
- [F] Flowering
- [S] Senescence
- [M] Maturity

**Atmospheric conditions graph**

The atmospheric conditions graph is located at the top of the screen.

- Average daily temperature
- Actual evapotranspiration
- Potential evapotranspiration
- Precipitation
- Runoff
- Actual transpiration
- Potential transpiration

The legend for the atmospheric conditions graph is located in the upper right corner of the screen. The legend shows the key to be pressed to toggle the graph display on/off, the name of the variable, and the scale of the variable. The scale of a variable is not adjusted to that of the other variables in the graph, however similar variables are scaled the same (potential and actual evapotranspiration, for example).

**Crop status graph**

The status graph is located in the center of the screen.

- Plant height
- Biomass
- Leaf area index
- Green area index
- Total stress
- Nitrogen stress
- Light stress
- Water stress
- Temperature stress

The legend for the crop status graph is located in the lower right hand corner of the screen.

**Plant Available Water graph**

The plant available water graph is a novel way of presenting information on the water content of the soil. A horizontal bar is displayed for each layer of the soil with respect to the thickness of the soil layer. For internal computation processes, soil layers which are greater than 10 cm are subdivided into sublayers which are less than or equal to 10 cm. These sublayers will be displayed in the graph, and in a graduated color scale. White horizontal lines delineate 10cm intervals. The scale is located above the crop status graph legend. The soil layers are displayed from top to bottom, with the top layer being the layer of evaporation. Under typical climatic conditions, the evaporative layer will vary dramatically in color, whereas the other soil layers will tend to dry out gradually during the growing season, and gradually recharge between cropping cycles.

**Plant Available Nitrogen graph**

The plant available nitrogen graph is similar to the plant available water graph; it shows the relative quantity of nitrogen (both in the form of ammonium and nitrate).

As with the water graph, a horizontal bar is displayed for each layer of the soil with respect to the thickness of the soil layer. White horizontal lines delineate 10cm intervals.

Only one soil profile graph can be displayed at a time. To switch between drawing the water and the nitrogen graph, press the next letter greater than the last letter displayed in the crop status graph (Q).

Under typical conditions, the amount of nitrogen will decrease as the plant grows, and will increase as organic matter in the soil profile denatures. Nitrogen will also gradually move into deeper soil layers as water from rain and irrigation flushed through the soil profile.

**Growth stage**

For each day, the date, the crop rotation, the growing degree days, the current crop name, and the growth stage are displayed at the right side of the screen. During fallow periods, the crop name is replaced by a (-) marker. Fallow periods may either be Post-Harvest' or Preplanting'. Preplanting fallow indicates that the simulation is ready to plant a crop, but is waiting for adequate planting conditions. (Crop computed planting day mode forecasts the weather for the next five days.)

**Harvest totals**

On harvest dates, the year of the harvest, the crop name, the yield, the biomass at harvest, soil leaching
and erosion are displayed on the right side of the screen. Only the last seven years remain on the screen. These values are all recorded in yearly and/or harvest output files in a format suitable for importation into a spreadsheet or graph program.

32 bit console mode

A 32bit console mode version of CropSyst may also be provided in the CropSyst Suite distribution. This is the same version as the 16bit version but compiled using Delphi as a Windows or Windows NT console mode application. This version does not provide run time graphics or soil profile display modes, only the simple text with harvest summary mode. Since the program is a 32bit mode with the slower display modes removed, this version of the simulation can run much faster than the 16bit version.

This program can be run in and DOS mode window using the following command line

CS_D_32 PARAMA.SIM REPORTQ.FMT

You can also select the CS_D_32.EXE program as the default simulation model to be run by the Windows CropSyst parameter editor by selecting the program in the Simulation/Options menu.

Caveats

Note that the CROPSYST.EXE and CS_D_32.EXE versions of CropSyst written in Pascal/Delphi are no longer being maintained with the new features which are being added to the new C++ version of the model and may produce slightly different results.
CropSyst provides facilities for specifying the following management practices: tillage, residue, irrigation, nitrogen, clipping and soil conservation. The user may specify automatic and/or specific management events.

The management entry forms consist of several sections for each type of management.

Harvest
Irrigation
Nitrogen
Clipping
Conservation
Tillage

Actual calendar date, relative date or phenologic synchronization

A number of management events or automatic selections allow date scheduling to be specified with actual dates, relative dates, or dates computed by the model with respect to phenologic stage of plant development. (the last option is available in most, but not all options)

For actual dates, enter the year and day the event is to occur. Actual events are applied only once during the simulation. Actual dates are used when running CropSyst to compare against actual field experiments or real data.

In relative date mode, the year value corresponds to the year relative to planting. The relative year is added to the crop planting year to derive the actual date the event is to occur. Since the relative year is added to the planting date year to derive the actual year, use a value of 0 for the relative year to indicate the day is in the same year as the planting date, -1 etc. to indicate the year(s) before planting and 1 ect. to indicate years after planting. Relative dates are often used when running crop and management rotations that are repeated.

For dates computed relative to plant development mile stones; the user can specify the number of days before planting , after planting, after emergence, after flowering, after the start of senescence, after the point of maturity, or after harvest. This mode is usually used when running CropSyst for prediction scenarios.

Note that for relative dates or days before the planting date, the date refers to the expected date of planting, not the actual date if the planting date is computed or postponed by CropSyst.
Automatic management

With automatic management, the simulation will apply management practices whenever appropriate (based on the current conditions). Automatic management options should be used when the user is not concerned with the effects of management on the simulation run, but still wants reasonable management practices to be applied; or, if the user wishes CropSyst to apply water or nitrogen.

Specific management

In addition to or in lieu of automatic management, the user may create tables of specific management events. The specific events tables allows the user to create a customized event schedule of irrigation, tillage, fertilization, clipping and residue stubble management practices.

To add a new event, click on the button corresponding to the event to be added. A dialog will open in which the user may specify when the event is to be applied. Additional windows may be presented allowing the user to choose the specific operation to be performed and any additional parameters for the operation. The management event schedule table is then updated with these practice parameters.
To delete an entry in the table, select the entry to be removed and click on the [Delete] button.

To edit an entry, double click on the entry. A date/phenologic synchronization button is provided in each of the event parameter editors to allow the date to be changed.

**Annual management**

Management events with specific dates are loaded when the simulation starts. In some simulation scenarios such as daily center pivot irrigation, there may be dozens or hundreds of dated events. If the simulation rotation runs for many years, all these events can slow down the program which continuously scans the event lists for the next event to process. In the DOS version of the program all these events can possibly exceed the memory capacity. Additionally, the large event files can be difficult to keep organized. To help eliviate these problems, the specific management events can be stored in separate files organized by year.

- create a subdirectory in the same directory as the simulation the mangement file will be used in, having the same name as the simulation file, without the extension.
- Put the separate management files in this directory.
- Name these management files will the year the specific managements event occur in. (I.e. 1999.MGT).
- CropSyst will load these management events in these files when the simulation reaches each year.

Note that only the specific management events with actual dates will be loaded in the manner, all other parameters (I.e. automatic management) are ignored. Some CropSyst scenario building utilities create these management files. (I.e. the center pivot irrigation optimizer).

These annual managements are loaded in addition to any other specific management events that may be applied with the crop in a rotation; so this is also a convenient way to supplement relative dated events in a repeated rotation with events specific for certain years.
Harvest management

Number of days to wait for harvest after physiological maturity

The user may specify the number of days after physiological maturity that the crop will be harvested.

Latest date to harvest

Under certain conditions, particularly with perennial crops, a crop might not achieve thermal time to reach full maturity which triggers harvest. This date will force the crop to be harvested on this date if not already done.

The year of the date specifies the year of the crop. For (spring) crops that complete between
January and December the year will usually be 0. For crops that grow past December, and harvest in the following year, the harvest date year will be 1. For perennial crops, this can be used to perform a final harvest at the end of the growing season, before leaf drop.

**Fraction (percentage) of straw remaining after harvest**

This is the portion of non-grain or non-harvested biomass that is to remain in the field after harvest.

This biomass will later be incorporated into the soil by tillage operations etc..

*Note that this used to be a crop parameter "Fraction of non-grain biomass -> surface residue (0-1)"

These harvest parameters are not used by perennial crops.
Irrigation

The **Automatic irrigation** check box enables automatic irrigation.

Automatic irrigation will apply sufficient water to bring the water content of the soil to a level such that the plant available water (PAW) is refilled to the specified amount (usually around 100%) whenever the plant available water falls below a specified amount (usually around 40%).

Currently, the water is applied directly to the soil. It does not affect canopy or residue storage or runoff or ponding.

The user must specify the 'Minimum allowable plant available water' before irrigation is triggered, and the plant available water refill point (expressed as decimal numbers between 0 and 1). The minimum PAW must be less than the refill PAW. The minimum PAW does not need to be
specified if automatic irrigation is not used, however the refill PAW may be used in a special case of specified irrigation events and should always be specified if irrigation events are used.

The automatic irrigation during fallow periods option allows the simulation to irrigation even when to crop is growing. The default behaviour is to irrigate only during the growing season.

**Maximum allowable depletion**

This is the plant available water computed to the depletion observation depth that will trigger an irrigation event.

**Depletion observation depth**

This is the depth to which the plant available water will be computed for the depletion constraint.

**Net irrigation multiplier**

This value will be multiplied by the irrigation amount determined. A non-zero value can be used to specify the efficiency.

**Maximum irrigation application**

This will limit the actual irrigation that can be applied. This can be used to simulate the physical mechanical hydraulic limitations of the irrigation equipment.

**Irrigation period (starting and ending dates)**

This is the period to limit the irrigation to. Actual or relative dates or plant development times can be used to specify the irrigation period.

In the case of perennial crops, the year part of the date is used to limit the years irrigation occurs. The month/day is used to indicate the day in each year irrigation starts and stops respectively.

**Specific irrigation events**

For an irrigation event, the user supplies an amount of water (in millimeters) that is to be applied. If a value of zero is entered, the simulation will determine the amount of water that would recharge the soil to the refill PAW point.

The specific irrigation events which have selected "Use general automatic irrigation constraints" option will use the parameters specified on this screen to determine the amount of irrigation to apply.
Automatic clipping is used to allow the simulation to determine when and how much biomass to be removed from the crop.

Events specified in the clipping events table are not affected by any of the automatic clipping modes. Any specific clipping events will always be processed.

Three options are available for automatic clipping simulation.

**Disabled (default)**

This option disables automatic clipping.
Based on biomass

In this mode, clipping events will be performed when the biomass reaches the specified level. This mode is usually used for perennial crops such as alfalfa. A clipping event will occur if either of the following conditions are met:

- If the current crop biomass reached the maximum biomass that forces clipping, the crop will always be harvested.
- The simulation will count the number of days of consecutive low growth. If at any time the crop resumes normal growth, this counter is reset. Low Green Area Index (GAI) growth is characterized by the following condition:
  - The daily GAI ≤ low GAI rate * Clipping relative growth rate adjustment

If the count of consecutive days of low growth reaches 14 days, the crop will be harvested.

- An additional special case will force clipping to occur if the crop has not reached the specified biomass but it is the end of the growing season. This case applies to perennial crops such as alfalfa.

The following parameters are required for this option:

**Clipping relative growth rate adjustment (0-2)**

This parameter is used to adjust what is considered a low green area index growth rate (start of with a value of 1). Increasing this number will increase clipping frequency.

**Minimum biomass required for clipping (kg/ha)**

This specifies the amount of biomass that must be produced before clipping will occur (in normal growing conditions).

**Maximum biomass that forces clipping (kg/ha)**

This specifies the amount of biomass that will always trigger a clipping event.

**Percent biomass to remove (0-100%)**

This is the amount of biomass to remove. See clipping fate to specify what to do with the clipped biomass.

**Latest date to clip**

For perennial crops, towards the end of the growing season, biomass and leaf/green area production diminishes and might not reach a levels sufficient to trigger a clipping event; however, farmers will typically perform one last harvest of available material.
before the onset of dormancy and leaf drop. This date is used to simulate this special case. This event will occur only if the minimum amount of biomass required to cip has been reached.

Periodic

In this option, clipping will be performed with a specified interval.

The percentage of biomass to remove is specified by the user as a harvest index crop parameter.

This mode is usually used for perennial crops such as tea.

A clipping event will occur if the following conditions are met:

- The perennial crop will count the number of days since the last clipping event. Clipping will not be performed until this count reaches the clipping frequency days.
- The LAI must be is greater than the minimum LAI required for clipping.
- The current date is within the clipping period.

The following parameters are required for this option:

**Frequency (days)**

This is the number of days this simulation should wait after a clipping event before the next clipping event can occur.

**Minimum LAI required for clipping**

During early growth (I.e. after a crop is planted or after any period of dormancy, leaf-drop or die-off) the simulation will allow the crop to reach this specified leaf area index before clipping will be started.

**Clipping period**

A limit of the period of the year where clipping events will be possible may be specified. This can be used to indicate a harvesting season.

If the ending date is a month prior to the starting date, CropSyst will take the period as a growing season for the southern hemisphere.

Use January 1, and December 31 to allow clipping to occur uninterrupted.
Clipping fate

For either the Based on biomass and the Periodic clipping modes, the following options are available for disposing of the clipped biomass:

Remove

This removes the clipped biomass from the system. These clipping events will only be reported in the schedule output file; however biomass reduction can be observed in the daily report.

Harvest litter to the surface

This will collect the clipped biomass and add it as residue. These clipping events will only be reported in the schedule output file; however biomass decrease and residue increase can be observed in the daily report.

Harvest

This creates a yield of the clipped biomass. These clipping events will be reported both in the schedule and as harvest events in the harvest report.

Note that some of the phenologic growth stages are typically not applicable to clipped crops so some of the reported phenologic growth stage dates may be constant or have no value in the harvest report.

Specific clipping events

Clipping events for specific dates can be made. The percent of biomass to be removed is specified.
Soil conservation management

Soil conservation practice factor

The erosion control practice factor (0-1) is similar to that used by the Universal Soil Loss Equation or the revised version RUSLE. When no management is specified in a rotation, CropSyst uses 1.0. A value of 0.0 will prevent erosion. A value of 1.0 will obviate the soil conservation practice factor.

It can be determined as follows (Schwab et al., 1993):

\[ P = P_c \cdot P_s \cdot P_t \]

where

\( P_c \)

is the contouring factor based on slope.
### Contouring factor

<table>
<thead>
<tr>
<th>Land Slope</th>
<th>Pc value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>0.6</td>
</tr>
<tr>
<td>3-5</td>
<td>0.5</td>
</tr>
<tr>
<td>6-8</td>
<td>0.5</td>
</tr>
<tr>
<td>9-12</td>
<td>0.6</td>
</tr>
<tr>
<td>13-16</td>
<td>0.7</td>
</tr>
<tr>
<td>17-20</td>
<td>0.8</td>
</tr>
<tr>
<td>21-25</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Ps is the strip cropping factor for crop strip widths.

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>for contouring only or for alternating strips of corn and small grain.</td>
</tr>
<tr>
<td>0.75</td>
<td>for 4-year rotation with 2 year of row crop.</td>
</tr>
<tr>
<td>0.50</td>
<td>for 1 year of row crop.</td>
</tr>
</tbody>
</table>

Pt is the terrace sedimentation factor.

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>for no terraces.</td>
</tr>
<tr>
<td>0.2</td>
<td>for terraces with graded channel sod outlets.</td>
</tr>
<tr>
<td>0.1</td>
<td>for terraces with underground outlets.</td>
</tr>
</tbody>
</table>

### Land treatment

For runoff computation, `land treatment` must be selected as specified in the *USDA/SCS National Engineering Handbook* (USDA-SCS, 1988a).
Automatic nitrogen fertilization

There are three modes for automatic nitrogen application:

**Optimal N allocated directly to crop tissues**

With this option, the simulation will continuously supply N to the crop to optimize plant growth. The total N supplied is reported in the output report. This mode can be used to help determine crop nitrogen requirements for optimal growth.
Based on nitrogen balance

Need description

Based on local calibration

Need description

**Crop N uptake for target yield**

This parameter is used for the mode based on nitrogen balance.

Need description (kg/ha)

**Critical soil NO3 - N at planting for no response**

This parameter is used for the mode based on local calibration

Need description (kg/ha)

**Soil sampling depth**

This parameter is used for both the the mode based on nitrogen balance and the mode based on local calibration.

Need description

**Fertilizer use efficiency**

This parameter is used for both the the mode based on nitrogen balance and the mode based on local calibration.

Need description

**Specific nitrogen application**

Either organic or inorganic nitrogen applications can be made.

**Inorganic nitrogen application**

For an inorganic nitrogen application event, an amount of nitrate and/or ammonium (in kg/ha of Nitrogen) is specified.
An optional percentage of ammonium volatilization loss at the time of application can be specified, or the volatilization loss can be calculated by CropSyst by specifying the ammonium source and method of application.

![Nitrogen application interface](image)

**Organic nitrogen application**

For an organic nitrogen application event, the amount of ammonium in the form of organic manure check: (in kg/ha of Nitrogen) is specified.

Each organic N application creates a residue pool which decomposes over time very similar to straw and root biomass residue pools which are created when harvest litter is applied to the surface. To simulate the decomposition of the organic matter pool, a decomposition time constant is specified, or this value can be calculated by CropSyst by selecting the source or the organic N.

Organic matter from animal wastes may have an associated amount of ammonia (NH₃) which may additionally be entered. The volatilization loss of this ammonia at application time can be specified, or this value can be calculated by CropSyst by selecting the application method and form of the matter.
### Organic nitrogen applied

**Amount of nitrogen in the form of organic manure**: 40 kg/ha

**Decomposition time constant**: 60 Days

- **Organic N (manure) source**
  - Poultry (layers)
  - Poultry (fresh) broilers or turkeys
  - Poultry (broilers) or turkeys (aged)
  - Dairy (fresh)
  - Dairy (tank storage)
  - Dairy (anaerobic lagoon storage)
  - Beef (fresh)
  - Beef (aged) 2.5% N (dry wt. base)
  - Beef (aged) 1.5% N (dry wt. base)
  - Beef (aged) 1.0% N (dry wt. base)
  - Swine

**Amount of nitrogen in the form of ammonia (NH3)**: 0.000 kg/ha

**Volutilization loss**: 0.000%

- **Application method**
  - Surf. broadcast not incorp.
  - Sprinkler
  - Surf. broadcast (incorp.)
  - Knifed

- **Form**
  - Liquid
  - Solid

**8 Days After emergence**

[OK] [Cancel]
Tillage and residue stubble operations

For a tillage or residue stubble operation, over eighty tillage practices are available. Tillage and residue operation lists are grouped by 'Primary tillage', 'Secondary tillage', 'Conventional tillage', 'No till', and 'Residue operations'. Tillage affects residue incorporation. The extent of these effects were taken from the Tillage operation table provided by the USDA Soil Conservation Service (Spokane, WA office).

If a tillage practice is not listed in the tillage practices table, select a practice that has similar residue incorporation characteristics.

Additionally, tillage affects surface roughness for surface water storage.
## Tillage operations

### Primary tillage operations

<table>
<thead>
<tr>
<th>SCS Code</th>
<th>Description</th>
<th>Surface residue</th>
<th>Shallow residue</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Combination chisel-disc</td>
<td>65</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>Chisel-straight</td>
<td>70</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>101</td>
<td>Chisel 24&quot; spacing</td>
<td>75</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>125</td>
<td>Chisel-straight 18&quot; spacing w/legume</td>
<td>35</td>
<td>55</td>
<td>7</td>
</tr>
<tr>
<td>126</td>
<td>Chisel-straight 24&quot; spacing w/legume</td>
<td>40</td>
<td>50</td>
<td>7</td>
</tr>
<tr>
<td>127</td>
<td>Chisel-twisted 18&quot; spacing w/legume</td>
<td>25</td>
<td>65</td>
<td>8</td>
</tr>
<tr>
<td>128</td>
<td>Chisel-twisted 24&quot; spacing w/legume</td>
<td>30</td>
<td>60</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>Chisel-twisted 18&quot; spacing</td>
<td>50</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>102</td>
<td>Chisel-twisted 24&quot; spacing</td>
<td>55</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>Chisel-following stubble</td>
<td>35</td>
<td>55</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>Disc plow-deep</td>
<td>40</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>Disc plow-shallow</td>
<td>60</td>
<td>35</td>
<td>7</td>
</tr>
<tr>
<td>16</td>
<td>Moldboard uphill furrow slice</td>
<td>40</td>
<td>30</td>
<td>8</td>
</tr>
<tr>
<td>17</td>
<td>Moldboard plow early slow or shallow</td>
<td>25</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>Moldboard plow-mod. depth &amp; speed</td>
<td>10</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>19</td>
<td>Moldboard plow-late fast, deep</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>28</td>
<td>Moldboard any plow (follow flail)</td>
<td>5</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>21</td>
<td>Subsoil 48&quot; spacing</td>
<td>85</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>106</td>
<td>Subsoil 36&quot; spacing</td>
<td>85</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>22</td>
<td>Heavy disk with legume any depth</td>
<td>15</td>
<td>80</td>
<td>9</td>
</tr>
<tr>
<td>23</td>
<td>Regular sweep</td>
<td>80</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>24</td>
<td>Wide blade-sweep (towner or noble)</td>
<td>90</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>107</td>
<td>Landlord 30&quot; spacing</td>
<td>70</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>108</td>
<td>Landlord 40&quot; spacing</td>
<td>75</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>109</td>
<td>Paraplow</td>
<td>95</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>20</td>
<td>Regular offset disc</td>
<td>55</td>
<td>30</td>
<td>9</td>
</tr>
<tr>
<td>27</td>
<td>Regular offset with legume</td>
<td>15</td>
<td>80</td>
<td>11</td>
</tr>
<tr>
<td>103</td>
<td>Irrigated soil moist</td>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>104</td>
<td>Irrigated soil optimum</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Secondary tillage operations
(first operation after moldboard)

<table>
<thead>
<tr>
<th>SCS Code</th>
<th>Description</th>
<th>Surface residue</th>
<th>Shallow residue</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>Disc harrow-light 1-10cm</td>
<td>60</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td>26</td>
<td>Disc harrow w/legume</td>
<td>30</td>
<td>65</td>
<td>10</td>
</tr>
<tr>
<td>32</td>
<td>Field cultivator</td>
<td>85</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>Field cultivator *</td>
<td>95</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>130</td>
<td>Field cultivator w/legume</td>
<td>45</td>
<td>55</td>
<td>10</td>
</tr>
<tr>
<td>36</td>
<td>Rod weeder with sweeps or chisel</td>
<td>85</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>46</td>
<td>Rod weeder with sweeps or chisel *</td>
<td>95</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>37</td>
<td>Rod weeder plain</td>
<td>90</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>47</td>
<td>Rod weeder plain *</td>
<td>100</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>34</td>
<td>Rotary hoe or cultivator</td>
<td>75</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>31</td>
<td>Rotary tiller</td>
<td>30</td>
<td>50</td>
<td>17</td>
</tr>
<tr>
<td>38</td>
<td>Spike harrow-10 bar</td>
<td>80</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>48</td>
<td>Spike harrow-10 bar *</td>
<td>90</td>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>29</td>
<td>Skew treader backward</td>
<td>80</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>30</td>
<td>Skew treader forward</td>
<td>70</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>43</td>
<td>Spike harrow-5 bar</td>
<td>90</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>56</td>
<td>Spike harrow-5 bar *</td>
<td>100</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>35</td>
<td>Spring tooth cultivator</td>
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<tr>
<td>45</td>
<td>Spring tooth cultivator *</td>
<td>95</td>
<td>0</td>
<td>18</td>
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<tr>
<td>110</td>
<td>Swedish harrow</td>
<td>90</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>49</td>
<td>Tandem-any spike or tine-3 bar</td>
<td>95</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>44</td>
<td>Tine harrow-5 bar</td>
<td>90</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>58</td>
<td>Tine harrow-5 bar *</td>
<td>100</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>39</td>
<td>Tine harrow-10 bar</td>
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<td>14</td>
</tr>
<tr>
<td>57</td>
<td>Tine harrow-10 bar *</td>
<td>95</td>
<td>5</td>
<td>18</td>
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<tr>
<td>87</td>
<td>Seedbed marker</td>
<td>85</td>
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</table>

### Planting operations (dry)
<table>
<thead>
<tr>
<th>SCS Code</th>
<th>Description</th>
<th>Surface residue</th>
<th>Shallow residue</th>
<th>Group</th>
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</thead>
<tbody>
<tr>
<td>50</td>
<td>Semi-deep furrow drill</td>
<td>85</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>51</td>
<td>Deep furrow drill</td>
<td>80</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>52</td>
<td>Hoe drill</td>
<td>80</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>53</td>
<td>Double disc drill-7 inch</td>
<td>90</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>54</td>
<td>Air seeder-chisel type</td>
<td>70</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>55</td>
<td>Air duck foot</td>
<td>60</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>59</td>
<td>Heavy double disc-legume</td>
<td>30</td>
<td>70</td>
<td>11</td>
</tr>
<tr>
<td>85</td>
<td>Aerial seeding</td>
<td>100</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>86</td>
<td>Brillion seeder</td>
<td>100</td>
<td>0</td>
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</tbody>
</table>

**Planting operations (irrigated)**  
(* Following strip tillage*)

<table>
<thead>
<tr>
<th>SCS Code</th>
<th>Description</th>
<th>Surface residue</th>
<th>Shallow residue</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>112</td>
<td>Corn planter</td>
<td>95</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>132</td>
<td>Corn planter *</td>
<td>90</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>113</td>
<td>Onion planter</td>
<td>75</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>133</td>
<td>Onion planter *</td>
<td>70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>114</td>
<td>Potato planter</td>
<td>60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>134</td>
<td>Potato planter *</td>
<td>55</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>115</td>
<td>Vegetable seed planter</td>
<td>90</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>135</td>
<td>Vegetable seed planter *</td>
<td>85</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Planting no-till drill operations**

<table>
<thead>
<tr>
<th>SCS Code</th>
<th>Description</th>
<th>Surface residue</th>
<th>Shallow residue</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>Chisel point or hoe opener</td>
<td>65</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td>60</td>
<td>Light double disc drill</td>
<td>75</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>116</td>
<td>Light double disc irrig.33&quot;</td>
<td>90</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>117</td>
<td>Light double disc 36&quot; sp</td>
<td>95</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>61</td>
<td>Heavy double disc drill</td>
<td>60</td>
<td>40</td>
<td>11</td>
</tr>
<tr>
<td>59</td>
<td>Heavy double disc w/legume residue</td>
<td>30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>64</td>
<td>Heavy double disc w/grain residue</td>
<td>45</td>
<td>55</td>
<td>11</td>
</tr>
<tr>
<td>118</td>
<td>Heavy double disc irrig. 33&quot;</td>
<td>80</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SCS Code</td>
<td>Description</td>
<td>Surface residue</td>
<td>Shallow residue</td>
<td>Group</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-------</td>
</tr>
<tr>
<td>119</td>
<td>Heavy double disc irrig. 36&quot;</td>
<td>85</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>120</td>
<td>Heavy double disc w/corn residue 36&quot;</td>
<td>75</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>62</td>
<td>Heavy double disc w/scuffer</td>
<td>50</td>
<td>50</td>
<td>12</td>
</tr>
<tr>
<td>65</td>
<td>Heavy double disc w/grain residue</td>
<td>45</td>
<td>55</td>
<td>12</td>
</tr>
<tr>
<td>66</td>
<td>Heavy double disc w/legume residue</td>
<td>30</td>
<td>70</td>
<td>12</td>
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<td>77</td>
<td>No till drill 1</td>
<td>90</td>
<td>10</td>
<td>18</td>
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<tr>
<td>78</td>
<td>No till drill 2</td>
<td>75</td>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>

### Residue manipulation operations

<table>
<thead>
<tr>
<th>SCS Code</th>
<th>Description</th>
<th>Surface residue</th>
<th>Shallow residue</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>Stubble flail,chop,bust</td>
<td>100</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>81</td>
<td>Stubble grazing</td>
<td>65</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>82</td>
<td>Stubble baling</td>
<td>35</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>83</td>
<td>Stubble burning</td>
<td>10</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>100</td>
<td>Corn stubble grazing</td>
<td>50</td>
<td>0</td>
<td>18</td>
</tr>
</tbody>
</table>
Crop parameter editor

The crop parameters are probably the most sensitive set of parameters the simulation responds to. It is most important to carefully select these parameters. Do not rely too heavily on the default values.

The crop parameter editor consists contain several pages of parameters grouped by function.

- **Description and classification**
- **Planting**
- **Growth**
- **Morphology**
- **Phenology**
- **Vernalization**
- **Photoperiod**
- **Harvest**
- **Residue**
- **Nitrogen**
- **Salinity**
- **CO₂**
- **Dormancy**

Click on the name of the parameter group in the list box to display the corresponding page of parameters.

Some parameters apply only to certain types of crops. For example, dormancy parameters apply only to perennial crops. Parameters such as those for Nitrogen, Salinity and CO₂ may be left to default values if they are not to be simulated. (For example, if nitrogen simulation will be disabled in the simulation control).

Whenever applicable, crop parameter values refer to a crop without stress.

When first entering parameters for a new crop, each page of parameters should be entered in sequence because some selections may enable or disable parameters in following pages.

In DOS version of CropSyst, when creating a new crop parameter file, the user was first prompted to select one of several crop classes which set up the parameters available to the specified crop class.

In the Windows version, the selection of parameters optional for various types of crops are selected with check boxes on the parameter pages. For example, for crops that respond to vernalization, a checkbox on the vernalization page will enable the vernalization parameters. This allows a convenient way to quickly change general simulated crop characteristics.
Crop classification

The first parameter page allows selection of some basic classification and simulation options for the Crop.

Description

The description is usually only informational.

When using advanced simulation options and analysis tools such as the Arc Coöperator, the description is used to separate different crop harvest data. It is therefore necessary that an entry be the description field unique for the crop.

Default values

A small database of default values for a number of common crops are provided. Click on the combo box and select a crop. Click on the [Load defaults] button to load the default values. This will replay all current parameters with default values, so this button should only be used when initially creating a new crop.

Land use

For runoff simulation using the SCS curve number method, land use must be selected. During fallow periods, the simulation automatically reverts to fallow land use runoff curve numbers as specified in the USDA/SCS National Engineering Handbook (USDA-SCS, 1988a).
Photosynthetic pathway

This parameter affects.....

Table xxx identifies photosynthetic species of several common crops.

Perennial

Perennial should be selected for crops such as alfalfa and tea. Dormancy parameters should be provided for perennial crops.

This selection will enable perennial crop simulation.
Crop planting parameters

Crop planting parameter window

Planting mode

Crop planting may either be in a fixed planting date mode or a computed planting date mode.

With the fixed planting date mode, the crop will be planted based on the date specified in the crop rotation cycle in the simulation control rotation table.

With the computed planting date mode, the crop will be planted based on two input parameters: the temperature for a 5-day window and the soil water content specified as plant available water required for planting. The model will search for suitable planting conditions from the date specified in the crop rotation table.

Information source:

- The temperature threshold is found by correlating air temperature and the time when farmers actually plant their crops.
- Information from the literature can also be used.
- The required water content of the top soil layer is found by determining the minimum water content that farmers will tolerate when planting.
Crop growth

Crop growth parameters define the crop sensitivity to environmental conditions.

Biomass-transpiration coefficient

This value represents the above ground biomass production per meter of transpiration under given conditions of atmospheric vapor density deficit (3.0-9.0 ((kg/m²) . kPa)/m).

Information Source:
- Experimental data.
- Literature.
- Suggested values for C₃ and C₄ crop species are given in the following table.

<table>
<thead>
<tr>
<th>C₃ species crop</th>
<th>Biomass transpiration coefficient ((kg/m²)kPa)/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td></td>
</tr>
<tr>
<td>Beans (dry)</td>
<td></td>
</tr>
<tr>
<td>Lentils</td>
<td></td>
</tr>
<tr>
<td>Oats</td>
<td></td>
</tr>
<tr>
<td>Peas (dry)</td>
<td>3.5 - 6.0</td>
</tr>
</tbody>
</table>
The following table lists some suggested values for a few common crops.

<table>
<thead>
<tr>
<th>C₄ species crop</th>
<th>Biomass transpiration coefficient ((kg/m²)kPa)/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize (corn)</td>
<td>6.0 - 8.5</td>
</tr>
<tr>
<td>Sorghum</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C₃ species crop</th>
<th>Light to biomass conversion (g/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>2.3 - 2.7</td>
</tr>
<tr>
<td>Lentils</td>
<td>2.0 - 2.5</td>
</tr>
<tr>
<td>Oats</td>
<td>2.3 - 2.7</td>
</tr>
<tr>
<td>Peas</td>
<td>2.0 - 2.5</td>
</tr>
<tr>
<td>Rye</td>
<td>2.3 - 2.7</td>
</tr>
<tr>
<td>Soybean</td>
<td>2.0 - 2.5</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.0 - 3.0</td>
</tr>
<tr>
<td>Grass (cropped)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Uses:**
- Calculation of transpiration-based above ground biomass production.

**Light to biomass conversion**

This value represents the above ground biomass production per unit of light intercepted by the crop canopy (1-5 g/MJ).

**Information Source:**
- Experimental data.
- Literature.
- Some suggested values for a few common crops are listed in the following table.
<table>
<thead>
<tr>
<th>C4 species crop</th>
<th>Light to biomass conversion (g/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize (corn)</td>
<td>3.5 - 4.0</td>
</tr>
<tr>
<td>Sorghum</td>
<td>3.5 - 4.0</td>
</tr>
<tr>
<td>Sunflower</td>
<td>3.0 - 4.0</td>
</tr>
</tbody>
</table>

Uses:
- Calculation of radiation/light-based above ground biomass production.

**AT/PT ratio where leaf area growth ceases**

The ratio of actual transpiration to potential transpiration at which leaf elongation is expected to stop. The ratio is represented by a number between 0 and 1.

**Information Source:**
- Experimental data.
- Literature.

Uses:
- Stress threshold affecting the above ground biomass-leaf area index relation.

**AT/PT ratio where root growth ceases**

The ratio of actual to potential transpiration at which root proliferation is expected to stop. The ratio is represented by a number between 0 and 1.

**Information Source:**
- Experimental data.
- Literature.

Uses:
- Stress threshold determining actual root penetration.

**Temperature below which growth rate is reduced**

Temperature effects are usually included in the empirical determination of the light to biomass conversion input parameter, which is normally estimated during the linear phase of crop growth. However, during early growth (before or at the beginning of the linear growth phase), cool weather may affect growth which is not accounted for. The optimum temperature for growth is the temperature above which growth (as accounted for by the light to biomass conversion input parameter) will not be affected.

*This parameter used to be called "Optimum temperature for growth"*
Thermal time to cease temperature limitation

The growing degree days thermal time (C-days) at which temperature limitation is no longer applied in the computation of radiation-dependent growth. A value of 0.0 may be entered to disable temperature limitation.

This parameter used to be called "Thermal time at which temperature limitation ceases"

Maximum water uptake

This is the maximum water uptake (7-13 mm/day) for a fully developed green crop, completely covering the ground, unstressed, fully watered, with unrestricted root growth, and under environmental conditions providing large atmospheric evaporative demand.

Information source:
- Experimental data.
- Literature.
- If typical evapotranspiration (ET) rates during full canopy are known for the region, this value can be obtained from the maximum water uptake tables. Under most circumstances, typical peak ET rates can be sustained when plant available water in the soil are above a specified threshold which is crop dependent according to the Limiting PAW table. Lower boundary values in this table correspond to humid climates, while upper boundary values should be used for arid climates. Select in the table your estimated typical ET rate, and run to the right of the table to find the appropriate limiting PAW for your regional cultivar from the Limiting PAW table, and then record the corresponding value of maximum uptake rate.

<table>
<thead>
<tr>
<th>Water Stress Sensitivity</th>
<th>Crops</th>
<th>PAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Wheat</td>
<td>0.25-0.35</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sorghum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oats</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>Corn</td>
<td>0.35-0.45</td>
</tr>
<tr>
<td></td>
<td>Sunflower</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soybean</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beans</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Potatoes</td>
<td>0.50-0.65</td>
</tr>
<tr>
<td></td>
<td>Tomatoes</td>
<td></td>
</tr>
</tbody>
</table>
**Critical leaf water potential**

This is the leaf water potential just before the beginning of stomatal closure due to water deficit (J/kg).

**Information source:**
- Experimental data.
- Literature.
- Typical values of this parameter are given in the Leaf water potentials table.
- Lower and upper boundaries apply to humid and arid environments, respectively.

**Uses:**
- Actual transpiration.

**Wilting leaf water potential**

This is the leaf (and soil) water potential at the point when the crop can no longer extract water from the soil (J/kg).

**Information source:**
- Experimental data.
- Literature.
- Lower and upper boundaries apply to humid and arid environments, respectively.
- Typical values of this parameter are given in the following Leaf water potentials table.

**Leaf water potentials**

<table>
<thead>
<tr>
<th>Water Stress Sensitivity</th>
<th>Crops</th>
<th>Critical J/kg</th>
<th>Perm. Wilt J/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Wheat</td>
<td>-1,330 to -2,000</td>
<td>-2,000 to -3,000</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sorghum</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oats</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>Corn</td>
<td>-930 to -1,200</td>
<td>-1,400 to -1,800</td>
</tr>
<tr>
<td></td>
<td>Sunflower</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peas</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Soybean</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Beans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Potatoes</td>
<td>-670 to -800</td>
<td>-1,000 to -1,200</td>
</tr>
<tr>
<td></td>
<td>Tomatoes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Uses:**
Actual transpiration.
The depth of the roots measured in meters from the soil surface when the plant reaches the end of vegetative growth (beginning of senescence).

**Information Source:**
- Empirical measurements.
- Observed water extraction patterns.
- Root depths for some common crops are given in the [Crop morphology parameters table](#).
- Maximum root depth may be higher than values suggested here under very favorable conditions, or lower under restricted conditions. Local experience must be used for proper parameter selection.
- The literature.

**Uses:**
- Current root depth as a function of plant development.
- Soil water uptake in soil layers penetrated by the roots (section).
- Water drainage as any water passing the potential root zone in the Cascade and Finite Difference infiltration models.
- Current root density distribution in soil layers as a linear function of root depth.
Maximum leaf area index (LAI)

The leaf area index at the end of vegetative growth (m²/m²).

**Information Source:**
- Experimental data.
- Literature.
- Some values for common crops are given in the [Crop morphology parameters table](#).

**Uses:**
- [Daily leaf area index](#).
- [Light interception by the crop canopy](#).

Fraction of maximum Leaf Area Index at physiological maturity

This corresponds to the total canopy leaf area index (senescent plus green leaves), expressed as a fraction of peak leaf area index, that the crop has and which shades the soil at physiological maturity (0-1).

**Information Source:**
- Based on local experience.

**Uses:**
- [Leaf Area Index at maturity](#).

Specific leaf area

This corresponds to the leaf area per unit of leaf biomass. It is used to determine the amount of green area index produced in a day. Values of SLA usually range between 15 and 25 (m²/kg) but they must be determined empirically.

[See the equation for daily green area index.](#)

Leaf/stem partition

This parameter adjusts the proportion of cumulative biomass that is partitioned to green leaf area production as the crop accumulates biomass during the active growth stage. It is used to determine the amount of green area index produced in a day. Values for LeafStemPart may range between 1 and 10 (m²/kg).

[See the equation for daily green area index.](#)

Leaf duration (deg-days)

This corresponds to the degree-days elapsed between the appearance and senescence of new green area index. Values range from 700 to 1000 C-days.
See the equation for daily green area index.

**Leaf duration sensitivity to water stress**

This parameter affects the accumulation of thermal time during the life time of green area, accelerating the daily accumulation of degree days as water stress increases. Typical range of fluctuation for GAI sensitivity is from 1 (no effect) to about 3.

See the equation for daily green area index.

**Extinction coefficient for solar radiation**

This coefficient depends on the canopy structure and determines the ability of a canopy of a given LAI to intercept solar radiation. Its value is about 0.35-0.4 for canopies with vertical tendency, 0.4-0.5 for canopies with random (spherical) leaf angle distribution, 0.5-0.6 for canopies with horizontal tendencies, and 0.55-0.65 for heliotropic crops (sunflower).

**Information Source:** Literature.

**Uses:** Computing the fraction of incident solar radiation intercepted by the canopy.

**ET crop coefficient at full canopy**

This value represents the ratio of unstressed crop ET to reference (short grass) ET when the crop has developed a full canopy.

**Information Source:**
- Experimental data.
- Literature.

**Uses:**
- Determination of crop maximum ET rate in equation.

**Crop morphology constants**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Max. root depth (m)</th>
<th>Max. LAI (m²/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley (Spring)</td>
<td>1.2-1.6</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Beans (Dry)</td>
<td>0.9-1.3</td>
<td>3 - 4</td>
</tr>
<tr>
<td>Lentils</td>
<td>0.9-1.3</td>
<td>3 - 4</td>
</tr>
<tr>
<td>Maize</td>
<td>1.5-2.0</td>
<td>4 - 7</td>
</tr>
<tr>
<td>Oats</td>
<td>1.2-1.6</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Peas (Dry)</td>
<td>0.9-1.3</td>
<td>3 - 4</td>
</tr>
<tr>
<td>Sorghum</td>
<td>1.4-1.8</td>
<td>6 - 10</td>
</tr>
<tr>
<td>Crop Type</td>
<td>Value Range</td>
<td>Season Range</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Soybean</td>
<td>1.4-1.8</td>
<td>4 - 7</td>
</tr>
<tr>
<td>Sunflower</td>
<td>1.7-2.2</td>
<td>4 - 5</td>
</tr>
<tr>
<td>Wheat (spring)</td>
<td>1.2-1.6</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Wheat (winter)</td>
<td>1.5-2.0</td>
<td>5 - 8</td>
</tr>
<tr>
<td>Grass (cropped)</td>
<td>0.8</td>
<td>4.0</td>
</tr>
</tbody>
</table>
Crop phenology

Crop development in CropSyst is based on thermal time. The thermal time (degree days) required for each of the phenologic stages of development must be specified. Degree days are accumulated from planting. Depending on crop type, certain growth characteristics are relevant: emergence, tuber initiation, beginning of flowering, peak LAI, end of flowering, beginning of grain filling, and physiological maturity.

### Crop phenology window

**Phenologic growth stages thermal time requirements**

Peak LAI occurs near flowering depending on the type of crop:

- grain crops before beginning flowering
- grain legumes beginning of grain filling
- root crops after beginning of flowering

<table>
<thead>
<tr>
<th>Phenologic stage</th>
<th>Grains crops (non-legumes)</th>
<th>Grain legumes</th>
<th>Root crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>emergence</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>tuber initiation</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>beginning of flowering</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>peak LAI</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>end of flowering</td>
<td>-</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
### Base and Cutoff temperatures

The base and cutoff temperatures for the computation of elapsed degree-days must also be specified. These numbers may vary depending on location and cultivar.

**Information source:**
- Growing degree days (thermal time) can be empirically determined as follows:
  1. Identify the dates the plant reaches each phenologic stage.
  2. From literature, choose a base thermal time temperature and a cutoff temperature adequate for the crop species. These are temperatures below and above which thermal time does not accumulate.
  3. Starting from the planting date, accumulate the daily degree days.
  4. The thermal time the plant reaches a growth stage is the accumulated daily degree-days for the respective date.

**Uses:**
- Growth stage determination.

### Phenological sensitivity to water stress

Water stress tends to increase the crop canopy temperature, which may accelerate the accumulation of degree-days.

The parameter "Phenological sensitivity to water stress", which ranges from 0 to 1, allows one to determine the degree of the effect of water stress. For most applications, this value should be set to 1. Note that for some crops, like sorghum, phenology may actually be delayed by water stress. In such a case, select 0 for this parameter.

**Information source:**
- Experimental data.
- Literature.

**Uses:**
- Calculation of growing degree days.
Maximum crop water uptake

The following tables show the relation between average crop ET during full green canopy and the maximum attainable crop water uptake at different values of plant available water for crops with low, medium and high sensitivity to water stress.

### Maximum Attainable Crop Water Uptake (mm/day)

<table>
<thead>
<tr>
<th>Maximum weekly average ET (mm/day)</th>
<th>5.0</th>
<th>5.5</th>
<th>6.0</th>
<th>6.5</th>
<th>7.0</th>
<th>7.5</th>
<th>8.0</th>
<th>8.5</th>
<th>9.0</th>
<th>9.5</th>
<th>10.0</th>
<th>10.5</th>
<th>11.0</th>
<th>11.5</th>
<th>12.0</th>
<th>12.5</th>
<th>13.0</th>
<th>13.5</th>
<th>14.0</th>
<th>14.5</th>
<th>15.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>1.0</td>
<td>0.55</td>
<td>0.42</td>
<td>0.35</td>
<td>0.31</td>
<td>0.28</td>
<td>0.25</td>
<td>0.23</td>
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<td>-</td>
</tr>
<tr>
<td>5.5</td>
<td>-</td>
<td>1.0</td>
<td>0.57</td>
<td>0.44</td>
<td>0.37</td>
<td>0.32</td>
<td>0.29</td>
<td>0.26</td>
<td>0.24</td>
<td>-</td>
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</tr>
<tr>
<td>6.0</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>0.59</td>
<td>0.46</td>
<td>0.39</td>
<td>0.34</td>
<td>0.30</td>
<td>0.28</td>
<td>0.26</td>
<td>0.24</td>
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<tr>
<td>6.5</td>
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<td>1.0</td>
<td>0.60</td>
<td>0.47</td>
<td>0.40</td>
<td>0.35</td>
<td>0.32</td>
<td>0.29</td>
<td>0.27</td>
<td>0.25</td>
<td>0.23</td>
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<tr>
<td>7.0</td>
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<td>-</td>
<td>-</td>
<td>1.0</td>
<td>0.62</td>
<td>0.49</td>
<td>0.41</td>
<td>0.36</td>
<td>0.33</td>
<td>0.30</td>
<td>0.28</td>
<td>0.26</td>
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<tr>
<td>7.5</td>
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<td>-</td>
<td>-</td>
<td>1.0</td>
<td>0.63</td>
<td>0.50</td>
<td>0.42</td>
<td>0.37</td>
<td>0.34</td>
<td>0.31</td>
<td>0.29</td>
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<td>0.24</td>
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<td>8.0</td>
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<td>1.0</td>
<td>0.64</td>
<td>0.51</td>
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<td>0.35</td>
<td>0.32</td>
<td>0.30</td>
<td>0.28</td>
<td>0.26</td>
<td>0.25</td>
<td>0.23</td>
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<td>8.5</td>
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<td>-</td>
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<td>-</td>
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<td>-</td>
<td>1.0</td>
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<td>0.52</td>
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<td>0.36</td>
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<tr>
<td>9.0</td>
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<td>-</td>
<td>-</td>
<td>1.0</td>
<td>0.66</td>
<td>0.53</td>
<td>0.46</td>
<td>0.41</td>
<td>0.37</td>
<td>0.34</td>
<td>0.31</td>
<td>0.29</td>
<td>0.28</td>
<td>0.26</td>
<td>0.25</td>
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</tr>
<tr>
<td>9.5</td>
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<td>1.0</td>
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<td>0.54</td>
<td>0.47</td>
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<td>0.38</td>
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<td>0.32</td>
<td>0.30</td>
<td>0.28</td>
<td>0.27</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Leaf water potential of -1,600 J/kg for stomatal closure and -2,500 J/kg for permanent plant wilt

### Maximum Attainable Crop Water Uptake (mm/day)

<table>
<thead>
<tr>
<th>Maximum weekly average ET (mm/day)</th>
<th>5.0</th>
<th>5.5</th>
<th>6.0</th>
<th>6.5</th>
<th>7.0</th>
<th>7.5</th>
<th>8.0</th>
<th>8.5</th>
<th>9.0</th>
<th>9.5</th>
<th>10.0</th>
<th>10.5</th>
<th>11.0</th>
<th>11.5</th>
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<th>15.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>1.0</td>
<td>0.55</td>
<td>0.42</td>
<td>0.35</td>
<td>0.31</td>
<td>0.28</td>
<td>0.25</td>
<td>0.23</td>
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<td>6.0</td>
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<td>0.59</td>
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<td>0.39</td>
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<td>0.30</td>
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<td>0.40</td>
<td>0.35</td>
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Leaf water potential of -1,070 J/kg for stomatal closure and -1,600 J/kg for permanent wilt
Crop vernalization

Vernalization is defined as the low temperature promotion of flowering. Thermal time accumulation is limited until vernalization requirements are met. A vernalization factor that takes on values from 0-1 to adjust thermal time as calculated based on the following parameters. These parameters are only relevant for winter crops.

Vernalization checkbox

This checkbox enables vernalization. When disabled, the vernalization parameters have no effect.

Low temperature threshold for optimum vernalization (°C)

The low end threshold temperature above which vernalization accumulation is optimum.

High temperature threshold for optimum vernalization (°C)

The high end threshold temperature below which vernalization accumulation is optimum.

Vernalization requirement to start (days)

The sum of vernalization-days at which the vernalization factor is set to a minimum and starts increasing towards 1.
Vernalization day requirement to complete (days)

is the sum of vernalization-days at which the vernalization requirement is completed.

Minimum vernalization factor (0-1)

The value of the vernalization factor at the beginning of the vernalization process. This parameter should be set to zero if the vernalization-days required to start parameter is set larger than zero; otherwise, it must be set greater than or equal to zero.
Crop Photo-period

Some crops accumulate thermal time when the day length exceeds a threshold (long-day crops); others accumulate when the day length is less than a minimum threshold value (short-day crops). Therefore, the input parameters to calculate photo-period effects on physiological (thermal) time accumulation have different definitions.

Photo-period crop parameter window

Photo-period checkbox

This checkbox enables the photo-period. When disabled, photoperiod parameters have no effect.

Day length for insensitivity (hours)

For long-day crops, this is the day length threshold above which maximum accumulation of thermal time occurs.
For short-day crops, this is the day length threshold below which maximum accumulation of thermal time occurs.

Day length to inhibit flowering (hours)

For long-day crops, this is the day-length threshold below which no accumulation of thermal time occurs.
For short-day crops, this is the day length threshold above which no accumulation of thermal time occurs.
Crop harvest

Harvest classification

The method of biomass collection at harvest is determined by the selection of harvest classification. Harvest index parameters will be enabled or disabled depending on this selection.

Harvest index

Crop yield is calculated from total biomass at harvest multiplied by a harvest index (Unstressed harvest index) defined as the ratio of yield to biomass for a crop without stress.

*Note that some crops (e.g. soybean) drop a sizeable amount of leaves before harvest. Therefore, observed harvest indices that do not include dropped leaves are higher than required by the model, which does not simulate the loss of biomass due to dropped leaves.*

**Information source:**
- Harvest indices for some common crops are given in [Unstressed harvest index values table](#).

**Uses:**
- [The harvest index computation](#).

Sensitivity to water stress

Harvest indices vary based on crop/cultivar sensitivity to water stress during flowering and grain filling. The harvest index sensitivity to water stress during flowering, and during grain filling can be adjusted using the respective sensitivity coefficient (0-1). Values of zero may be entered if no water
stress sensitivity is to be simulated.

Translocation factor

The fraction of above ground biomass at flowering that can be translocated to the grains during grain filling (0.0-0.4).

This gives a second estimate of yield. **CropSyst** takes the maximum yield resulting from either harvest index calculation or biomass translocated to the grains. If severe stress occurs during flowering, the translocation mechanism is deactivated (poor sink strength).

### Unstressed harvest index values

<table>
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<tr>
<th>Crop</th>
<th>Harvest Index</th>
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<td>Orzo (Primavera)</td>
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<tr>
<td>Beans (Dry)</td>
<td>0.45 - 0.55</td>
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<tr>
<td>Lentils</td>
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<tr>
<td>Maize</td>
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<tr>
<td>Peas (Dry)</td>
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<tr>
<td>Oats</td>
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<tr>
<td>Sorghum</td>
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<td>Soybean</td>
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<td>Sunflower</td>
<td>0.30 - 0.35</td>
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<tr>
<td>Wheat</td>
<td>0.40 - 0.55</td>
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</table>
Crop residue

The amount of residue present at any given time affects runoff, erosion, soil evaporation and the amount of water infiltrating into the soil.

Residue parameters define decomposition rate, the fraction of above ground biomass that remains in the soil as residue after harvest, and the degree of shading of the soil surface by residue.

Information source:

- Residue parameters for some common crops are given in the residue constants table.
- These parameters are computed from empirical measurement as reported by McCool and Krauss, 1981 and Bristow et al., 1986, for the residue decomposition time constant and Gregory, 1982 and McCool (personal communication, 1992) for the area to mass ratio of residue cover.

Uses:

- Residue decomposition.
- Residue soil surface cover factors in soil erosion.

<table>
<thead>
<tr>
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<th>Residue decomp. time const. (days)</th>
<th>Area mass ratio (m²/kg)</th>
<th>Fract. biomass residue 0-1</th>
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<tr>
<td>Sunflowers</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter wheat</td>
<td>60</td>
<td>2.7-5.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Winter wheat (large stem)</td>
<td>60</td>
<td>4.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Winter wheat (medium stem)</td>
<td>60</td>
<td>5.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Spring oats</td>
<td>60</td>
<td>2.8-1.4</td>
<td></td>
</tr>
<tr>
<td>Spring barley</td>
<td>60</td>
<td>4.3-8.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Corn</td>
<td>60</td>
<td>3.2-4.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Soybeans</td>
<td>2.1-7.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybeans (stems)</td>
<td></td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Soybeans (leaves)</td>
<td></td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>Cotton (stems)</td>
<td></td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Small diameter stem</td>
<td></td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>Spring peas</td>
<td>30</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>Winter barley</td>
<td>60</td>
<td>5.7</td>
<td>1.0</td>
</tr>
<tr>
<td>very fine stems</td>
<td></td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>fine stems</td>
<td></td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>medium stems</td>
<td></td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>large stems</td>
<td></td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>very large stems</td>
<td></td>
<td>1.0-4.0</td>
<td></td>
</tr>
</tbody>
</table>

**Residue decomposition time constant (days)**

The approximate number of days (1-300) required for the residue to decompose 63% of the initial residue mass under ideal moisture and temperature conditions.

**Area to mass ratio of residue cover (m²/kg)**

This value represents the projected area of residue covering the soil surface in relation to the mass of the residue (m²/kg). This value determines the degree of soil shading by residue.
Crop nitrogen

Nitrogen fixation

For legume crops, simulation of nitrogen fixation can be enabled.

Nitrogen uptake

The following crop nitrogen parameters are used in computing nitrogen uptake. Information Source:

- Experimental data
- Literature

Nitrogen uptake adjustment

Because a generic value for maximum nitrogen uptake rate per unit of root length is coded in the model, this parameter allows calibration for specific crops and cultivars. (0-2).

Nitrogen availability adjustment

This parameter affects the curvature of the relationship between relative availability (0-1) and soil layer nitrogen concentration (kg/ha equivalent). A normal value is 1 (range 0-2). Increase this value to increase relative availability and vice-versa.
**Amount of residual nitrogen**

This is the amount of nitrogen (0-10 kg/ha) equivalent for each 0.1m soil sublayer that remains unavailable for crop uptake. Choose a value of zero to indicate that all nitrogen in the soil solution can be exhausted if required by the crop.

**Maximum nitrogen concentration during early growth**

Nitrogen concentration, during early linear growth, of a crop well-supplied with nitrogen (kgN/kg biomass).

Typical maximum nitrogen concentration of grasses is 0.02 to 0.04. Non-leguminous dicotyledons have a value 10% higher than grasses, and legumes about 30% higher than grasses.

**Maximum and minimum nitrogen concentration at maturity**

Maximum/minimum nitrogen concentration at maturity (combining grain and vegetative portions of the plant) for a crop well supplied with nitrogen (kgN/kg biomass).

**Minimum nitrogen concentration at harvest**

Minimum nitrogen concentration at harvest (combining grain and vegetative portions of the plant) for a crop well supplied with nitrogen (kgN/kg biomass).

**Maximum nitrogen concentration of the stubble**

Maximum nitrogen concentration of the stubble at harvest (kgN/kg biomass).
Crop salinity

Osmotic potential for 50% yield (kPa)

Needs description

Van-Genuchten salinity tolerance exp (2-9)

Needs description
Crop CO$_2$

**Elevated reference atmospheric CO$_2$ concentration (ppm)**

Needs description

**Ratio of growth at elevated reference and 350 ppm atmospheric CO$_2$ concentration (1-1.5)**

Needs description
Crop dormancy

Average temperature for 7 consecutive days to induce dormancy: 10.00, 0.9-1.3
First date to start looking for dormancy: 12/30
First date to start looking for restart after dormancy: 12/30
<table>
<thead>
<tr>
<th>Property</th>
<th>Units/Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>Several, &lt; 0.3 meter</td>
</tr>
<tr>
<td>Volumetric Perm. Wilt. Pt.</td>
<td>Cascade infiltration, 0.03-0.20 m³/m³</td>
</tr>
<tr>
<td>Volumetric Field Cap.</td>
<td>Cascade infiltration, 0.06-0.42 m³/m³</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>Soil porosity, 0.9-1.8 g/cm³</td>
</tr>
<tr>
<td>Vol. WC at -1500</td>
<td>Finite diff. Infiltration, 0.03-0.20 m³/m³</td>
</tr>
<tr>
<td>Vol. WC at -33</td>
<td>Finite diff. Infiltration, 0.06-0.42 m³/m³</td>
</tr>
<tr>
<td>Bypass Coefficient</td>
<td>Infiltration, 0-1</td>
</tr>
<tr>
<td>Saturated hydraulic conductivity</td>
<td>Various, m/day</td>
</tr>
<tr>
<td>Air entry potential</td>
<td>Infiltration, J/kg</td>
</tr>
<tr>
<td>Campbell b</td>
<td>Infiltration</td>
</tr>
</tbody>
</table>
Soil parameter editor

The soil entry form consists of a page for the general characteristics of the soil, a page for the soil texture profile, and a page for the soil hydraulic properties.

The parameters listed in soil parameters table must be provided.

Description

For the soil description, we recommend that the user provide a full name for the soil and the soil ID. The soil description is printed on the second line of report headers if the report header option is enabled.
Soil characteristics

Volatilization in the top horizon

Runoff

RUSLE

Leaching observation

Soil texture

Hydraulic properties

<table>
<thead>
<tr>
<th>Soil parameters</th>
<th>Parameter</th>
<th>Description</th>
<th>Use</th>
<th>Usual range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Informative</td>
<td>80 chars</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hydrologic Condition</td>
<td>Runoff</td>
<td>Poor-Good</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hydrologic Group</td>
<td>Runoff</td>
<td>A-D</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Steepness</td>
<td>Runoff</td>
<td>0-100</td>
<td>%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Number of soil layers</td>
<td>Several</td>
<td>1-11</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Thickness</td>
<td>Several</td>
<td>&lt; 0.3</td>
<td>meter</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Volumetric Perm. Wilt. Pt.</td>
<td>Cascade infiltration</td>
<td>0.03-0.20</td>
<td>m³/m³</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Volumetric Field Cap.</td>
<td>Cascade infiltration</td>
<td>0.06-0.42</td>
<td>m³/m³</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Bulk Density</td>
<td>Soil porosity</td>
<td>0.9-1.8</td>
<td>g/cm³</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Vol. WC at -1500</td>
<td>Finite diff. Infiltration</td>
<td>0.03-0.20</td>
<td>m³/m³</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Vol. WC at -33</td>
<td>Finite diff. Infiltration</td>
<td>0.06-0.42</td>
<td>m³/m³</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Bypass Coefficient</td>
<td>Infiltration</td>
<td>0-1</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Saturated hydraulic conductivity</td>
<td>Various</td>
<td></td>
<td>m/day</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Air entry potential</td>
<td>Infiltration</td>
<td></td>
<td>J/kg</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Campbell b</td>
<td>Infiltration</td>
<td></td>
<td></td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
Soil volatilization

Volatilization of chemicals occurs in the top soil layer.

Cation exchange capacity

description needed (millequivelents / 100g)

pH

description needed
Soil leaching observation

The depth at which soil water drainage and chemical leaching is observed can be specified. The depth will select the corresponding layer. Leaching that is reported in the output report files is the leaching at this depth. The leaching used to validate the water balance is always from the bottom of the soil profile. Also the leaching reported in the water balance report is from the bottom of the soil profile.

Soil leaching observation depth is currently only valid when using the cascade infiltration model.
SCS Curve number runoff

CropSyst uses the curve number approach in computing runoff as described in the \textit{USDA/SCS National Engineering Handbook} (USDA-SCS, 1988a).

Hydrologic condition and soil group

Note that the fair hydrologic condition is only valid for pasture, range, or woodland, and runoff numbers may not exist for certain land uses and land treatments.

Numerical solution runoff soil characteristics

Surface storage

The Surface storage parameter allows one to specify possible ponding depth (in mm) for water that cannot be infiltrated by the F.D. model in a given time step. Ponded water will be held for infiltration in successive time steps (or held over for the next day). Non infiltrated water that exceeds this storage ponding depth is taken as runoff.

The surface storage parameter is only effective when using the \textit{Numerical runoff model}.

In contrast, in the \textit{SCS curve number method} the runoff is determined prior to infiltration.
RUSLE parameters

Steepness (a percentage 0-100)

The steepness parameter specifies the grade of the land measured as the number of meters of vertical variation per 100 meters of horizontal run.

Slope length (m)

The horizontal slope length used in determining the RUSLE slope length factor.
## Soil texture

The table shows the percent sand, clay, and silt for each layer in the soil. The sum of these three numbers must equal 100. The parameter editor will enter the third number after entering the first two.

Enter a new value for any one of these texture values will cause new hydraulic properties to be calculated. This is necessary because inconsistent hydraulic properties will cause a failure of the Finite Difference infiltration model.

Press the [Texture] button to use the **Soil Texture Triangle: Hydraulic properties calculator** to select the texture and estimate hydraulic properties.

### Percent Sand, Clay, Silt

The sum of these three numbers must equal 100, the parameter editor will enter the third number after entering the first two.

Enter a new value for any one of these texture values will cause new hydraulic properties to be calculated. This is necessary because inconsistent hydraulic properties will cause a failure of the Finite Difference infiltration model.

Press the [Texture] button to use the **Soil Texture Triangle: Hydraulic properties calculator** to select the texture and estimate hydraulic properties.
Uses

- The soil texture is used within the parameter editor to estimate hydraulic properties.
- The soil texture of the first soil layer is used in RUSLE erosion calculations.

**Soil texture and physical properties**

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Field capacity m³/m³</th>
<th>Permanent wilting point m³/m³</th>
<th>Bulk density g/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>0.10-0.20</td>
<td>0.03-0.10</td>
<td>1.55-1.80</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>0.11-0.19</td>
<td>0.03-0.10</td>
<td>1.60</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>0.15-0.27</td>
<td>0.06-0.12</td>
<td>1.40-1.60</td>
</tr>
<tr>
<td>Loam</td>
<td>0.20-0.30</td>
<td>0.11-0.17</td>
<td>1.35-1.50</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>0.22-0.36</td>
<td>0.09-0.21</td>
<td>1.30</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>0.31-0.42</td>
<td>0.15-0.20</td>
<td>1.30-1.40</td>
</tr>
<tr>
<td>Silt Clay Loam</td>
<td>0.30-0.37</td>
<td>0.17-0.24</td>
<td>1.35</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>0.35-0.46</td>
<td>0.17-0.22</td>
<td>1.25-1.35</td>
</tr>
<tr>
<td>Clay</td>
<td>0.33-0.49</td>
<td>0.19-0.24</td>
<td>1.20-1.30</td>
</tr>
</tbody>
</table>
Soil layers

The number of soil layers (horizons) can be selected by moving the soil layer radio button marker to the respective number. There may be up to 11 soil layers. The soil layers will be subdivided by CropSyst into approximately 10cm sublayers.

Layer Thickness

Soil layer thickness must be provided in meters. The layers are numbered from top to bottom. The first soil layer is the layer of evaporation. Usually the first soil layer is about 10 cm (0.1 m).

The remaining soil layers may have any thickness, but the total depth should not exceed 3 meters.

The user should provide data for soil layers to a depth that the deepest penetrating root system that will be used might grow into. Roots will not grow beyond the bottom soil layer. If the maximum rooting depth for an unstressed crop is potentially larger than the available soil depth, then rooting depth will be limited to soil depth but root density will be properly adjusted.

Uses:

- Soil layer thickness is used throughout the program in relation to the soil water balance.
Soil hydraulic properties

The permanent wilting point is defined as the water content at a matric potential of -1,500 kPa (-15 bars). It roughly corresponds to the lower limit of the plant available water.

The water content of the soil at field capacity defines the upper limit of the plant available water or drained upper limit. It roughly corresponds to a matric potential of -30 kPa (-0.3 bars) in most soils and to -10 kPa (-0.1 bars) in sandy soils. If field capacity is found at a matric potential other than -30 kPa, enter the volumetric water content at -30 kPa.

These values are expressed in m³ water/m³ soil.
Information Source:
- soil properties table.

Uses:
- Both: Soil water storage in the soil water balance.
- Both: Plant available water (PAW).
- Both: Irrigation.
- PWP: Soil water potential.
- PWP: Soil water loss and water content.
- FC: Soil layer freezing.
- FC: Evaporation.
- FC: Transpiration.

**Bulk density**

Bulk density is used in the computation of soil porosity. The value is expressed in grams of soil mass per cubic centimeter of soil volume.

Information Source:
- soil properties table.

Uses:
- Soil freezing.
- Nitrogen exchange.
- Nitrogen transformation.

**Bypass coefficient**

The Bypass coefficient (BC) defines the fraction of water in the soil layer (0-1) that is bypassed during the infiltration process, while (1-BC) represents the fraction of the soil water subject to piston-like displacement. The fraction of soil water bypassed (and its solute content) is not mixed with new incoming water during infiltration.
Location parameter editor

Location parameters refer to information that is specific to the study site. The primary function of the location parameters is to identify the daily weather data files, and the latitude to generate solar radiation when real data is not available.

Location parameter editor windows

Description

This commentary parameter may be printed in the header of reports if the report header option is activated.

Weather file

The weather file must be selected or the simulation will not be able to run. The CropSyst text file format places weather data for each year in separate files with filenames composed of a prefix code and a 4 digit year. Use the file selector button to select any one of the weather data files, CropSyst will use the selected file to locate and compose the filenames for the other years as needed.

You may find it convenient to create a directory structure for storing your weather data files.

In the DOS version, instead of selected a single file, you must select the directory containing the
weather files and specify the prefix code that CropSyst will use to construct the weather data file names.

This four character/digit code is used in constructing the weather file name. The weather filename consists of these four characters followed by the four digit year with the extension (.DAT or .GEN): I.e. PULL1990.DAT, where PULL is the weather file code.

Latitude

The latitude is used in computing daily radiation values when actual values are not available in the weather files. The latitude is given as the angle of degrees from the equator whether from the northern or southern hemisphere. Degrees-minutes must be converted to degrees: I.e. 45° 30' is given as 45.5. A negative value should be used for the southern hemisphere.

Refinement parameters

Additional parameters can refine the simulation of weather. These refinements can improve the simulation provided additional data is available.

Precipitation

The precipitation parameters allow generation of 30 minute precipitation events.

Winter

These parameters improve simulation of freezing conditions

Evapotranspiration model

These parameters allow selection of the evapotranspiration model and constants required by the models

Wind

These parameters for wind speed are also used by the evapotranspiration model.

ClimGen

You will notice that many of the location parameters are also used by ClimGen; indeed, CropSyst and ClimGen location files are interchangable. You can use ClimGen to fit several of the location parameters.
Location precipitation

Given total daily precipitation, CropSyst can generate 30 minute storm events. The distribution of the daily precipitation into 30 minute intervals are used for the following:

- To estimate rainfall energy intensity which is used in the RUSLE equation for erosion.
- To give a more realistic infiltration pattern in the finite difference model.
- The finite difference model also gives a more realistic runoff model (which is used in the **Rural watershed modeling module**).

Storm events are produced randomly so you can expect slightly different infiltration patterns and rainfall energy intensity effects on erosion each time you run the simulation.

If you need constant storm events, you can use a [storm event file](#).

Mean peak 1/2 hour fraction of total rainfall

The average monthly values of the maximum portion of total rainfall during 1/2 hour intervals during storm events (0.0208 - 1.0).

![Location precipitation window](image)

**Information Source:**

- These values may be obtained empirically by taking the ratio of the maximum 1/2 hour rainfall amount, to the total rainfall amount for each event for the entire period of record as detailed by


Values for selected locations, published by Arnold et al., are shown in the following table.

<table>
<thead>
<tr>
<th>Location</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Spt</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa City, IA</td>
<td>0.22</td>
<td>0.21</td>
<td>0.30</td>
<td>0.38</td>
<td>0.49</td>
<td>0.59</td>
<td>0.56</td>
<td>0.54</td>
<td>0.47</td>
<td>0.37</td>
<td>0.32</td>
<td>0.22</td>
</tr>
<tr>
<td>Stillwater, OK</td>
<td>0.30</td>
<td>0.27</td>
<td>0.39</td>
<td>0.56</td>
<td>0.55</td>
<td>0.61</td>
<td>0.61</td>
<td>0.57</td>
<td>0.51</td>
<td>0.42</td>
<td>0.36</td>
<td>0.21</td>
</tr>
<tr>
<td>Tifton, GA</td>
<td>0.32</td>
<td>0.32</td>
<td>0.36</td>
<td>0.44</td>
<td>0.47</td>
<td>0.66</td>
<td>0.60</td>
<td>0.65</td>
<td>0.58</td>
<td>0.41</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Reynolds, ID</td>
<td>0.22</td>
<td>0.28</td>
<td>0.23</td>
<td>0.39</td>
<td>0.43</td>
<td>0.57</td>
<td>0.64</td>
<td>0.56</td>
<td>0.45</td>
<td>0.26</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Saffor, AZ</td>
<td>0.33</td>
<td>0.32</td>
<td>0.32</td>
<td>0.45</td>
<td>0.50</td>
<td>0.68</td>
<td>0.75</td>
<td>0.72</td>
<td>0.63</td>
<td>0.48</td>
<td>0.35</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Storm event file

In lieu of randomly generated 30 minute storm events, actual or generated events data can be provided in a Universal Environmental Database format file.

This file must have the same name as the location file with a .UED extension and located in the same directory as the location file.

Currently this file can only be created using ClimGen. This file can also contain daily real and/or generated precip, temperature, radiation, etc. data. Eventually these UED files will replace daily text files.
Location parameters for winter simulation

Soil Freezing conditions

Winter parameters windows

The following values are relevant to freezing climates only and can be ignored for locations that do not have freezing climate conditions. These values are used in computing the depth of frozen soil as it affects runoff and water available for uptake.

Information Source:
- These are calibrated parameters which may vary from location to location.
- The freezing climate parameters table should help in choosing values for these parameters.

Snow insulation factor

This value is a calibrated adjustment parameter which affects the influence of snow insulation with soil depth (1/cm). Its value ranges from 0.01 to 0.09.

Information Source:
- Known snow insulation factors for sites in the USA are reproduced in the freezing climate...
For other sites, this value can be estimated by running the simulation using various values until a freezing depth profile is obtained that matches empirical data for a number of years.

### Freezing climate parameters for locations in the USA.

<table>
<thead>
<tr>
<th>Location</th>
<th>Initial cumulative freezing index °C days</th>
<th>Snow Insulation factor (1/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aberdeen, Idaho</td>
<td>-50</td>
<td>0.025</td>
</tr>
<tr>
<td>Dubois, Idaho</td>
<td>-75</td>
<td>0.073</td>
</tr>
<tr>
<td>Moscow, Idaho</td>
<td>-30</td>
<td>0.020</td>
</tr>
<tr>
<td>Parma, Idaho</td>
<td>-20</td>
<td>0.015</td>
</tr>
<tr>
<td>Rexburg, Idaho</td>
<td>-20 to -60</td>
<td>0.085</td>
</tr>
<tr>
<td>Sandpoint, Idaho</td>
<td>-5</td>
<td>0.015</td>
</tr>
<tr>
<td>Twin Falls, Idaho</td>
<td>-20 to -30</td>
<td>0.010</td>
</tr>
<tr>
<td>Bozeman, Montana</td>
<td>-30</td>
<td>0.095</td>
</tr>
<tr>
<td>Huntley, Montana</td>
<td>-30</td>
<td>0.040</td>
</tr>
<tr>
<td>Havre, Montana</td>
<td>-30</td>
<td>0.040</td>
</tr>
</tbody>
</table>
Evapotranspiration model

The evapotranspiration model is the predominate component of CropSyst crop growth model. CropSyst allows the user to choose between reference evapotranspiration simulation models depending on the available weather data, as show in the Evapotranspiration model data requirements table.

Evapotranspiration model windows

Reference evapotranspiration model selection

CropSyst will examine the weather file data for each year that is processed and automatically select the evapotranspiration model to be used for that year. Also, if a particular day has missing data (a value of zero for solar radiation, Max/Min relative humidity, or wind speed), a model that requires only the available data will be used for that one day.

Evapotranspiration model data requirements

<table>
<thead>
<tr>
<th>Model</th>
<th>Weather File Data Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple ET model</td>
<td>Precipitation, Max. temp., Min Temp.</td>
</tr>
<tr>
<td>Priestley-Taylor</td>
<td>Precipitation, Max. Temp., Min Temp., Solar Radiation</td>
</tr>
<tr>
<td>Penman-Monteith</td>
<td>Precipitation, Max. Temp., Min Temp., Solar Radiation, Max relative humidity</td>
</tr>
</tbody>
</table>
For example, suppose that weather files for a site for 1975, 1977 and 1978 have precipitation, temperature, radiation, humidity and wind speed measurements, but 1976 only has precipitation, temperature and solar radiation measurements; the simulation will simulate ET using the Penman-Monteith model for 1975, 1977 and 1978, and the Priestley-Taylor model for 1976. Further suppose that some of the records in these files are missing solar radiation data; then for those dates, the simulation will use the simple ET model.

**Information Source:**
- Experimental data.
- Literature.

**Uses:**
- [The Priestley-Taylor ET model](#).
- [The Penman-Monteith ET model](#).

### Evapotranspiration model parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model</th>
<th>Usual range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Priestley-Taylor constant</td>
<td>Simple ET model</td>
<td>1.2-1.3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Priestley-Taylor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aridity factor for VPD</td>
<td>Priestley-Taylor</td>
<td>0.0-0.1</td>
<td>kPa⁻¹</td>
</tr>
<tr>
<td>Wind measurement height</td>
<td>Penman-Monteith</td>
<td>1.5-10.0</td>
<td>meter</td>
</tr>
</tbody>
</table>

**Priestley-Taylor Constant**

The Priestley-Taylor constant is a proportionality factor that compensates for the elimination of the aerodynamic component of the Penman Monteith model.

This constant is required by the Priestley-Taylor and the simple ET models. Priestley and Taylor experimentally derived an average value of 1.26 for this constant in short grasses and humid conditions. The constant should be increased for arid and semi-arid climates. This is adjusted by the model during execution depending on the value of the vapor pressure deficit for each simulation day.

**Information Source:**
- CropSyst allows the user to experiment with different Priestley-Taylor constant values which tends to depend on local conditions and crop.
Aridity factor for VPD

A constant used in the computation of maximum daylight vapor pressure deficit (Dx). The value of Dx is predicted from maximum and minimum temperature with the assumption that the air cools to dew point temperature every night. This assumption is not met well in arid areas. The aridity factor, with values fluctuating between 0 to 0.1 kPa⁻¹, helps to correct for the deficiency.

Information Source:
○ This value can be fit using ClimGen

Ratio of daily to maximum VPD

Daily mean vapor pressure deficit (VPD) is required for daily adjustments of the Priestley-Taylor constant. Because the Simple and Priestley-Taylor models do not have observed daily mean VPD available, this is calculated as a fraction of the VPD maximum for the day which is estimated from temperature data. Values of the ratio of daily mean to maximum VPD range from 0.5 to 0.6 as humidity of the site increases from arid to humid.

Information Source:
○ This value can be fit using ClimGen

B value for solar generation (summer and winter)

This value is required to estimate solar radiation from temperature when using the Simple ET model. A value of 0.3 for summer and 0.2 for winter are good values for many locations the range of values are a function of latitude.

Information Source:
○ This value can be fit using ClimGen
Wind

Wind parameters are used by the evapotranspiration model. When daily windspeed values are not available, generalized values can be provided for the ET models.

Wind measurement height

This value is the height (in meters) that the wind speed measurements have been taken. The Penman-Monteith equation calculates a turbulent transport resistance for vapor exchange which is dependent on wind speed.

Values of temperature and humidity should be corrected to the same height of wind measurements.

Characteristic wind speed

When real wind speed data is not available, select the characteristic wind speed for the area, or specify an average daily value.
Weather files organization

It is recommended that weather files be organized using a DOS hierarchical subdirectory structure by location. MS-DOS has limitations on the number of files that can be stored in subdirectories (particularly on floppy disks). By proper disk management, problems of files storage can be avoided.

For example, subdirectories could be organized by country, state/provence, county, recording site. I.e.:

```
D:\WEATHER\USA\WASHINGTON\WHITMAN\PULLMAN
   \PALOUSE
   \COLFAX
   \YAKIMA
   \KITTITAS
\OREGON
\CANADA\BC\PENTICTIN
   \GRACE
```
Daily weather Files

Weather files are text files that are created and manipulated by any text editor that the user may have available (such as EDIT.EXE). There is a special integer binary format which uses 10 times less space than the text file format. The Universal Environmental Database utilities can be used to convert files to/from this format.

Text file format

There must be one file for each year of interest following the CropSyst daily weather text file naming convention.

The weather text files have the following characteristics:

- Each line represents one day of data.
- There must be either 365 (or 366 for leap year) lines.
- Depending on the format used, all column entries must be provided.
- If data for precipitation or max/min temperature is missing from the original data set for a day, it must be estimated. Missing solar radiation, relative humidity, or wind speed can be represented with 0.0.
- The day of year number must be an integer.
- All other numbers may have integer or real number format.
- The file must be sorted by day of year.
- There must be at least one space or tab between each number.

The weather files may have one of the following formats depending on available data and evapotranspiration model to be used.

1. Day of year, precipitation (mm), max temperature (C), min temperature (C); i.e.
   
   1 0 7.3 4.4 2 0 6 4 3 6 9.6 3 : : : : :

2. Day of year, precipitation (mm), max temperature (C), min temperature (C), Solar radiation ((MJ/m²)/day); i.e.
   
   1 0 7.3 4.4 2 2 0 6 4 2.1 3 6 9.6 3 2.1 : : : : :

3. Day of year, precipitation (mm), max temperature (C), min temperature (C), Solar radiation ((MJ/m²)/day), Max Relative humidity (%), Max Relative humidity (%), WindSpeed (m/s); i.e.
   
CropSyst is designed to support a number of variable output options. The runtime graphs provide quick visual feedback on the progress of the simulation; however, for more detailed information, CropSyst can output about 200 different computed variables in a user definable format. There are three types of output variables:

- Daily variables computed each day.
- Yearly or Annual variables provide an annual summary of values accumulated throughout the calendar year.
- Harvest variables provide harvest yield and relevant crop and soil conditions at harvest time accumulated throughout the growing season.
- The current soil profile can also be printed for selected dates.

Output reports are formatted as Excel spreadsheets. The spreadsheet files contain four rows of title information, and five rows of column headers with the remaining rows as data. The soil profile output shows the soil profile parameters by sublayer followed by the detail lines, one line for each reported date with the values for each profile variable spread to the right.

The Simulation/Options menu provides an option to automatically convert the spreadsheets to text file versions after the simulation is run. (Not currently implemented)

## Daily, Harvest and Annual reports

Each report (daily, yearly, and harvest) may have a different format. For example, the daily report may be formatted without headers while the annual and harvest reports might be formatted for printing with the headers. Report format selection can be saved and used again for other simulation runs.
General layout options

Currently the report header and pagination options are disabled in the Windows version. These will be reenabled in a future versions.

Report header

For the text file output, the user may enable or disable the generation of the title.

When the report header option is enabled, four lines will be printed at the top of the report:

- An indicator of the report (I.e. daily, yearly, harvest report).
- The description line of the simulation parameter file.
- The description line of the location parameter file for the simulation.
- The description line of the soil parameter file for the simulation.

Column headers

For the text file output, the user may enable or disable the generation of the column headers.

With the column headers option enabled, the columns of output will be labelled at the top of the report following the report header (if activated). Four lines of text plus a blank line will be printed. (In the spreadsheet file, the blank line is omitted.)
To reduce waste of space, some column header labels may be abbreviated.

**Paginate**

*This option currently is not activated.* For the text file output, the user may enable or disable pagination. With the pagination option enabled, the report file will have embedded form feed characters for page breaks. If the report header and/or the column header options are activated, the respective header will be printed at the top of each page. The user may specify the number of lines that will be printed on a page before the page break is made.

**Separate years**

*This option currently is not available* With the separate year option activated (available only on the daily report), each year of daily output will be placed in a separate file. In this case, the report files will be named with the name of the simulation parameter file name, and a 3 digit extension consisting of the last three digits of the simulation year. The daily report (.XLD) for every day of the simulation will not be recorded.

**Output time step**

The user may restrict the amount of information printed in the daily report by specifying a time step interval. For example, to print a detail line only every 5 days, enter 5 for the time step. The time step is reset on the first day of each year. For example, with a time step of 5, January 5, will always be the first detail line of the year.

**Variable selection**

The user may select the variables to appear in the output file in any order. For each report, the user is presented with a list of variables available in the report. The user simply: selects the variable to be printed, selects the position in the report and presses the [Insert] button in the dialog box. There may be variables listed that are not yet available in the current version of CropSyst. These will be marked accordingly. If these variables are selected, they will not appear in the report. Variables that have already been selected for output are check-marked. The user may also edit the format by removing a selection with the button [Delete], replacing a selection with the button [Overwrite] or appending the selected entry with the button [Append].

**Balance selections**

The check boxes for balances will provide output of a set of variables related to the balance of various chemicals:

- **Nitrogen**
  - includes nitrate, ammonium, organic matter and nitrite.

- **Salinity**
  - includes the generalized salt profile.

- **Pesticide**
includes a balance for each chemical enabled in the simulation control.

The balance variables appear in columns that are to the right of the individually selected variables.

**Soil profile**

For output to the soil profile report, dates to be output must be selected. There are two options for selecting profile dates. Either or both options may be used using either option will enable the soil profile output generation.

**Selected dates**

On the soil profile dates window, simply click on the [Add Date] and [Delete Date] buttons to add or remove dates from the list.

**Timestep**

A time step number may be entered to print the profile at a daily interval corresponding. If the time step is 0, a soil profile will only be generated for any specifically selected dates. This time step is unrelated to the daily report time step.
Output report format editor DOS version

notes

Unlike the Windows version, the DOS version of CropSyst places the output files in the current working simulation directory. All the output files will have the same name as the simulation file that was run. Both Excel spreadsheets and optionally DOS text files may be generated.

The following extensions are distinguish the files:

<table>
<thead>
<tr>
<th>Extension</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.XLD</td>
<td>Daily report</td>
</tr>
<tr>
<td>.DLY</td>
<td>Daily report</td>
</tr>
<tr>
<td>.XLH</td>
<td>Harvest report</td>
</tr>
<tr>
<td>.HRV</td>
<td>Harvest report</td>
</tr>
<tr>
<td>.XLY</td>
<td>Yearly/Annual report</td>
</tr>
<tr>
<td>.YLY</td>
<td>Yearly/Annual report</td>
</tr>
<tr>
<td>.XLS</td>
<td>Soil profile report</td>
</tr>
<tr>
<td>.PRF</td>
<td>Soil profile report</td>
</tr>
</tbody>
</table>

In the text version of the soil profile, output is the same as the runtime soil profile screen.

The soil profile is always output to both a text file and a spreadsheet

Water balance accumulation

For accumulated variables from the water balance, the values may either be accumulated for the year or just for the growing season. Yearly accumulations should be used when checking the water balance. Growth period accumulations should be used for other purposes such as comparing with experimental data.

Converting report spreadsheets to text files

When running the CropSyst simulation under the parameter editor environment, the spreadsheet files are converted to text after the simulation run. When not working within the CropSyst parameter editor environment, the utility WKS2TXT can be used to produce text files. the format option will be used to customize the text file so that it may be suitable for a printed report or imported into another application such as a database program or some other simulation.
The Arc CropSyst Coöperator is simulator environment extension in the CropSyst Suite of programs which facilitates GIS based spatially oriented simulation capabilities to the CropSyst simulation. The Coöperator is designed to work with database files generated by Arc/Info or ArcView GIS software. In particular it uses the Polygon Attribute Table files produced by either Arc/Info or Arc/View.

The Coöperator uses CropSyst parameter files which have been associated with polygons in Arc/Info or ArcView coverages to generate and run a set of simulations to produce a new Polygon Attribute Table of CropSyst output variables which can be used by Arc/Info or ArcView to produce maps of the CropSyst outputs.

- How do I use the Arc-CropSyst Coöperator?
- What is Arc/Info?
- What is ArcView?
- What is a Polygon Attribute Table?
- What is a coverage?
- How do I organize my parameter files?
How to use the Arc CropSyst Coöperator

There are five main steps to prepare a Coöperator project and performing the analysis.

(Watershed simulation projects have additional steps.)

1. Prepare a combined simulation map polygon attribute table.
2. Prepare a set of CropSyst simulation parameter files.
3. Create and run ArcCS simulation project file.
4. Use the ArcCS analysis tools with the results of the ArcCS simulation run.
5. Use the GIS software to display the results.

Using GIS software such as Arc/Info or ArcView
Using CropSyst
Using the ArcCS project editor

The project editor is used to setup Arc CropSyst Coöperator and Watershed simulation projects.

What is needed to prepare a Coöperator/Watershed project

Before you can create a Coöperator or Watershed project you first need a combined simulation polygon attribute table prepared using GIS software. You will also need a set of CropSyst parameter files and a CropSyst report format file.

Maps

The maps page of the project editor specified the coverages to be used for the simulation.

1. Click on the file name button labelled: "Arc/Info polygon attributes table (PAT.DBF) of combined

   1. 3.
coverage" and select the the PAT.DBF file of the combined simulation map prepared using the GIS software. In Arc/Info this file is stored in the subdirectory having the same name as the coverage. In most situations this, should never have to be edited and can be used immediately after the overlay operation that creates the combined simulation map.

2. Once the PAT file is selected, a number of additional input fields will be displayed in the project editor "Maps" page.

3. In the combobox labelled "Select proper polygon ID attribute from PAT" select the name of attribute corresponding to the column that uniquely enumerates the combined simulation map polygons. This attribute will have the same name as the combined simulation map with "_ID" appended to it, and will usually be the fourth entry in the combobox.

4. Click on the filename button labelled "Simulation template file". This simulation control file must be a working simulation control file.

5. Mark the check boxes for the various maps that were included in the combined simulation map. Selected maps will display a combobox. In each of the comboboxes, select the polygon attribute table for the columns containing the respective polygon code/filename or value.

Output
The output page is used to specify the CropSyst report format file that selects the outputs from the simulation of each polygon. From these selected variables, statistical analysis can be performed and the results will be output to a new polygon attribute table that can be used to visualize the results using the GIS software.

For harvest variables, there is an option to separate tallied variables by crop ("Separate by crops"). You will probably always want to check this option when dissimilar crops are used in the rotation. In order for the "Separate by crops" option to work properly, it is imperative that the description field in all crop parameter files it filled in and supplied with a unique description.

The output files that are produced by the Coöperator are detailed in Coöperator outputs.

Run

The run window is not yet fully implemented. Currently you can only select to run all the polygons or a subset of polygons whose ID is between the specified range.

In the future it will be possible to select a subset of polygons based on values of the various attributes in the polygon attribute table. This will be useful to perform analysis on a subset of polygons with out
having to run all the polygons.

Analysis

The analysis tools available in the Analysis page are further detailed in Using analysis tools.

Running the simulation

Before you can start the simulation, you must complete the Maps page and the Output page.

To start the simulation, press the [OK] button.

Once the simulation is started you can abort the run by pressing the [Cancel] button.
Questions

- What is a "combined simulation map".
- What is a "polygon attribute table".
Preparing parameter files

The parameters files used in the Arc CropSyst Coöperator and Watershed simulations are normal CropSyst parameter files.

You will need to have all the parameter files that may be specified in the combined simulation map polygon attribute table. Any parameter file that is missing will cause the Coöperator or Watershed simulator to skip the run and tally of that polygon since the simulation will assume the polygon to be an "offsite" area.

Simulation control template

A simulation control file must be created which will serve as the template by which the Coöperator and Watershed simulator will generate simulations for all the polygons specified in the combined simulation map polygon attribute table.

You should run the CropSyst simulation on this template .SIM file to make sure the simulation will run correctly and insure that the paths of the file names (soil, crop, management, location, and daily weather files) are all correct. Indeed you will likely use this template simulation control file when calibrating your crop files.

The Coöperator and Watershed simulator uses the filenames specified in the simulation control file to construct new simulation files for the polygons that are simulated. It preserves the filename paths, replacing the file name part with the respective code/filename from the associated attribute in the combined simulation polygon attribute table.

If a map option in the Coöperator project is not selected (I.e. "Soils mapped" is not selected), the filename is simply copied from the simulation template file and all the simulations will use the same (I.e. soil) file.

Consequently if your template simulation file can be run succesfully under CropSyst, it should work fine for the Coöperator project.

Report format file

You will need to create a report format with CropSyst output variables selected with which you might want the Coöperator or Watershed simulator to perform statistical analysis or advanced analysis functions. Because the Coöperator or Watershed simulator could potentially create hundreds of simulations runs, it is recommended that your report format not include daily variable selections or output soil profiles. The daily reports are not used for the simulator's analysis functions anyway.

The yearly format must include the "Year" output variable.

If you select harvest variables analysis to be "Separated by crop" you must selected the "Crop name/description", "Planting date (YYYY.JJJ)" and "Maturity date (YYYY.JJJ)" variables the in the harvest report format.
Note that only the numeric fields are available for analysis functions. But there is no restriction on the variables that may be selected for output, other than the required variables. The required variables may be positioned in any order the the report format.

*Note that if you change a report format used in a Coöperator or Watershed project, you will need to rerun the simulation project in order for the analysis to correctly locate the new variables in the simulation output.*

**Questions**

- Where should I put the parameter files.
Organizing parameter files

As with any CropSyst simulation, there is no restriction on the directory organization. However, in order for the Coöperator or Watershed simulator to locate component parameter files, all files of a given type must be stored in the same directory. I.e. all soils files will need to be in the same directory, all locations files must be together in the same directory. This is because the simulator composes the soil and location filenames from the respective filenames specified in the simulation template file.

It is recommended that you create a separate directory for each simulation project. The simulator project (.ACS) file will need to be located in this directory.

It is recommended that the simulation template be located in the same directory as the project (.ACS) file, but this is not a requirement.

Questions:

● What is a Coöperator/Watershed project (.ACS) file?
● What is a simulation template file?
GIS Coverages/Themes

A GIS Coverage is an Arc/Info parlance for a map or map layer. ArcView refers to these map entities as themes.

In the Context of an Arc CropSyst Coöperator project, one or more coverages may be needed. These are digitized or generated using GIS software.

Soil

The polygons in the soil coverage will be associated with CropSyst soil parameter files. You will almost always want to specify at least the soil coverage. The soil coverage might be omitted if the simulation is to use a single soil type.

Weather region

The polygons in the weather region coverage will be associated with CropSyst location parameter files (and their associated daily weather files). This coverage may be desired if the study area has more than one different weather pattern (i.e. serviced by multiple weather stations). The weather region coverage can be omitted if there are no regional weather variations in the study area.

Cropping system

The polygons in the cropping system coverage will be associated with CropSyst rotation files. This coverage will be needed to specify different crop rotation or management practices (i.e. different crops or management in different fields or study plots represented in the map). This coverage can be omitted when the same cropping system is applied to the entire study area.

In addition to these principle coverages you may also want to create a map of soil steepness, initial nitrate, or initial plant available water. Often, these parameters follow the same polygon boundaries as the soil map; so instead of redigitizing a map, it may be convenient to simply add a new attribute column to the soil coverage polygon attribute table.

These coverage are combined using the GIS software to produce a single combined simulation map coverage/theme which serves as the input to the Coöperator and Watershed project.

In the case of Watershed projects, the combined simulation map theme will need to be converted to a grid.

Questions

- What is a Polygon Attribute Table?
- How do I prepare a combined simulation map?
Polygon Attribute Table

The following tables show a portion of a polygon attribute table that was used in an ArcCS project.

This table was produced by an Arc/Info overlay operation in which a map of soils and a map of weather locations were overlayed to produce a combined simulation map with this respective table. The Arc/Info IDENTITY command was use to produce a combined simulation map.

Polygon attribute tables always have at least four attributes or table column labels.

- **AREA** and **PERIMETER** are computed by the GIS software. These are not currently used by the Coöperator or Watershed simulations.
- There will be an attribute having the same name as the coverage with an underscore "_" concatenated. (For example if the name of the coverage is SOIL, the attribute will be named SOIL_.). The unique numbers in this column enumerate each polygon. This number is assigned as polygons are identified by the GIS software.
- There will be an attribute having the same name as the coverage with an underscore "_ID" concatenated. This number is assigned either by the user or by a GIS command that generated the map coverage. This number is not unique. In this example, in the soil map the number is used to identify the type of the soil found in the polygon not necessarily a unique identifier of the polygon. However, in the COMBSIM coverage which is generated by the IDENTITY command, the COMBSIM_ID will be unique. This column will be used by the Coöperator and Watershed simulations to organize simulations and output files generated by the simulations. (You can also use COMBSIM_, but we recommend using the COMBSIM_ID field for consistancy).

In addition to these four attributes which are always present in the table, there will very likely be other attributes containing user supplied information. The user can add any number of such attributes. In this example the soil map has the field SOIL and the weather region map has the field LOCATION. These fields correspond in this example to codes used to identify CropSyst parameter files associated with the respective polygons. You will need to add such attributes to your coverages and assign the respective code/filename to each polygon.

For polygons which are not intended for simulation, any code/filename for which there is no corresponding CropSyst parameter file will cause the Coöperator or Watershed simulation to omit the polygon from the simulation (this is not an error condition, but such polygons will be noted in the simulation log). In this example, the codes UNKNOWN, URBAN, INDUSTRIAL are used in the soil map to identify polygons with no soil data. No soil files are created having these file names, so any polygons thusly named with be omitted from the simulation. Blank entries will also be excluded.

Note that there will be a polygon (Usually the first entry in the table) with a negative area. This is the rectangular polygon bounding the extent of the coverage. This polygon should usually be assigned an UNKNOWN code.

<table>
<thead>
<tr>
<th>AREA</th>
<th>PERIMETER</th>
<th>COMBSIM_</th>
<th>COMBSIM_ID</th>
<th>REGION_ID</th>
<th>LOCATION</th>
<th>SOIL_ID</th>
<th>SOIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1576586000.000000</td>
<td>224853.900000</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>269391500.000000</td>
<td>245091.500000</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>paderna</td>
<td>0</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>765547.400000</td>
<td>6171.758000</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>paderna</td>
<td>1</td>
<td>URBAN</td>
</tr>
<tr>
<td>46941.510000</td>
<td>1028.909000</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>paderna</td>
<td>2</td>
<td>CAS1</td>
</tr>
<tr>
<td>517171.300000</td>
<td>4276.688000</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>paderna</td>
<td>3</td>
<td>CAS1</td>
</tr>
<tr>
<td>9337191.000000</td>
<td>13752.080000</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>paderna</td>
<td>4</td>
<td>CAS1</td>
</tr>
<tr>
<td>1454818.000000</td>
<td>11556.710000</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>paderna</td>
<td>5</td>
<td>INDUSTRIAL</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>151128800.000000</td>
<td>206153.800000</td>
<td>68</td>
<td>67</td>
<td>2</td>
<td>modena</td>
<td>0</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>5603472.000000</td>
<td>11995.560000</td>
<td>69</td>
<td>68</td>
<td>2</td>
<td>modena</td>
<td>64</td>
<td>RSD1</td>
</tr>
<tr>
<td>268956700.000000</td>
<td>9137.461000</td>
<td>70</td>
<td>69</td>
<td>2</td>
<td>modena</td>
<td>65</td>
<td>CAS1</td>
</tr>
</tbody>
</table>
This is only a portion of an actual table which had many hundreds of polygons. There will also be columns SOIL_ and REGION_ carried from the overlay operation which are not used by the Coöperator or Watershed simulations.

### Soil map (SOIL) polygon attribute table.

<table>
<thead>
<tr>
<th>AREA</th>
<th>PERIMETER</th>
<th>SOIL_</th>
<th>SOIL_ID</th>
<th>SOIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1576586000.000000</td>
<td>224853.900000</td>
<td>1</td>
<td>0</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>3529891500.000000</td>
<td>245091.500000</td>
<td>2</td>
<td>0</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>543447.400000</td>
<td>6171.758000</td>
<td>3</td>
<td>1</td>
<td>URBAN</td>
</tr>
<tr>
<td>64441.510000</td>
<td>1028.909000</td>
<td>4</td>
<td>2</td>
<td>CAS1</td>
</tr>
<tr>
<td>134171.300000</td>
<td>4276.688000</td>
<td>5</td>
<td>3</td>
<td>CAS1</td>
</tr>
<tr>
<td>3457191.000000</td>
<td>13752.080000</td>
<td>6</td>
<td>4</td>
<td>CAS1</td>
</tr>
<tr>
<td>5464818.000000</td>
<td>11556.710000</td>
<td>7</td>
<td>5</td>
<td>INDUSTRIAL</td>
</tr>
<tr>
<td>346128800.000000</td>
<td>206153.800000</td>
<td>40</td>
<td>0</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>1243472.000000</td>
<td>11995.560000</td>
<td>41</td>
<td>64</td>
<td>RSD1</td>
</tr>
<tr>
<td>1234567.000000</td>
<td>9137.461000</td>
<td>42</td>
<td>65</td>
<td>CAS1</td>
</tr>
<tr>
<td>3452745.000000</td>
<td>21426.680000</td>
<td>43</td>
<td>66</td>
<td>SMB2</td>
</tr>
</tbody>
</table>

### Weather region (REGION) map polygon attribute table.

<table>
<thead>
<tr>
<th>AREA</th>
<th>PERIMETER</th>
<th>REGION_</th>
<th>REGION_ID</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1576586000.000000</td>
<td>234224853.900000</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5245824900.000000</td>
<td>435245091.500000</td>
<td>2</td>
<td>1</td>
<td>paderna</td>
</tr>
<tr>
<td>634568-908.000000</td>
<td>656406153.800000</td>
<td>3</td>
<td>2</td>
<td>modena</td>
</tr>
</tbody>
</table>

### Questions

- **How do I create combined simulation maps.**
- **How can I tell which polygons were not simulated.**
- **How can I view the simulation log.**
Creating combined simulation maps

In this simple example there are three maps to be combined: Location, Cropping system and Soil.

The procedure for overlaying component maps to produce the combined simulation map is detailed in the ArcCS manual.

Polygon attribute tables

Their polygon attribute tables will look similar to the following:

Location polygon attribute table (LOC\PAT.DBF)

<table>
<thead>
<tr>
<th>AREA</th>
<th>PERIMETER</th>
<th>LOC_</th>
<th>LOC_ID</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.000</td>
<td>12.0</td>
<td>1</td>
<td>0</td>
<td>OFFSITE</td>
</tr>
<tr>
<td>1.8523</td>
<td>7.8</td>
<td>2</td>
<td>1</td>
<td>LOWTON</td>
</tr>
<tr>
<td>2.1477</td>
<td>8.1</td>
<td>3</td>
<td>2</td>
<td>MIDTON</td>
</tr>
</tbody>
</table>

Soil polygon attribute table (SOIL\PAT.DBF)

<table>
<thead>
<tr>
<th>AREA</th>
<th>PERIMETER</th>
<th>SOIL_</th>
<th>SOIL_ID</th>
<th>SOIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.000</td>
<td>12.0</td>
<td>1</td>
<td>0</td>
<td>OFFSITE</td>
</tr>
<tr>
<td>0.124</td>
<td>2.5</td>
<td>2</td>
<td>1</td>
<td>SOIL1</td>
</tr>
<tr>
<td>2.01</td>
<td>8.5</td>
<td>3</td>
<td>2</td>
<td>SOIL2</td>
</tr>
</tbody>
</table>
During the overlay operations, the polygon attributes tables from each of the component maps will be joined to produce a polygon attribute table for the combined simulation map that resembles the following:

<table>
<thead>
<tr>
<th>AREA</th>
<th>PERIMETER</th>
<th>COMBSIM_</th>
<th>COMBSIM_ID</th>
<th>ROT_</th>
<th>ROT_ID</th>
<th>ROTATION</th>
<th>SOIL_</th>
<th>SOIL_ID</th>
<th>SOIL</th>
<th>LOC_</th>
<th>LOC_ID</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.000</td>
<td>12.0</td>
<td>1</td>
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<td>OFFSITE</td>
<td>0</td>
<td>1</td>
<td>OFFSITE</td>
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<td>OFFSITE</td>
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</tr>
<tr>
<td>0.46</td>
<td>12.32</td>
<td>2</td>
<td>1</td>
<td>FALLOW</td>
<td>3</td>
<td>2</td>
<td>SOIL2</td>
<td>2</td>
<td>1</td>
<td>LOWTON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.06</td>
<td>0.534</td>
<td>3</td>
<td>2</td>
<td>CORN</td>
<td>3</td>
<td>2</td>
<td>SOIL2</td>
<td>2</td>
<td>1</td>
<td>LOWTON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.11</td>
<td>1.323</td>
<td>4</td>
<td>3</td>
<td>CORN</td>
<td>2</td>
<td>1</td>
<td>SOIL1</td>
<td>2</td>
<td>1</td>
<td>LOWTON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td>0.023</td>
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<td>4</td>
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<td>3</td>
<td>2</td>
<td>SOIL2</td>
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<td>2</td>
<td>MIDTON</td>
<td></td>
<td></td>
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<tr>
<td>0.17</td>
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<td>7</td>
<td>6</td>
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<td>MIDTON</td>
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<tr>
<td>0.14</td>
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<td>8</td>
<td>7</td>
<td>FALLOW</td>
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<td>1</td>
<td>SOIL1</td>
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<td>8</td>
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<td>1</td>
<td>SOIL1</td>
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<tr>
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<td>9</td>
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<td>3</td>
<td>2</td>
<td>SOIL2</td>
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<td>2</td>
<td>MIDTON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.14</td>
<td>1.325</td>
<td>11</td>
<td>10</td>
<td>BRLYWWHT</td>
<td>3</td>
<td>2</td>
<td>SOIL2</td>
<td>3</td>
<td>2</td>
<td>MIDTON</td>
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</tr>
<tr>
<td>0.73</td>
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<td>11</td>
<td>BRLYWWHT</td>
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<td>3</td>
<td>SOIL3</td>
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<td>SOIL1</td>
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<td>1</td>
<td>LOWTON</td>
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<td>SOIL2</td>
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<tr>
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<td>SOIL1</td>
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<td>MIDTON</td>
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<tr>
<td>0.13</td>
<td>1.532</td>
<td>16</td>
<td>15</td>
<td>CORN</td>
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<td>2</td>
<td>SOIL2</td>
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<td>SOIL3</td>
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<td>MIDTON</td>
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<tr>
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<td>MIDTON</td>
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<td></td>
</tr>
<tr>
<td>0.02</td>
<td>0.042</td>
<td>19</td>
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<td>FALLOW</td>
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<td>2</td>
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<tr>
<td>0.19</td>
<td>2.983</td>
<td>20</td>
<td>19</td>
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<td>3</td>
<td>SOIL3</td>
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<td>2</td>
<td>MIDTON</td>
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</tr>
<tr>
<td>0.01</td>
<td>0.009</td>
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<td>20</td>
<td>CORN</td>
<td>3</td>
<td>2</td>
<td>SOIL2</td>
<td>3</td>
<td>2</td>
<td>MIDTON</td>
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</tr>
<tr>
<td>0.15</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>CORN</td>
<td>3</td>
<td>2</td>
<td>SOIL2</td>
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<td>1</td>
<td>LOWTON</td>
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<tr>
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<td>1</td>
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</tr>
<tr>
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<td>2</td>
<td>SOIL2</td>
<td>3</td>
<td>2</td>
<td>MIDTON</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The **overlay** operation effectively generates all possible simulation scenarios that appear in the map.
ArcCS outputs

A number of output files will be produced. The first two dBase tables listed here are compatible with Arc/Info and ArcView.

- A database file containing the tallied output of the yearly reports named Yxxx.dbf where xxx is the same of the project. Each record in this database table corresponds to the tallied variable. The attribute/attribute name is an acronym of the full variable name as display in the report format editor, shorted to conform to dBase attribute naming conventions. The attribute name will be prefixed with AV for the average tally, CV for the coefficient of variation, or the 2 digit percent of probability.

- A database file containing the tallied output of the harvest reports named Hxxx.dbf where xxx is the same of the project. If the "Separate by years" option is selected for the harvest report, a dBase table for each crop will be output instead of the Hxxx.dbf files. These files will be named according to an acronym derived from the respective input crop parameter file description. This is why all crop files must be given a description in order to use the "Separate by years" option.

- A simulation file will be created for each polygon that was simulated. The same of the simulation files will correspond to the polygon ID number from the polygon attribute table. This file can be use to run an individual simulation if needed. (You will need to copy the respective template rotation file to a file with the matching simulation name (polygon number) and .ROT extension).

- A subdirectory name results will be created in the same directory as the project (.ACS) file. This will contains CropSyst (daily, harvest, fallow,annual) report files with variables as selected in the report format file. Only reports for the first simulation of each unique combination of input parameter files will be generated since duplicate parameter file combinations would give identical results. The simulator optimizes run time by assembling tallies from the from equivelent files.

These files will be useful to check that the simulation ran correctly and are giving correct results for the exemplar locations.

- A file results\equiv.equ.

This file (which you will find in the results directory) is produced by the ArcInfo CropSyst Coöperator (in fairly recent versions of CropSyst), is used by the Coöperator to optimize the tallying of statistics for polygons with identical simulation conditions. (This file does not apply to Watershed simulations.

The Coöperator used to keep copies of all the (often duplicated) output files to be run through the statistical analysis after all the simulations were run. With this file it now only needs to keep the output from the actual polygons that were run. This can save many megabytes of disk space.

The file might be useful if you wanted to see the output of the simulation of a particular polygon that was 'optimized' by the Coöperator.

The first number of each entry is the polygon ID, followed by an '=' followed by the equivalent polygon number. If the equivalent polygon number is -1 a simulation was run for the polygon otherwise the polygon as the equivalent simulation conditions as the specified previously run polygon ID.
So simply look up the polygon ID, if the equivalent number is -1 then there will be output (report) files stored in the results directory. If it is a positive number then the output files named using this equivalent polygon number would have the same results as the polygon of interest.
A detailed error log file (errors.txt) is generated as the Cooperator project is run.

The following information is recorded in this file:

- Each generated polygon simulation to be run is validated and any errors are recorded in this file.
- If a parameter file specified in the combined simulation map polygon attribute table is not located, the warning "ID:999 Unable to open file:xxxx.xxx" will appear in the log, but this is not specifically an error.
Using analysis tools

This window provides some extended analysis that can be performed after the Cooperator project has been run. The results from these analysis will be displayed using MicroSoft Excel spreadsheet program, and stored in the file `results\notes.xls`.

View water holding capacity for all soils

*This operation can be done at any time (Even before the run) once the Maps page has been filled out.*

This function reports for each soil encountered in the combined simulation Polygon Attribute Table:

- A polygon which will be run in the simulation representative of the soil.
- The depth of the lowest horizon (last layer) of soil profile.
- The water holding capacity at the lowest horizon.
- The water holding capacity a 1 meter depth.

If there is no soil map specified, only the one soil in the simulation control template file will be reported.

Perform analysis for probability distribution

This is a special in-house function that is not documented at this time. If you need to create probability distribution graphs please contact us for further details `rnelson@mail.wsu.edu`

The output files will be found in the results directory

- AVG_YLY.XLS
- AVG_HRVx.XLS (one for each crop in the rotation)
Visualizing Coöperator outputs

Once the simulation runs are completed, several polygon attribute tables will be generated by the Coöperator.

These tables are compatible with both Arc/Info and ArcView. While maps showing the simulation results can be created using Arc/Info, the process is significantly easier using ArcView.

The polygon "_ID" attribute of the combined simulation map will be included in the table which will allow the table to be joined to the combined simulation map polygon attribute table so the table can be use to produce maps of the results of the simulation.

Visualizing using ArcView

1. Start ArcView.
2. Open the project that was used to create the combined simulation map.
3. Select the Tables icon in the project window.
4. Click on the [Add] button.
5. Use the file requestor to select the output table files generated by the Coöperator. (You will find these in the same directory as your .ACS project file.) You can add all the tables at this time.
6. In the table you wish to visualize, click on the combined simulation polygon ID field. The button at the top of the table display will become highlighted.
7. Go back to the project window.
8. Open the view containing the combined simulation map.
9. Select the combined simulation map theme.
10. Select the menu Theme/Table.
11. The polygon attribute table for the combined simulation map.
12. Click on the combined simulation polygon ID field. This will usually have the same name as the polygon ID fields in each of the generated tables (If you followed the prescribed steps in generating the polygon attribute table).
13. Select the menu option Table/Join. The attributes from the generated table will be added to the combined simulation polygon attribute table.
14. Click here to see an example of the Join operation in ArcView
15. Go to the combined simulation map view window, select the map theme, and use the menu option Theme/Edit legend.
16. Use the legend editor to color the map:
   1. Usually the Graduated color option is most suitable for visualizing these kinds of output variables.
   2. Select the table attribute (Classification field) that corresponds to the variable to be visualized.
   3. You will probably want to reclassify the range of variable values.
You will probably want to change the symbol colors and legend range texts
- Use the color ramp button to produce a smooth graduated color scale
- It is highly recommended that you select a range of values that will be used to display consistently in all output maps in a set.
- You can save your legends and load them into other similar views you may create.
- When you close the legend editor the map will be colored based on the selected output variable.
  - Click here to see an example of the legend editor in ArcView

17. You can create new views and/or add the same combined simulation map theme and create a legend for each variable to be visualized.

18. Use the facilities of ArcView to produce layouts or perform additional spatially oriented analysis using the attributes joined from the Coöperator output tables.

The following is an example of map showing nitrogen leaching
Watershed wizard

The Watershed wizard is a CropSyst component to help create watershed simulations projects.

The Watershed wizard dialog box consists of a set of pages describing each step in preparing and running a watershed simulation.

For each step there is a brief summary of what needs to be accomplished before proceeding to the next step.

This button will display additional detailed information and/or further instructions for the step.

This button will start the editor or launch a program that can be used to complete the step.

Note that there are many ways to setup watershed simulation scenarios. The watershed wizard instructions describe the most common intended methodology. As you become more familiar with CropSyst, the Arc/CropSyst Coöperator and the watershed project editors you may find other approaches your simulations.
Utilities

CropSyst provides several utilities for handling output.

- **Report viewer**
  This displays the output files from the last simulation run.

- **Graphics viewer**
  A graphing utility is provided to graph daily variables from simulation runs.

- **Standalone validation program**
  A utility for detailed validation of the simulation and included parameter files.
Graphics viewer

This utility is available in the DOS version only. In the Windows version, CropSyst outputs a Universal Environmental Database file. This file can be viewed using the UED graphics viewer utility.

Graphics viewer functions

The 'View graphics' file menu option will display daily report file variables from the last simulation run. This graphics display provides detailed graphics and each curve can be displayed separately.

All the graphable output variables that have been generated by CropSyst in the daily report are available for graphics display. Up to four variables can be selected for simultaneous display.

A secondary file may be displayed using a background color, thus two daily report data files can be compared against each other graphically. This feature is useful to compare CropSyst simulation runs against actual field observations (experimental data), or to compare the results of two simulation runs. (The default file extension for an experimental data file is (.EXP)).

To setup the output report files for use with the graphics viewer:
1. Create/edit a report format using the report format editor.
2. Select the variables to be displayed in the graph. (Only variables that can be graphed will appear in the display. Variables such as dates, crop name, growth stage and most of the accumulated variables cannot be graphed. These variables may still be selected and will still appear in the daily report.)
3. The variables Year' and Day of Year' must also be selected. If these variables are not selected, a graph cannot be generated. The Year' and Day of Year' may appear any where in the report variable selection list.
4. The daily time step must be set to 1.
5. The header, column headers, pagination, and year separation can be either turned on or off.
6. Save the report format and run the simulation.

Using the graphics display

1. A file requestor is displayed where the primary report data file may be selected. The primary file data values are graphed using highlighted colors. **The report files must be daily reports.**
2. Next, a file requestor is display where the report format of the primary report data file may be selected. The report format may contain titles, column headers and pagination. However, if these options are used, the report report data file must have been generated by CropSyst. **The report format must contain the Year and the Julian day of year variables**.
3. Next, file requestors are displayed for a secondary report data and report format files. The secondary data is graphed using darker color shades. If you don't wish to display data from a secondary data file, simply [Cancel] the secondary file selection.
4. A window is presented which up to four variables from the primary report may be selected for graphing at a time.

5. To select the variables to be graphed, click on the respective [Variable] button and click on the variable name from the list of available variables, then click on the [Ok] button. If a secondary report file is used the selected variable must exist in both files in order for graphics to be generated.

6. Two types of graphs may be generated:
   - The time series graph will draw a continuous curve. If the data file is missing daily values, a marker will be displayed for dates where values are available.
   - The one-to-one comparison graph can be drawn if a secondary file was selected.

7. A color may be selected to graph the variable in. Click on the [Ok] button to graph the selected variables.

8. The graphics will remain displayed until the [Return] key is pressed.

9. The variable graph options window is present for selection of other variables to be graphed.
Report viewer

This utility is available in the DOS version only. In the Windows version, you can use the Windows Explorer to display available files in the simulation output directory. Simply double click on the file icon to view the output file with the associated application.

The report data viewer is provided to quickly display the output files generated by the last CropSyst simulation run.

For each output file (such as the daily, yearly and harvest reports), a window is displayed on the screen. To move around the file, simply click on the scroll bars on the bottom and side edges of the window or using the cursor keys. Note that the file view can only display the first 255 column of text.

Menu options in the Windows menu allow quick organization of the file windows.

Additional text files can be displayed by opening a new file from the File menu. Initially the filename search pattern is set to look for all files associated with the last simulation run.

The number of files that can be open at a time is limited by available memory.

The CropSyst output files from a simulation run which are initially loaded by the report viewer are:

* .ROT Crop rotation.
* .SCH Event schedule.
* .DLY Daily report.
* .YLY Yearly report.
* .HRV Harvest report.

Additional files generated by the simulation run which are not opened are separated years daily reports and soil profile report (*.PRF).
Parameter validation

The validate program can be run outside the main menu environment from the DOS command line or in a batch file. The command is:

```
VALIDATE
```

or

```
VALIDATE filename .SIM
```

The `filename` is a simulation control file and the `.SIM` extension must be provided. If no file name is specified, the last simulation control file edited with parameter editor (as specified in the file LASTSIM) will be validated.

The validate utility color codes messages as follows:

- Blue shows the status of the validation.
- Yellow shows warnings.
- Red show errors.

Status and warning messages can be ignored.

When the validation is performed within the parameter editor only warning and error message are displayed. Also, warnings and errors which are detected by the input field gadgets, as numbers are typed in to numeric input fields, are not displayed by the validation. Warning messages generally indicate that the value entered for a parameter falls outside of reasonable bounds, and may cause invalid data. Warning messages may also be given if the value for the parameter may affect the general appearance of the output files.

Error messages are given for values that fall outside constrained bounds. Errors must be fixed or CropSyst will not be able to properly process the input parameters. Attempting to run the simulation with errors will probably cause the simulation to abort or even crash.

Validate simply displays the error messages. After a warning or an error message is displayed, press [Return] to continue the validation. Validate does not pause when displaying status and informational messages. It also does not pause when displaying missing weather file messages. Use the [Pause] key to stop the scrolling of these messages.
Batch run editor

The batch run editor is an optional utility which runs (unattended) a list of simulations. Simulations may include basic simulations and/or advanced simulation modules such as Arc/CropSyst Coöperator simulations.

That batch run editor is only used for running multiple simulations, it is not needed to run a single simulation. To run a single simulation, use the 'Run simulation' menu option.

At the top of the screen is a file name button for selecting the simulation model program that will be used for running the simulations. This is followed by the simulation run list showing the name of the simulation and the report format file to be used (advanced modules usually have the report format selection made within the respective module editor so the report format is not displayed in the list for these entries).

Entering simulation runs

Initially the simulation run list is empty. To enter a simulation run in the list:

1. Click on the simulation button. This will display a file requestor for selecting simulations. Simulations from other directories can be selected by providing the full file path. When each simulation is run, the directory containing the simulation file will be set as the current simulation directory.
2. Click on the report format button. This will list available report formats that can be selected.
3. Click on the word 'Insert' in the status line or press the [Return] key. This will enter the selected simulation, report file and options into the simulation run list.
4. Repeat these steps for each simulation you want to run in the batch file.

Editing simulation runs

A simulation run can be deleted from the simulation run list by first clicking on the simulation run line and then clicking on the word 'Delete' in the status line (or by pressing the [Del] key).

DOS version notes:

In the DOS version, the batch run editor can only run basic CropSyst simulations not the advanced simulation modules that are available only under Windows.

When the batch run editor generator is used, the last batch run that was edited will be executed when the 'Simulation Run' menu option is selected. The batch run can be executed outside of the menu environment by entering the batch file name at the MS-DOS prompt. Saving a batch run file will set the 'Simulation Run' menu option to batch run mode. Saving a simulation control file in the parameter editor
will set the ‘Simulation Run’ menu option to single run mode.

The batch run generator generates MS-DOS batch files with commands for running CropSyst, printing reports and deleting printed reports. The report printing feature option is not available in the Windows version.
DOS version batch run editor

Like the Windows version, the DOS version batch run generator allows the user to run (unattended) a number of simulations (CropSyst simulation only) but also has the option to send the output to a printer. The batch editor generates MS-DOS batch files with commands for running CropSyst, printing reports and deleting printed reports. When the batch run generator is used, the last batch run that was edited will be executed when the Simulation Run' menu option is selected. The batch run can be executed outside of the menu environment by entering the batch file name at the MS-DOS prompt. Saving a batch run file will set the Simulation Run' menu option to batch run mode. Saving a simulation control file in the parameter editor will set the Simulation Run' menu option to single run mode.

At the top of the screen is the simulation run list showing:

- Print and cleanup options.
- Simulation file.
- Report format file.

Entering simulation runs

Creating the simulation run list is similar to the Windows version. Initially the simulation run list is empty. To enter a simulation run in the list:

1. Select the desired print and clean-up options. The selected reports in the print options will be sent to the printer. After a report is printed, it may be optionally deleted by selecting the corresponding clean-up option. These options allow the user to minimized disk space requirements. This is helpfull in simulations where many large reports may be generated.
2. Click on the simulation button. This will display a list of simulations that can be selected from the current directory. Simulations from other directories can be selected by providing the full file path.
3. Click on the report format button. This will list available report formats that can be selected.
4. Click on a line in the simulation list where the simulation run is to be placed.
5. Click on the word Enter' in the status line or press the [Return] key. This will enter the selected simulation, report file and options into the simulation run list.

Editing simulation runs

A simulation run can be deleted from the simulation run list by first clicking on the simulation run line and then clicking on the word Delete' in the status line (or by pressing the [Del] key).

Blank lines can be inserted into the simulation run list by first clicking on the simulation run line to be moved down and then clicking on the word Insert' in the status line (or by pressing the [Ins] key).

To replace a simulation run with another, simply select the new print and clean-up options, simulation file and report file; click on the simulation run to be replaced, and Click on the Enter' word in the status line.
Tips to using the batch run editor

Keep in mind the following when using the batch run editor.

- First select the Print and Clean-up options to be used. In most cases you will want all the print and all the clean-up options to be disabled (no X's in the check boxes). When the print options are disabled, the batch file will not try to print the reports on your printer. When the cleanup options are disabled, the batch file will not delete the reports, instead, the report files will be left in the current working directory.

- To make an entry in the batch run table:
  1. Select the report format to be used (right green button).
  2. Select the simulation file.
  3. Click on the first blank line at the end of the list of simulation runs
  4. And click on the word 'Enter' at the bottom of the screen to insert the selected simulation and format.

Repeat 2, 3, 4 for each simulation you want to run in the batch file.
Hints & Trouble Shooting:

1. CROPSYST validation says there are missing files: Data files may contain references to files and directories that might not have the same directory structure as your harddisk. (This may be the case if you move data files around, copy them from a different machine, or if you run CROPSYST on a floppy disk.) Before these datafiles can be used, the file names may have to be changed:
   1. Run the CROPSYST menu: CS
   2. Select the [E]dit parameter option from the menu.
   3. Edit the location files and change the weather directory name to match your directory structure and save the location file:
      In the parameter editor:
      - Click on Location in the menu bar.
      - Click on the XXXX.LOC file to be edited.
      - Click on Open.
      - Click on the Weather directory bar.
      - Select the directory containing the weather files.
      - Click on ChDir.
      - Click on OK
      - This will return you to the Location edit window.
      - Click on Exit.
      - Click on OK to save the file with the name listed in file requestor.

4. Now you need to register the change so that CROPSYST will validate the simulation control (and the respective location file) for you:
   - Select the Control menu bar option.
   - Click on the simulation control file to be edited (####.SIM).
   - Click on OPEN, the simulation control parameter screen will be displayed.
   - Check that the location file is correct (make sure that path is correct, especially the drive designator). If the location filename is not correct, click on the location file name bar, select (click on) the correct location file and click on OK.
   - Click on Exit.
   - Click on OK; this tells CROPSYST us validate this simulation file and to use this control the next time the simulation is run.

5. Now exit the parameter editor from the File/Exit menu option. This will validate the simulation control file displaying any error messages. Any errors should be corrected before the simulation is run. If an error message says that it can not find weather files, make sure that the weather directory is set correctly in the location file. Also make sure that you have complete weather files for each year specified in the simulation control parameters for simulation period.
6. Now you need to tell CROPSYST which report file format to use when running the simulation:
   ■ Select the Report format edit menu option.
   ■ In the report format editor, simply select the File|Save menu option
   ■ and simply save the report format with the same name (or a new name).
7. Exit the report format editor with the File/Exit.

2. Avoid storing data files in the CROPSYST program directory: It is strongly recommend that data not be stored in the CROPSYST program directory. That is, you should not run CS while in the CROPSYST directory. It is also advisable not to store data in subdirectories of the CROPSYST directory.

3. Use separate directories for different simulations: CROPSYST generates many data files, it is best to create separate directories for your simulation runs:
   ○ It is easier to differentiate the files from different simulation runs.
   ○ It makes removing old data files easier.
   ○ It makes copying/moving CROPSYST to other drives/computers easier.
   ○ It ensures that the installation of CROPSYST uptakes goes smoothly.
   ○ It allows CROPSYST to run be from or on Floppy disks or RAM disks.
   ○ It allows for better disk management from MS-DOS and provides for easier icon startups from MS-Windows.
Simulation model

This model is a daily time step model.

Mass balances

The following are the mass balances maintained by the model.

- Water balance
- Chemical balance for each pesticide
- Nitrogen balance
- Organic matter pool
- Residue pools
Water balance

The amount of water used for crop growth can be determined by modeling the components of the soil water balance. The water budget components considered are: irrigation, precipitation, rainfall intercepted by the crop and surface residue, surface runoff, soil and residue evaporation, infiltration through soil layers, transpiration, deep percolation and water storage in the soil profile.

Irrigation

Irrigation amounts and timing are either user selected or automatically assigned if the automatic irrigation option is selected. To simulate dryland conditions, irrigations are not scheduled as part of the management and the automatic irrigation is turned off. In the current version of CropSyst, no runoff or canopy/residue interception of applied irrigation water is subtracted and, therefore, all irrigation amounts scheduled or calculated are infiltrated into the soil.

Precipitation and snowfall

Precipitation is derived from actual daily weather data (or generated daily data). Additionally, for the finite difference infiltration, 30 minute precipitation events can be generated. Snowfall is estimated from the daily precipitation data and temperature.

Interception

When precipitation (and/or snow melt) occurs, interception by the crop canopy and interception by the residue layer are determined and subtracted from the total precipitation leaving the effective amount of water entering the soil. The influence of the residue on the water budget is modelled by adding the residue to the soil surface as a layer which could store and evaporate water (Bristow et al., 1986).

When precipitation occurs, and after canopy interception is deducted, the residue layer is filled to its saturated water content ((4 kg H2O)/(kg Residue)) and then passes the water on to the soil layers.

Runoff

CropSyst can be run with the following runoff options:

- No runoff
- USDA-SCS curve number method (occurs only with precipitation events)
- Numerical method (under the finite difference model) (occurs daily).
Infiltration and soil water storage

The amount of water available for infiltration is the precipitation minus crop canopy and residue interception, and the surface runoff plus irrigation. Additional adjustments are made for freezing conditions. CropSyst provides the option for two infiltration models:

**Cascade model.**

In this model, it is assumed that there is no water flow upward in the soil profile, so the source of evaporated water is precipitation and/or irrigation entering the top soil layer.

**Finite difference model.**

In this model, water flow may be up or down. Water moving up out of the first soil layer may contribute to water ponded on the surface (to be entered in following days) and runoff.

Surface storage and ponding

In the finite difference model, surface storage is based on soil surface depressional storage. Water that cannot be infiltrated is ponded to be infiltrated later. In the numerical runoff model, water depth that exceeds the depressional storage is runoff.

Potential crop evapotranspiration

CropSyst provides two options for the computation of the daily maximum crop evapotranspiration (ET) (m/day)

- **Priestley-Taylor model** (Priestley and Taylor, 1972)
- **Penman-Monteith model** (Monteith, 1965).

The potential evapotranspiration is partitioned to crop transpiration, soil evaporation and residue evaporation.

Residue evaporation

Actual residue evaporation is based on the water holding capacity and temperature.

Soil evaporation

Actual soil evaporation is based on the soil water content of the first and second soil layers. It is slightly different for the cascade and finite difference models.
Actual transpiration (Crop water uptake)

The calculation of actual transpiration follows closely the approach proposed by Stöckle et al., 1992.
Precipitation

Precipitation is taken directly from the daily weather files. In the case of freezing conditions, the precipitation may be temporarily stored in the snow pack. Any water melted from the snow pack and/or precipitation in the form of rain is referred to as effective precipitation in the model which serves as the water input to the daily water balance.

Snow fall and snow pack accumulation and melting

During winter seasons in climates where freezing conditions encourage snowfall, CropSyst will store precipitation as snowfall thereby inhibiting water from entering the soil water budget until the temperature is sufficient for melting.

When the average temperature for a day is less than -1.5 °C, then any of the precipitation for that day is accumulated to snow liquid water equivalent.

When the average daily temperature for a day exceeds -1.5 °C, then the snow liquid water equivalent is depleted by melting as follows:

\[
\text{Melt}_{\text{act}} = \begin{cases} 
\text{Melt}_{\text{pot}} & \text{if Melt}_{\text{pot}} \leq \text{snowwater} \\
\text{snowwater} & \text{if Melt}_{\text{pot}} > \text{snowwater} \\
0.0 & \text{if snowwater} = 0.0
\end{cases}
\]

where

snowwater (m) is the liquid water equivalent of the snow pack.
Melt_{act} (m) is the actual amount of water melted from the snow pack.
Melt_{pot} (m) is the potential amount of water that could be melted with the current conditions if that amount of snow were available:

\[
\text{Melt}_{\text{pot}} = (T_{\text{avg}} - 1.0) \cdot 0.0025
\]

where

\( T_{\text{avg}} \) (°C) is daily average air temperature.
0.0025 ((m/day)/°C) is a degree day melt factor.

The snow liquid water equivalent stored in the snow pack is multiplied by a density factor of 5 to determine snow pack thickness. The snow pack on the ground also affects soil freezing by serving as an insulation layer.
Net radiation

The net radiation ((MJ/m²)/day) is calculated as the sum of short-wave net radiation (Rad\text{sw}) and daytime long-wave isothermal (air temperature = canopy temperature) net radiation (Rad\text{lwi}):

\[
\text{Rad}_{\text{net}} = \text{Rad}_{\text{sw}} + \text{Rad}_{\text{lwi}}
\]

\[
\text{Rad}_{\text{sw}} = (1 - \text{Albedo}) \cdot \text{Rad}_{\text{solar}}
\]

\[
\text{Rad}_{\text{lwi}} = - (a \cdot \text{Rad}_{\text{solar}} \cdot \text{Rad}_{\text{solarcloudless}} + b) \cdot \Delta \text{Emiss} \cdot \sigma \cdot \left[ \left( \frac{T_{\text{max}} + 273.1}{4} \right)^4 + \left( \frac{T_{\text{min}} + 273.1}{4} \right)^4 \right] / 2
\]

where

- $\sigma$ (MJ/m²) is the solar constant ($4.903 \times 10^{-9}$ (MJ/m²)/day).
- Rad\text{solarcloudless} (MJ/m²) is expected solar radiation on a cloudless day:
  \[
  \text{Rad}_{\text{solarcloudless}} = \text{Rad}_{\text{pot}} \cdot 0.75
  \]
- Rad\text{solar} (MJ/m²) is the actual measured solar radiation from the .
- Rad\text{pot} (MJ/m²) is the potential solar radiation (Campbell and Diaz, 1988):
  \[
  \text{Rad}_{\text{pot}} = 117.5 \cdot \left( h_s \sin \phi \sin \delta + \cos \phi \cos \delta \sin h_s \right) / \pi
  \]
- $\phi$ (radians) is the location parameter latitude .
- $\delta$ (radians) is the solar declination, computed from the day of the year using (Campbell, 1985):
  \[
  \delta = \sin ^{-1} \left( 0.39785 \cdot \sin \left[ 4.869 + 0.0172 \cdot \text{day} + 0.03345 \cdot \sin \left( 6.224 + 0.0172 \cdot \text{day} \right) \right] \right)
  \]
- $h_s$ (radians) is the half day length , calculated from:
  \[
  h_s = \cos ^{-1} \left( -\tan \phi \cdot \tan \delta \right)
  \]
- $a = 1.1$
- $b = -0.1$
- Emiss are fitted constants in a term representing cloud effects on sky emissivity.
- $\Delta \text{Emiss} = - 0.02 + 0.261 \cdot e^{-7.8 \times 10^{-4} \cdot T_{\text{avg}}}$
Potential evapotranspiration

The potential evapotranspiration models used are two-step approaches, where the potential evapotranspiration from a reference crop, defined as a short clipped grass, 0.12m high, completely covering the ground and with plentiful water supply, is multiplied by a crop coefficient to obtain the potential crop evapotranspiration.

Two potential evapotranspiration models. The selection of the model is done automatically, as data available for each day is determined.

The simulation can be forced to always select the Priestly-Taylor model irrespective of the available data by specifying the preferred ET model in the location parameters.

**Priestly-Taylor**

This model only requires max/min temperature and solar radiation.

**Penman-Montieth**

This model requires, additionally, max/min relative humidity or dew point temperature and wind speed.

The ET models have been abstracted to compute a potential evapotranspiration for a reference crop (i.e. grass) This value (RefET\textsubscript{pot}) is then adjusted to give the potential evapotranspiration the current crop (or fallow) as in the following equation:

$$ET_{pot} = \frac{\text{RefET}_{pot} \cdot K_c}{\lambda}$$

where

- \text{RefET}_{pot} is the potential evapotranspiration for a reference crop computed by either the Priestly-Taylor or Penman-Montieth model.
- \(K_c\) (0-1) is the **ET crop coefficient**.
- \(\lambda\) (MJ/kg) is the **latent heat of vaporization**.

In the case of a CO\textsubscript{2} simulation, \(ET_{pot}\) is adjusted by the daily ratio of elevated reference CO\textsubscript{2} to CO\textsubscript{2} at 350ppm.
Priestly-Taylor evapotranspiration model

This model is based on the Priestley-Taylor equation:

\[
\text{RefET}_{\text{pot}} = \frac{\text{PT}_c \cdot \text{Slope}_{\text{vpf}} \cdot (\text{Rad}_{\text{net}} - \text{SoilHeatFlux})}{(\text{Slope}_{\text{vpf}} + \gamma)}
\]

where

- \(\text{PT}_c\) (kPa) is the Priestley-Taylor constant location parameter.
- \(\text{Rad}_{\text{net}}\) ((MJ/m\(^2\))/day) is the net radiation.
- \(\text{Slope}_{\text{vpf}}\) (kPa/°C) is the slope of saturation vapor pressure function of temperature.
- \(\gamma\) (kPa/C) is the psychometric constant.
- \(\text{SoilHeatFlux}\) ((MJ/m\(^2\))/day) is the soil heat flux.
Penman-Monteith evapotranspiration model

If daily air temperature solar radiation, maximum and minimum relative humidity (RHmax and RHmin) (or dew point temperature from which relative humidity can computed) and wind speed are available, then the Penman-Monteith equation may be used to calculate potential evapotranspiration.

\[
\text{RefET}_{\text{pot}} = \frac{\text{Slope}_{\text{vpf}} \cdot (\text{Rad}_{\text{net}} - \text{SoilHeatFlux}) + (\text{DayFract} \cdot \text{VPD} \cdot \text{C}_{\text{va}})}{\text{Slope}_{\text{vpf}} + \gamma \cdot (1 + \frac{r_c}{r_a})}
\]

where

- SoilHeatFlux ((MJ/m²)/day) is the soil heat flux.
- DayFract (0-1) is the fraction of the day that is in daylight.
- \(C_{\text{va}}\) ((MJ/m³)/°C) is the volumetric heat capacity of air taken as 1.2x10⁻³.
- \(\gamma\) (kPa/°C) is the psychometric constant.
- \(\text{Slope}_{\text{vpf}}\) (kPa/°C) is the slope of saturation vapor pressure function of temperature.
- VPD (kPa) is the Vapor pressure deficit
- \(\text{Rad}_{\text{net}}\) ((MJ/m²)/day) is the net radiation.
- \(r_a\) and \(r_c\) (day/m) are the aerodynamic and canopy resistances to vapor transfer of the reference crop. For a short clipped grass (0.12m height), these are

\[
r_a = \frac{\ln((h_s - 0.744 \cdot hp) / (0.026 \cdot hp)) \cdot \ln((h_s - 0.640 \cdot hp))/(0.013 \cdot hp)}{0.16 \cdot ws}
\]

\(r_c = 0.000787034\) (this may be adjusted in the case of CO₂ simulation).

where

- \(ws\) (m/s) is the wind speed. (Note that wind speed is stored in daily weather files a m/day but will be converted to m/s).
Vapor pressure deficit (VPD) is the day time mean vapor pressure deficit calculated from the day time maximum vapor pressure deficit.

\[ \text{VPD} = \text{VPD}_{\text{max}} \cdot 0.66 \]

Where 0.66 is the ratio of daily \( \text{VPD}_{\text{max}} \) to daily VPD.

**Maximum VPD**

The model will attempt to provide a day time maximum vapor pressure deficit based on available data:

\[ \text{VPD}_{\text{max}} = \begin{cases} 
\text{VPD}_{\text{dewptmax}} & \text{if dew point temperature is provided} \\
\text{VPD}_{\text{relhumidmax}} & \text{if relative humidity is provided} \\
\text{VPD}_{\text{tempmax}} & \text{otherwise (estimated from temperature)}
\end{cases} \]

**Maximum VPD based on dew point temperature**

\[ \text{VPD}_{\text{dewptmax}} = \text{VP}_{\text{satTmax}} - \text{VP}_{\text{satDewptmax}} \]

**Maximum VPD based on relative humidity**

\[ \text{VPD}_{\text{relhumidmax}} = \text{VP}_{\text{satTmax}} \cdot \left( 1.0 - \frac{\text{Relhumid}_{\text{min}}}{100} \right) \]

**Maximum VPD estimated from temperature**

\[ \text{VPD}_{\text{tempmax}} = \frac{\text{VP}_{\text{SatTmax}} - \text{VP}_{\text{SatTmin}}}{1 - a \cdot \left[ \text{VP}_{\text{SatTmax}} - \text{VP}_{\text{SatTmin}} \right]} \]

**VPD parameters**

- \( \text{VP}_{\text{satTmax}} \) (kPa) **saturated vapor pressure at maximum temperature**.
- \( \text{VP}_{\text{satTmin}} \) (kPa) **saturated vapor pressure at minimum temperature**.
- \( \text{VP}_{\text{satDewptmax}} \) (kPa) **saturated vapor pressure at maximum dew point temperature**.
Relhumid$_{\text{min}}$  %  Is the minimum relative humidity
Common ET equations

The following equations are common to both ET models.

**Ratio of crop to reference potential evapotranspiration (Kc)**

This is the crop coefficient (ratio of crop to reference potential evapotranspiration)

\[
K_c = \begin{cases} 
1 + (K_c' - 1) \text{LAI} / 3 & \text{if } K_c' > 1 \text{ and } \text{LAI} < 3 \\
K_c' & \text{otherwise}
\end{cases}
\]

where

- \( K_c' \) is the ET crop coefficient input parameter.
- If \( K_c' < 1 \) then \( K_c = K_c' \).
- 3.0 Is maximum LAI (LAI\text{max}) of the reference crop.

**Slope\text{vpf} (kPa/ C)**

is the slope of saturation vapor pressure function of temperature given by the equation:

\[
\text{Slope}_{\text{vpf}} = \frac{V_{\text{sat}} \cdot 4098}{(T_{\text{avg}} + 237.3)^2}
\]

where

- \( V_{\text{sat}} \) (kPa) is the saturated vapor pressure at average air temperature.
- \( T_{\text{avg}} \) (°C) is the average air temperature.

**V_{\text{sat}T_{\text{max}}}, V_{\text{sat}T_{\text{min}}}**

are the saturated vapor pressure at maximum and minimum air temperature, respectively. Saturated vapor pressure at any temperature (\( T \)) is given by:

\[
V_{\text{sat}T} = 0.611 \cdot e^{17.27 \cdot T / (T + 237.3)}
\]
\( \lambda \) (MJ/kg)

is the latent heat of vaporization derived from average air temperature \( (T_{avg}^{\circ}C) \).

\[ \lambda = 2.501 - T_{avg} \cdot 0.002361 \]

\textbf{SoilHeatFlux}

the soil heat flux is simply derived from net radiation:

\[ \text{SoilHeatFlux} = \text{Rad}_{net} \cdot 0.1 \]

\( \gamma \) (kPa/\(^{\circ}C\))

is the psychometric constant given by:

\[ \gamma = \frac{C_p \cdot P}{0.622 \cdot \lambda} \]

where

\( C_p \) ((MJ/kg)/\(^{\circ}C\)) is the specific heat of air (about about 0.001).
\( P \) is the atmospheric pressure (taken as 96 kPa).
\( \lambda \) (MJ/kg) \textit{is the latent heat of vaporization.}
Partitioning potential evapotranspiration

The potential evapotranspiration ($ET_{pot}$) determined by any of the three ET models requires partitioning into potential transpiration (usually of a crop or reference plant type) ($Tr_{pot}$), potential soil evaporation ($EvapSoil_{pot}$), and potential residue evaporation ($EvapResidue_{pot}$).

### Potential transpiration

Potential crop transpiration in m/day is calculated from:

$$Tr_{pot} = fractCover_{green} \cdot ET_{pot}$$

where

- $fractCover_{green}$ is the fraction of incident radiation intercepted by the crop green leaf area.

### Potential residue evaporation

Potential residue evaporation (m/day) is a function of residue and canopy cover:

$$EvapResidue_{pot} = fractCover_{Residue} \cdot (1 - fractCover_{canopy}) \cdot ET_{pot}$$

where

- $ET_{pot}$ (m/day) is the potential crop evapotranspiration.
- $fractCover_{canopy}$ is the fraction incident radiation intercepted by the crop canopy.
- $fractCover_{Residue}$ is the fraction incident radiation intercepted by the residue, estimated from the mass of residue (Gregory, 1982):

$$fractCover_{Residue} = 1 - e^{-A_m \cdot M}$$

where

- $A_m$ (m²/kg) is the area covered by one average straw per mass of one average straw crop parameter.
- $M$ (kg/m²) is the total residue mass per unit soil area.

### Potential soil evaporation

Potential soil evaporation in (mm/day) is calculated from:

$$EvapSoil_{pot} = (1 - fractCover_{Residue}) \cdot (1 - fractCover_{canopy}) \cdot ET_{pot}$$
Soil evaporation

Actual soil evaporation is simulated by postulating two stages of drying. During the first stage, the evaporation proceeds at the potential rate until the water content in the top evaporative soil layer reaches the permanent wilting point (PWP). For second stage drying, the following equation (Campbell and Diaz, 1988) is used:

\[
\text{EvapSoil}_{\text{act}} = \text{EvapSoil}_{\text{pot}} \cdot \left[ \frac{\text{WC}_1 - \text{ADWC}}{\text{PWP}_1 - \text{ADWC}} \right]^2
\]

where:
- EvapSoil\(_{\text{act}}\) \((\text{m/day})\) is the actual soil evaporation.
- EvapSoil\(_{\text{pot}}\) \((\text{m/day})\) is the potential soil evaporation.
- WC\(_1\) \((\text{m}^3/\text{m}^3)\) is the water content of soil layer 1.
- PWP\(_1\) \((\text{m}^3/\text{m}^3)\) is the permanent wilting point water content of layer 1.
- ADWC \((\text{m}^3/\text{m}^3)\) is the air dry water content soil of the top soil layer, estimated as a third of the permanent wilting point.
Infiltation with the Cascade model

For the simulation of soil water storage, the soil is divided into layers 10cm (or less) thick. When water entering a layer fills the layer to field capacity, any excess water goes to the next layer. Water penetrating past the root zone is lost as drainage.
Runoff simulations

Two water runoff models are provided:

- **SCS Curve number approach**
- **A numerical method available when using the finite difference infiltration model (not yet documented)**
Runoff, after a precipitation event, is calculated using the USDA-SCS curve number approach (USDA-SCS, 1988a).

Runoff is computed as follows:

\[
Q = \begin{cases} 
\frac{(R - 0.2 S)^2}{R + 0.8 S} & \text{if } R > 0.2 S \\
0.0 & \text{if } R \leq 0.2 S
\end{cases}
\]

where
- \( Q \) (m) is the daily runoff.
- \( R \) (m) is the daily rainfall.
- \( S \) (m) is the surface retention factor. Fluctuations in the soil water content affect the surface retention parameter. Corrections for this effect were adapted from Sharpley and Williams, 1990: where
  \[
  S = s_i \cdot \left[ 1.0 - \frac{\text{PAW}^*}{\text{PAW}^* + e(w_1 - W_2 \cdot \text{PAW}^*)} \right]
  \]

\( s_i \) (m) are surface retention factors for each antecedent soil moisture condition (1,2,3) calculated from:

\[
s_i = 0.0254 \cdot \left[ \frac{1000}{\text{CN}_i} - 10 \right]
\]

\( \text{CN}_i \) is the curve number, dependent on soil, land use, management and slope. The subscript \( i \) represents the antecedent moisture conditions (1,2,3) as defined by (USDA-SCS, 1988a). \( \text{CN}_i \) values (and therefore \( s \) values) are different for each condition. In freezing climates, when soil layer 1 is frozen, \( \text{CN}_i \) is adjusted as a fraction of water-filled porosity in soil layer 1 to simulate infiltration reduction.

\[
\text{CN}_i = \text{CN}_i + (100 - \text{CN}_i) \cdot \frac{\text{WC}_1}{1 - \text{BD}_1 / 2.65}
\]

where
- \( \text{WC}_1 \) (m3/m3) is the water content of layer 1.
- \( \text{BD}_1 \) (g/cm3) is the bulk density of layer 1.

When soil layer 1 is frozen and the fraction of water-filled porosity is 1 (i.e. \( \text{WC}_1 = 1 - \text{BD}_1/2.65 \)), the value of \( S \) is set equal to zero, and the equation will predict that all rainfall runs off. However, the current version of CropSyst does not allow water contents to be greater than field capacity, thus this extreme condition is never reached.

\( \text{PAW}^* \) is a depth-weighted plant available water over the soil profile:
\[ \sum_{l=1}^{n_l} PAW_l \left[ \frac{Z_l - Z_{l-1}}{Z_l} \right] \]

\[ PAW^* = \frac{\sum_{l=1}^{n_l} PAW_l \left[ \frac{Z_l - Z_{l-1}}{Z_l} \right]}{n_l} \quad \text{for } Z_l \leq 1.0 \]

\( n_l \) is the number of layers. 
\( Z_l \) is the depth from the soil surface to the bottom of layer \( l \).

\( w_1, w_2 \) are retention curve shaping parameters computed as:

\[ w_2 = 2.0 \cdot \left[ \ln \left( \frac{0.5}{1 - s_2 / s_1} \right) - 0.5 - \ln \left( \frac{1}{1 - s_3 / s_1} - 1 \right) \right] \]

\[ w_2 = \ln \left( \frac{1.0}{1 - s_3 / s_1} - 1.0 \right) + w_2 \]

14.4.1 Freezing soil

Because runoff is affected by frozen soil conditions, it is important to account for this effect in those regions where freezing soil conditions may exist in part of the year.

Soil freezing can affect the curve number runoff.

When freezing occurs the curve number is adjusted by the following equation: Need the equation from the code.
### Runoff curve numbers

#### Runoff curve numbers for hydrologic soil cover complexes

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Erosion simulation

Soil loss due to water erosion uses the Revised Universal Soil Loss Equation (RUSLE) which computes the average annual erosion expected on the field slope as:

\[ E = C \cdot R \cdot K \cdot L \cdot S \cdot P \]

where

- **E** (tonne/ha) is soil erosion.
- **C** (unitless dimensionless) is the **crop management factor**.
- **R** (MJ·mm/ha·h) is the average annual **rainfall erosivity**.
- **K** ((tonne·ha·h)/(ha·MJ·mm)) is the **soil erodibility factor**.
- **L** (unitless dimensionless) is the **slope length factor**.
- **S** (unitless dimensionless) is the **steepness factor**.
- **P** is the **erosion control practice factor** management input parameter.

### Rainfall energy intensity factor (R)

To estimate **R**, recording rain-gage records for all the storms in each year for a long number of years is required. Mathematically, **R** is:

\[
R = \frac{1}{n} \sum_{j=1}^{n} \left[ \sum_{k=1}^{m} E \cdot I_{30} \cdot k \right]
\]

where

- **E** (MJ/ha) is total storm kinetic energy.
- **I_{30}** (mm/h) is the maximum 30-min rainfall intensity.
- **j** is the index of the number of years used to produce the average.
- **k** is the index of the number of storms in each year.
- **n** is the number of years used to obtain average **R**.
- **m** is the number of storms in each year.

The erodibility factor is based on the fractional contribution of rainfall energy intensity for a given day (**REI_{day}**):

\[
\text{REI}_{\text{day}} = \frac{\text{REI}_{\text{day}}}{\sum \text{REI}_{\text{day}}}
\]
REI\textsubscript{\text{day}} is 0 if no daily precipitation.

REI\textsubscript{\text{day}} is the daily rainfall energy intensity.
The rainfall energy intensity factor for each day is calculated as:

\[
\text{REI}_{\text{day}} = \text{precip}_{\text{day}} \cdot (0.199 + 0.0873 \cdot (\log_{10} r_{p} - 0.434) \cdot R_{0.5})
\]

where

\(\text{precip}_{\text{day}}\) (mm) is the daily precipitation from weather data.

\(r_{p}\) (mm/h) is the peak rainfall rate:

\[
r_{p} = 1.20 \cdot \text{precip}_{\text{day}} \cdot \ln(1.0 - \alpha_{0.5})
\]

\(R_{0.5}\) (mm) is the maximum ½ hour rainfall amount.

\[
R_{0.5} = \alpha_{0.5} \cdot \text{precip}_{\text{day}}
\]

\(\alpha_{0.5}\) expresses the maximum portion of total rainfall that occurs during an ½ hour (unitless 0.0208 - 1.0) It is generated by random sampling from a triangular distribution with a base ranging from 0.0208 to \(\alpha_{0.5u}\)

\[
\alpha_{0.5u} = 1 - e^{(-125/\text{precip}_{\text{day}})}
\]

with a probability density function peak at \(\alpha_{0.5u} \cdot \alpha_{0.5m}\).

\(\alpha_{0.5m}\) is the monthly mean maximum portion of total rainfall that occurs during a ½ hour period, location input parameter for the month in which day falls.

**Soil erodibility factor (K)**

This factor accounts for the influence of soil properties on soil loss during storm events. Soil erodibility factors are best obtained from direct measurements on material or simulated rainfall runoff plots. Because this type of data is not available for many locations, predictions based on soil properties are used. A general relationship based on published global data including 225 soils of measured K values obtained from natural and studies of simulated rainfall can be expressed as:

\[
K = 7.594 \times [0.0034 + 0.0405 \cdot e^{-1/2 \cdot [(\log_{10} D_{g} + 1.659)/0.7101]^2}]\]

where

\(D_{g}\) is the mean geometric particle diameter (mm).

\[
D_{g} = e^{\left(\sum f_{i} \cdot \ln m_{i}\right)}
\]

where

\(i\) is the soil texture component: Sand, Clay, Silt.

\(f_{i}\) is the primary particle size fraction in percent for sand, clay and silt input parameter.

\(m_{i}\) is the arithmetic mean of the particle size limits of that size:
The evaluation of the K-factor for soils subjected to freezing and thawing and soils with rock fragments are areas of concern. Users should consult the RUSLE documentation for further discussion on those conditions.

### Slope length factor (L)

This factor can be estimated based on the horizontal slope length as follows:

\[ L = \left[ \frac{\lambda}{22.13} \right]^m \]

where

- \( L \) (unitless) is the slope length factor.
- \( \lambda \) (m) is the horizontal slope length soil parameter.
- \( m \) is an exponent related to the ratio of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact).

### Slope steepness factor (S)

This factor is evaluated from McCool et al., 1987 as follows:

\[
S = \begin{cases} 
10.8 \sin \theta + 0.03 & \text{slope} < 9\% \\
16.8 \sin \theta - 0.5 & \text{slope} \geq 9 \% \\
3.0 \sin 0.8 + 0.56 & \text{slope} < 4.5\% 
\end{cases}
\]

where \( \theta \) is the slope angle.

The relationship between slope percent and slope angle is given by:

\[ \theta = \arctan \text{slope}\%/100 \]

where slope \% is the slope steepness.

### Soil Conservation Practice Factor (P)

The P-factor in RUSLE is the ratio of soil loss with a specific support practice to the corresponding loss with up and downslope tillage. For cultivated land, support practices include contouring (tillage and planting on or near the contour), strip cropping, terracing, and subsurface drainage. On dryland or rangeland areas, use of soil disturbing practices oriented on or near the
contours that store moisture and reduce runoff are also used as support practices.

The P-factor does not consider improved tillage practices such as no-till and other conservation tillage systems, sod-based crop rotations, fertility treatments, crop residue management, and surface roughening. Such erosion control practices are considered in the C-factor.

RUSLE recommended values for the P-factor are included in a large number of tables in the RUSLE documentation which are not practical to be reproduced in the brief summary presented here. Refer to the soil conservation practice management input parameter of a brief method for determining this value.

C-Factor

The CropSyst determination of the C-factor is similar to that presented by McCool, 1976 and McCool and Krauss, 1981 for long time steps, but is calculated daily and averaged for each year.

\[
\frac{\sum_{\tau = 1}^{n} SLR_{\tau} \cdot RR_{\tau}}{n}
\]

where

- \( SLR_{\tau} \) is the daily soil loss ratio.
- \( RR_{\tau} \) is the daily rainfall and runoff erosivity factor.
- \( n \) is the number of days in the year.
- \( \tau \) (day) is an index denoting time step.

Daily Rainfall and Runoff erosivity factor (RR)

In regions with predominately winter precipitation, water erosion is much more severe during the winter period. This corresponds to the time when crops such as winter wheat are too small to protect the soil from erosion. In the summer period, crop cover is less important for soil erosion. This difference is reflected in the rainfall and runoff erosivity factor.

Soil Loss Ratio

The soil loss ratio is defined as "the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow" (\( C \)). It is a product of five components:

\[
SLR_{\tau} = SR_{\tau} \cdot IR_{\tau} \cdot CC_{\tau} \cdot SDR_{\tau} \cdot SM_{\tau}
\]

Where

- \( SR_{\tau} \) (0-1) is the surface residue cover factor.
IR (0-1) is the incorporated residue factor.  
CC (0-1) is the Green crop cover factor.  
SDR (0-1) is the surface soil detachability and roughness (SDR).  
SM (0-1) is the Soil moisture factors.

Surface residue cover factor

The surface residue cover factor is based on the curve recommended by McCool (personal communication, 1991) based on previous work by Wischmeier.

\[ SR = e^{-5 \cdot \text{Residue}_{\text{surface}}} \]

where

\( \text{Residue}_{\text{surface}} \) (kg/m²) is surface residue.

As \( \text{Residue}_{\text{surface}} \) increases, the cover factor decreases, giving less soil erosion.

Incorporated residue factor (IR)

Shallow incorporated residue in the soil is assumed to reduce the cover factor 12% for each ton of buried material (or 54% for every kg/m²) (McCool, 1976). This is expressed by the equation:

\[ IR = e^{(-2.655 \cdot \text{Residue}_{\text{shallow}})} \]

where

\( \text{Residue}_{\text{shallow}} \) (kg/m²) is the shallow incorporated residue.

Crop Cover factor (CC)

The values of crop cover factor are calculated from crop fractional interception (\( \text{fractCover}_{\text{canopy}} \)). The function relating (CC) to \( \text{fractCover}_{\text{canopy}} \) is provided by McCool and Krauss, 1981.

Linear interpolation between specified values is used for obtaining CC for any crop cover. Seven pairs of data points are used to define the function. In fallow periods, CC is equal to 1.

Soil Moisture factor (SM)

According to McCool and Krauss, 1981, the soil moisture factor (SM) is unity when the soil profile is fully charged with water. SM is zero when soil water in the profile is fully depleted, which is the case when the water content of the surface layer is at air dry and the water content of the rest of the profile is at permanent wilting point. Relative available water is used as the moisture factor where available water is defined as the soil water content...
greater than air dry water content at the top soil layer and greater than permanent wilt water content in the rest of the soil profile within the rooting depth, but less than field capacity:

\[
\text{SM} = \frac{\sum_{l=2}^{RD_{\text{max}}} \left( \frac{WC_l - \text{ADWC}}{\left(FC_l - \text{PWP}_l \cdot (RD_{\text{max}} - 2) + FC_l - \text{ADWC} \right)} \right)}{	ext{RD}_{\text{max}}}
\]

where

- \(\text{SM}\) is the ratio of the available water in the whole rooting depth to the potential available water in that depth.
- \(RD_{\text{max}}\) (m) is the maximum rooting depth.
- \(WC\) (m³/m³) is the water content.
- \(l\) is the soil layer.

With this equation, SM is equal to 0 when soil evaporation and crop transpiration uses all the available water from the soil rooting depth, and SM reaches 1 when the soil profile is fully charged with water in the midwinter and spring and decreases naturally with depleting soil water in the growing season.
Rill/interrill relationships

Values of m are given in the following table as a function of percent slope and rill/interrill ratio. A low rill/interrill ratio corresponds to conditions such as rangeland and other consolidated soil conditions with cover. Moderate ratio corresponds to row-cropped agricultural and other moderately consolidated soil conditions with little to moderate cover. High ratio corresponds to freshly prepared construction and other highly disturbed soil conditions with little or no cover.

Slope length exponents for range of slope and rill/interrill erosion classes

<table>
<thead>
<tr>
<th>Parameter slope</th>
<th>Rill/Interrill ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>0.5</td>
<td>0.04</td>
</tr>
<tr>
<td>1.0</td>
<td>0.08</td>
</tr>
<tr>
<td>2.0</td>
<td>0.14</td>
</tr>
<tr>
<td>3.0</td>
<td>0.18</td>
</tr>
<tr>
<td>4.0</td>
<td>0.22</td>
</tr>
<tr>
<td>5.0</td>
<td>0.25</td>
</tr>
<tr>
<td>6.0</td>
<td>0.28</td>
</tr>
<tr>
<td>8.0</td>
<td>0.32</td>
</tr>
<tr>
<td>10.0</td>
<td>0.35</td>
</tr>
<tr>
<td>12.0</td>
<td>0.37</td>
</tr>
<tr>
<td>14.0</td>
<td>0.40</td>
</tr>
<tr>
<td>16.0</td>
<td>0.41</td>
</tr>
<tr>
<td>20.0</td>
<td>0.44</td>
</tr>
<tr>
<td>25.0</td>
<td>0.47</td>
</tr>
<tr>
<td>30.0</td>
<td>0.49</td>
</tr>
<tr>
<td>40.0</td>
<td>0.52</td>
</tr>
<tr>
<td>50.0</td>
<td>0.54</td>
</tr>
<tr>
<td>60.0</td>
<td>0.55</td>
</tr>
</tbody>
</table>
The soil freezing model described here is not longer implemented in this original form. It has been modified to perform freezing and thawing with freezing lenses.

The original soil freezing model was a modified version of a model developed by Jumakis (van Rooij, 1987) has been incorporated into CropSyst. Daily cumulative freezing index (CFI) for day d (C-days) is calculated as:

\[
\text{CFI}_d = D \cdot \text{CFI}_{d-1} - T_{\text{avg}} \cdot e^{(-0.4 \cdot S \cdot D_{sd})}
\]

where
- \( D \) (0.97) is the daily decay coefficient.
- \( T_{\text{avg}} \) (C) is the average daily air temperature.
- \( S \) (cm\(^{-1}\)) is the snow reduction coefficient.

\[
\begin{align*}
0.8 & \quad \text{if } T_{\text{avg}} \leq 0 \text{ (freezing periods)} \\
0.5 & \quad \text{if } T_{\text{avg}} > 0 \text{ (thawing periods)}
\end{align*}
\]

\( D_{sd} \) (cm) is snow depth on the ground on day d.

CFI is a measure of the available "climate freezing power". CFI\_d is initialized to a certain negative value at the beginning of the winter to represent a lag between climatic freezing conditions and the beginning of actual soil freezing. As freezing temperature prevail, CFI\_d becomes less negative first and positive, indicating potential to freeze the soil.

To calculate the frost depth, the freezing index required to freeze each one of the soil layers (RFII) must be calculated and compared with CFI\_d. Because the presence of a snow layer on the soil decreases the rate of penetration of frost, the thermal conductivity of the snow must be determined. This is done according to the following equation:

\[
\text{k}_{sn} = (22.7 \cdot \rho_{sn} - 0.46) \cdot 10^5
\]

where
- \( \text{k}_{sn} \) (cal/(cm \cdot s \cdot C)) is the snow thermal conductivity.
- \( \rho_{sn} \) (0.1 g/cm\(^3\)) is the snow density or one tenth the density of water.

The snow thermal resistance is given by:

\[
\text{r}_{sn} = \frac{D_s}{\text{K}_{sn} \cdot \text{SEDF}}
\]

where
- \( \text{r}_{sn} \) ((cm\(^2\) \cdot s \cdot C)/cal) is the snow thermal resistance.
- \( D_s \) (cm) is snow depth on the ground.

SEDF is a snow effect decrease with depth factor which is calculated daily and multiplied with the snow thermal resistance and the resulting value is added to the total resistance of all layers together. This decrease factor is given by:
\[ SEDF = e^{-SIF \cdot F_d} \]

where

- \( SIF \) (1/cm) is the snow insulation factor input parameter.
- \( F_d \) cm is the frost depth.

The thermal resistance of each soil layer is given by:

\[ r_l = \frac{\Delta Z_l}{K_l} \]

where

- \( r_{l} \) ((cm\(^2\) . s . C)/cal) is soil layer thermal resistance.
- \( Z_l \) (cm) is soil layer thickness.
- \( K_l \) (cal/(cm . s . C)) is the soil layer thermal conductivity.

To freeze the \( l \)th layer, the thermal resistance of all previous layers has to be exceeded before the freeze front can reach it, where the snow is treated as a layer with its own snow thermal resistance. The required freezing index is then given by:

\[ RFI_l = \left[ \frac{c \cdot CFI}{L_l + 2 \cdot fd} \right] \]

where

- \( RFI_l \) (C-days) is the required freezing index to freeze layer \( l \).
- \( L_l \) (cal/cm\(^3\)) is the latent heat released when freezing layer \( l \) calculated from the layer volumetric water content (\( WCl \)) and the latent heat of fusion (80 cal/cm\(^3\)) as:
  \[ L_l = 80 \cdot WCl \]
- \( C \) (cal/(cm\(^3\) . C)) is heat capacity.
- \( CFI \) (C-days) is the cumulative freezing index.
- \( fd \) (days) is the number of freezing days.
- \( Z_l \) (m) is the thickness of the \( l \)th soil layer.
- \( R_{tot} \) ((cm\(^2\) . s . C)/cal) is the total thermal resistance given by:
  \[ R_{tot} = r_{sn} + r_1 + r_2 \cdots + \left[ \frac{r_{nl}}{2} \right] \]
- \( r_{sn} \) is the thermal resistance of the snow layer.
- \( r_1, r_2 \ldots r_{nl} \) are the resistances of each soil layer.

A special case for the required freezing index to freeze the first soil layer is calculated according to the following equation:

\[ RFI_1 = \frac{L_1 \cdot \Delta Z_1}{84,400} \cdot \left[ \frac{r_1}{2} + r_n \right] \]
where
RFI1 (C- days) is the required freezing index to freeze layer 1.
L1 (cal/cm³) is the latent heat released when freezing layer 1.
WC1 is the volumetric water content of the first soil layer.
r_1 ((cm² . s . C)/cal) is the thermal resistance of the first soil layer.

The required freezing index for the entire soil profile (RFIt) is determined as the sum of the required freezing index for each soil layer:

\[ RFI_t = \sum_{l=1}^{n_l} RFI_l \]

The value of CFI_d for the current day is compared to RFI accumulated layer by layer. Frost depth is given by the layer where cumulative RFI become larger than CFI. The point of the freezing front in that layer is determined by linear interpolation.

### 14.4.2 Soil Heat Capacity

The heat capacity must consider the individual components in the soil and thus can be calculated by adding the weighted heat capacity of each of the different soil constituents to the total heat capacity:

\[ C = X_s \cdot C_s + X_w \cdot C_w + X_a \cdot C_a \]

where
C (cal/(cm³ . C)) is the volumetric heat capacity.
Xi (-) is the volume fraction of the component i.
Ci (cal/(cm³ . C)) is the volumetric heat capacity of component i.
s is the solid component.
a is the air component.
w is the water component.

The values of the volumetric specific heat capacity are 0.46, 0.45, 0.0003, 1.0 for mineral solid material, ice, air and water respectively. The air component was neglected in the calculations because of its small contribution to the total specific heat.

### Soil Thermal Conductivity

The thermal conductivity is calculated by:
\[
K = \frac{\sum M_i \cdot X_i \cdot K_i}{\sum M_i \cdot X_i}
\]

where

- \( K \) (cal/(cm . s . C)) is the thermal conductivity.
- \( i \) is the component in the soil.
- \( X_i \) is the volume fraction of component \( i \).
- \( K_i \) (cal/(cm . s . C)) is the specific thermal conductivity of component \( i \).
- \( M_i \) is the ratio of the average temperature gradient of each minor component and the corresponding quantity in the medium through which most of the heat is transported.

The value for \( M_i \) can be calculated dependent on the shape and size of the particles and their relative positions. Under the conditions that the granules are of ellipsoidal shape and that they are so far apart that they do not influence each other, the following expression can be used to calculate this parameter:

\[
M_{ia} = \frac{1}{3} \frac{k_i}{1 + \frac{k_i}{k_0 + 1}} \cdot G_a
\]

\[
M_i = M_{ia} + M_{ib} + M_{ic}
\]

where

- \( G_a \) is the depolarization factor of the ellipsoid in the direction of the a-axis.
- \( K_0 \) (cal/(cm . s . C)) is the specific thermal conductivity of the continuous medium in the soil (mostly water or ice).
- \( M_{ia} \) is the contribution to the factor \( M_i \) of the direction \( a \).

When the soil air content is between 0.0 and 0.337 then value for \( G_a \) can be calculated from:

\[
G_a = 0.333 - X_a / 0.427 \cdot (0.333 - 0.35)
\]

where

- \( X_a \) is the soil air volume content.

The specific thermal conductivities values taken were: 20.4, 7.0, 5.2, 1.3 (mcal/(cm . s . C)) for quartz, minerals, ice and water. The value for the \( G_a \) factor is also valid for \( G_b \). The value for \( G_c \) is calculated from:

\[
G_a + G_b + G_c = 1
\]
The use of these equations is explained as follows: when soil consists of only one component, such as quartz, the thermal conductivity would only be that of quartz; if water is also present, the value for thermal conductivity would be between quartz and water. When the conductivity of one substance is much smaller than the other, almost all the heat will be transported by the substance with the higher conductivity.
Crop simulation

The crop simulation is modelled using a crop object. The crop object is derived from a heirarchy of crop classes each providing more sophisicated higher level capabilities:

Basic crop

This class provides for basic growth characteristics common to all crop growth simulations.

Full crop

This class adds capabilities for responding to management operations such as
  o Waiting for ideal planting conditions.
  o Trimming, clipping and other special harvest operations.

Crop nitrogen

This class enhances crop growth simulation for consideration of nitrogen.

Complete crop

This class add capabilites specific to the CropSyst simulation:
  o Contribution to residue pools
  o Domancy of perennial crops.

Crop simulation steps

● Crop growth simulation first determines potential transpiration in the evapotranspiration model.
● Next potential growth based on phenology and morphology is determined.
● This is followed by the modelling of the soil water operations. This results in the adjustment of soil water potentials used by transpiration.
● > Finally, with soil water potentials updated for the day, actual growth and transpiration applying limitiations to crop growth based on current conditions can be simulated.
Crop growth and development

The crop growth and development cycle in CropSyst consists of several identifiable phenologic stages of development based on thermal time.

The thermal time accumulation serves as the basis of CropSyst's crop phenology simulation.

Development Stages

Different crops may have all or some of these simulated stages and events.

- **Planting event**
  - Begin accumulation of growing degree days.
- **Preemergence**
  - No canopy or above ground leaf development.
  - No actual transpiration.
- **Emergence**
  - Crop is established.
  - Initial root depth and leaf area index are defined.
  - Canopy biomass is initialized
- **Active growth**
  - Root growth.
  - Canopy development.
  - Leaf area development.
  - Transpiration.
  - Nitrogen uptake.
- **Flowering**
  - Root growth for many crops reaches maximum. (This crop characteristic is user specified)
  - Leaf area reaches maximum. (This crop characteristic is user specified)
  - Harvest index sensitivity to flowering stress accounted.
  - Transpiration.
  - Nitrogen uptake.
- **Grain filling (for grain crops)**
  - Grain filling is started.
  - Harvest index sensitivity to grain filling stress accounted.
  - Transpiration.
  - Nitrogen uptake.
- **Physiological maturity**
Crop is mature.
- No further accumulation of biomass (grain filling stops)
- Green area for most crop is minimal.
- Transpiration is minimal.

- **Harvest event**
  - Crop is harvested.
  - Crop biomass removed.
  - A fraction of crop canopy may remain in the field as residue.
  - No transpiration.

**Transpiration**

Transpiration or water uptake occurs throughout most of the crop's active development cycle and is used to derive biomass accumulation, leaf area, and root depth.

**Stress effects**

In CropSyst, an overall stress index is determined as one minus the ratio of actual to overall potential biomass growth for each day of the growing season. Overall potential growth is defined as the growth calculated from potential transpiration ($T_{pot}$) substituted for $T_{act}$.

Actual biomass growth is obtained after growth limitations have been applied. This overall stress index is partitioned into light, temperature, water, and nitrogen stress indices. These quantities are used as indicators of the plant response to environmental conditions. All these indices range from 0 to 1, where 0 is no stress and 1 is maximum stress.
Crop planting

CropSyst provides two modes for the simulation of crop planting. For the fixed planting mode, the simulation of crop growth begins on the specified date. For the computed planting mode, a five-day average air temperature above planting temperature requirement and a specified water content of the second soil layer are used as check conditions for planting (water contents of the top evaporative layer is highly fluctuating).

Planting (or beginning of the germination process) occurs if the following conditions are satisfied:

\[
\sum_{d=\text{today}}^{\text{today}+5} \left[ \frac{( \text{Tmax}_d + \text{Tmin}_d )}{2} \right] \geq \text{T}_{\text{req}}
\]

and

\[
\text{WC}_2 \geq \text{WC}_{\text{req}}
\]

where

- \text{today} is the date in the simulation.
- \text{Tmin}_d, \text{Tmax}_d (°C) are the minimum and maximum temperatures of day d.
- \text{T}_{\text{req}} (°C) is the planting date temperature requirement crop parameter.
- \text{WC}_2 (m^3/m^3) is the water content of the second soil layer.
- \text{WC}_{\text{req}} (m^3/m^3) is the water content required for planting crop input parameter.
Potential growth

The following morphologic calculations are performed to determine potential growth:

- Root depth
- Accumulation of thermal time
- Fraction of canopy cover
- Plant height
- Growth limitations
- Max pot transpiration
- Dormancy
Rooting

Root growth occurs soon after planting and continues while GAI accumulates or until flowering (flowering is a significant phenologic growth stage), or continuously in the case of a perennial.

Root depth

When computing root depth, because stress (water and nitrogen) seems to enhance root penetration, the ratio LAI/LAI\text{max} is affected to a power given by the minimum of the water or nitrogen stress indices. Root length is an accumulation of daily root length with root depth starting at the planting depth (currently taken as the bottom of the first sublayer). The accumulation of root length does not start until the daily RAI exceeds 0.001, The root depth is not allowed to exceed the maximum root depth (crop parameter).

The root length added each day is:

$$RD_{\text{max}} \cdot \left( \frac{(0.0083 \cdot LAI_{\text{max}} + RAI_d)}{LAI_{\text{max}} \cdot LAI_{\text{lag}}} \right)$$

where

- $RD_{\text{max}}$ is the maximum root depth crop parameter.
- $LAI_{\text{lag}}$ is the LAI lag factor
  $$\left(1 - \frac{0.7 \cdot LAI}{LAI_{\text{max}}}\right)$$
  Which is not allowed to be negative

For the calculation of root depth, LAI is determined as a function of above ground biomass, but the threshold to stop growth (biomass accumulation) due to stress is given by the AT/PT ratio where root growth ceases input parameter.

Root density

Root density is determined as a root length fraction. Root fraction is a function of rooting depth because rooting density is assumed to decrease linearly with depth (Campbell, 1988) with a maximum at the top of the soil profile and a value of zero at the tip of the current root depth. Therefore, if $Z_l$ is the depth (m) to the bottom of soil layer $l$:

if $Z_l \leq R_d$ then

$$f_l = \frac{\Delta Z_l \cdot (2 \cdot (R_d - Z_l) + \Delta Z_l)}{R_d^2}$$

if $Z_l - \Delta Z_l < R_d < Z_l$ then
\[ f_1 = \left[ \frac{R_d - Z_1 - \Delta Z_1}{R_d} \right] \]
Phenology

The stages of development are determined by the accumulation of thermal time (Growing degree days).

Thermal time for the crop is accumulated throughout the growing season (starting with planting until harvest).

A crop enters the next stage of development when the thermal time reaches the thermal time requirement for the respective stage.

Thermal time is computed with the following equation:

\[
GD_{\text{day}} = T_{\text{ave}} - T_{\text{GD day base}}
\]

\[
CGD_{\text{day}} = CGD_{\text{day-1}} + GD_{\text{day}}
\]

\[
T_{\text{ave}} = \begin{cases} 
T_{\text{GD day base}} & \text{if } T_{\text{ave}} < T_{\text{GD day base}} \\
T_{\text{cutoff}} & \text{if } T_{\text{ave}} > T_{\text{cutoff}} \\
\frac{(T'_{\text{max}} + T_{\min})}{2} & \text{otherwise}
\end{cases}
\]

where

GD_{\text{day}} \quad (\text{°C-days}) \text{ is today's thermal time.}

CGD_{\text{day}} \quad (\text{°C-days}) \text{ is today's accumulated thermal time since planting.}

T_{\text{GD day base}} \quad \text{are crop input parameters that define the range of temperatures for viable development.}

T_{\text{cutoff}} \quad \text{is the daily minimum air temperature.}

T'_{\text{max}} \quad (\text{°C}) \text{ is the daily maximum air temperature.}

Because many crops accelerate development if subjected to water stress, it is a user's option to activate a corrective mechanism. This is based on the assumption that plants will be warmer if transpiration is limited by water stress and will accelerate development. The correction is implemented by adding temperature to the \( T_{\text{max}} \) input to plant temperature equation according to the following equation:

\[
T'_{\text{max}} = [1 + (1.5 - VPD_{\text{max}})] \cdot \text{StressIndex}_{\text{water}} \cdot \text{PSWS}
\]

where

\( T_{\text{max}} \quad (\text{°C}) \text{ is the daily maximum air temperature.}

\text{StressIndex}_{\text{water}} \quad (0-1) \text{ ranging from 0 (no stress) to 1 (maximum stress) is the daily plant water stress index.}
VPD\text{max} \quad (\text{kPa}) \text{ is the maximum vapor pressure deficit (for saturated vapor pressure (VP}_{\text{sat}} \text{) at T}_{\text{max}} \text{ or T}_{\text{min}}.} \text{ VPD}_{\text{max}} \text{ is limited to a range of 0.0 to 0.6 kPa.}

\begin{equation}
\text{VPD}_{\text{max}} = \frac{\text{VP}_{\text{sat}}_{\text{T}_{\text{max}}} - \text{VP}_{\text{sat}}_{\text{T}_{\text{min}}}}{1 - \text{aridity} \cdot (\text{VP}_{\text{sat}}_{\text{T}_{\text{max}}} - \text{VP}_{\text{sat}}_{\text{T}_{\text{min}}})}
\end{equation}

\text{aridity} \quad \text{is the aridity factor.}

\text{PSWS} \quad \text{is the phenologic sensitivity to water stress crop input parameter}

\text{For crops whose development is not expected to be affected by water stress, this correction can be deselected by the user (PSWS = 0).}

\text{For some crops like sorghum, water stress may actually delay development (PSWS < 0).}

\textbf{Vernalization and Photo-period effects on thermal time}

\text{Some crops such as winter wheat undergo the process of vernalization. This requires an adjustment of thermal time to accomodate the vernalization process (f}_{\text{ver}} \text{) that occurs in such crops.}

\text{Some crop such as oats, sugarbeet, winter barley, soybeans, maize and rice are sensitive to day length. This requires an adjustment of thermal time to accomodate the sensitivity to photo period (f}_{\text{photo}} \text{) that occurs in such crops.}

\text{Each day, the thermal time calculated from temperature is multiplied by the minimum of f}_{\text{ver}} \text{ or f}_{\text{photo}} \text{ to determine the actual amount of degree-days accumulated for the day.}
Above ground biomass accumulation

Crop growth occurs during active growth until maturity, (but not after maturity is achieved) and only when potential transpiration has been determined by the evapotranspiration model.

Above ground crop growth is represented in terms of above ground biomass accumulation. Above ground biomass production is dependent on: intercepted radiation (radiation dependent), transpiration (water-dependent), and plant nitrogen uptake (nitrogen-dependent). Each of these factors is capable of limiting growth.

Radiation dependent growth

Radiation dependent biomass production (G<sub>R</sub>) (kg/m<sup>2</sup>/day) is calculated as:

\[
G_R = \frac{\text{LtBC} \cdot \text{Rad}_{\text{est}}}{2 \cdot (1 - e^{(\text{max}(-k_c \cdot 1.4 - 0.9) \cdot \text{GAI} \cdot (\text{clump} + (1.0 - \text{clump}) \cdot (1 - e^{-0.25 \cdot \text{GAI}})))} \cdot T_{\text{lim}}}
\]

where

LtBC (kg/MJ) (converted from g/MJ)

is a coefficient representing the conversion of photosynthetically active radiation (PAR) to above ground biomass input parameter.

Rad (MJ/m<sup>2</sup>/day)

is the total daily solar irradiance above the crop canopy. This is an actual value if available in the weather file, otherwise it is estimated.

fractCover* canopy (0-1)

is the fraction of incident PAR intercepted by the canopy.

0.5

is a constant to represent that PAR corresponds to approximately half of the total solar irradiance.

T<sub>lim</sub>

is a temperature limitation factor.

Temperature limitation is applied if the current thermal time accumulation is less than a user selected threshold (thermal time at which temperature limitation ceases crop input parameter. (If T<sub>lim</sub> < 0.01 it is assumed to be the most significant factor (given a value of essentially 0.0)).

\[
T_{\text{lim}} = \begin{cases} 
1.0 & \text{if } T_{\text{avg}} > T_{\text{opt}} \\
0.0 & \text{if } T_{\text{avg}} < T_{\text{base}} \\
\frac{(T_{\text{avg}} - T_{\text{base}})}{(T_{\text{opt}} - T_{\text{base}})} & \text{otherwise}
\end{cases}
\]

where
GD_{day} \text{ (growing degree days)}

is \text{ thermal time} determined for the current day.

T_{avg} \text{ (°C)}

is the daily average air temperature.

T_{base} \text{ (°C)}

is the crop input parameter: \text{ thermal time base temperature}.

T_{opt} \text{ (°C)}

is the \text{ optimal temperature for growth} crop input parameter.

It is assumed that temperature effects, after cumulative degree-days is larger than the threshold, are accounted for in the radiation conversion factor LtBC, which is empirically derived, usually using observations during the linear phase of biomass accumulation when temperatures are warmer.

**Water dependent growth**

Crop transpiration dependent biomass production \(G_{Tr}\) (kg/m²)/day is calculated using (Tanner and Sinclair, 1983):

\[ G_{Tr} = \frac{Tr_{act} \cdot BTR}{VPD} \]

where

BTR ((kg/m² · kPa)/m)

is the \text{ above ground biomass-transpiration coefficient} crop parameter.

\(Tr_{act}\) (m)

is the \text{ actual transpiration}.

VPD (kPa)

is the \text{ daily mean vapor pressure deficit}.

If VPD > VPD_{limit} (crop parameter) then \(G_{Tr}\) is set to \(G_{R}\)

**Nitrogen dependent growth**

Nitrogen dependent growth will be applied if nitrogen simulation is enabled.
Crop Transpiration

As a function of actual growth, crop transpiration occurs once the plant emerges and begins active growth and continues until the crop reaches maturity, outside of this period of growth, transpiration is zero. Perennial crops often do not reach a maturity; however, they may go into a period of dormancy, during this time, transpiration is shut down.

Potential transpiration

Potential transpiration serves as a guide line for determining actual transpiration and ultimately crop growth. Potential transpiration is a function of the evapotranspiration model.

Crop actual transpiration

In CropSyst, crop water uptake and actual crop transpiration are considered equal, i.e., crop water storage is assumed negligible.

For calculation of crop water uptake, the soil profile is divided into layers, and the water uptake of each layer is calculated from the water potential difference between the soil and the plant xylem, multiplied by plant conductance (mainly determined by root conductance).

The soil conductance is assumed to be large compared to root conductance so that water uptake is not limited by water movement towards the roots.

The water uptake (WU_l, in ((kg/m²)/day), equivalent to 0.001 m/day) from each soil layer (l) is given by:

\[ WU_l = K \cdot C_l/1.5 \cdot (\psi_{sl} - \psi_l) \]

In the case of freezing temperatures, there is no water uptake from frozen soil layers. No transpiration is allowed from soil layer one, the evaporative layer.

The total water uptake WU is the sum of the uptake from each soil layer.

\[ WU = \sum_{l=1}^{n} WU_l \]

where

\[ \psi_{sl} (J/kg or m²/s²) \] is the soil water potential of soil layer l.

The soil water potential for each layer is calculated using (Campbell, 1985):

\[ \psi_{sl} = -a \cdot WC_l^{-b} \]

where
$WC_l$ (m³/m³) is the water content of the lth soil layer. The values of a and b vary with soil texture. Based on known values of water content at soil water potential of (-30 J/kg) (field capacity for many soil) and (-1,500 J/kg) (permanent wilting point for some soil/crop species), then the parameters a and b can be estimated as:

\[
a = e \left( \ln(30) + b \cdot \ln(WC_{-30}) \right)
\]

\[
b = \frac{\ln \left[ \frac{-1,500}{-30} \right]}{\ln \left[ \frac{WC_{-30}}{WC_{-1500}} \right]}
\]

where

$WC_{-1500}$ (-1,500 J/kg) is the water content at a soil water potential.

$WC_{-30}$ (-30 J/kg) is the water content at a soil water potential.

$\psi_l$ (J/kg or m²/s²) is the leaf water potential calculated from:

\[
\psi_l = \text{avg}(\psi_s) - \frac{1.5 \cdot Tr_{pot}}{C_{Tc}} \cdot K
\]

where

avg($\psi_s$) is the average of the soil layer water potentials. The value of avg($\psi_s$) depends on the soil water potential and the fraction of total root length in each soil layer ($f_{sl}$):

$Tr_{pot}$ ((kg/m²)/day) is the potential crop transpiration (equivalent to 0.001 m/day).

$C_{Tc}$ is the current (today's) total root conductance.

K (86,400) is the number of seconds per day.

1.5 is a factor that converts total root conductance to total plant hydraulic conductance.

When $\psi_l$ (from the calculation of leaf water potential) is less than $\psi_{[l,sc]}$ (the leaf water potential (J/kg) just before the beginning of stomatal closure due to water deficit (a crop input parameter), but larger (less negative) than $\psi_{[x,wilt]}$ wilting plant leaf water potential (a crop input parameter), then $\psi_l$ is recalculated as:

\[
\psi_l = \frac{1.5 \cdot Tr_{pot} \cdot \psi_l - \psi_{l,wilt}}{\psi_{[l,sc]} - \psi_{l,wilt}}
\]

Because $\psi_l$ is in both sides of the equation, its value is calculated by solving for $\psi_l$ as follows:
\[ \psi_l = \psi_s \cdot \frac{C_{Tc} \cdot K \cdot (\psi_{l,sc} - \psi_{l,wilt}) - 1.5 \cdot Tr_{pot} \cdot \psi_{l,wilt}}{C_{Tc} \cdot K \cdot (\psi_{l,sc} - \psi_{l,wilt}) \cdot 1.5 \cdot Tr_{pot}} \]

If \( \psi_l \) from equation is less than \( \psi_{[l,wilt]} \) (wilting leaf water potential input parameter), then \( \psi_l \) is set equal to \( \psi_{[l,wilt]} \).

\( C_l \) is the layer root conductance determined from current total root conductance \( (C_{Tc}) \) in \((kg \cdot s/m^4)\) and the fraction of total root length in each layer:

\[ C_l = f_l \cdot C_{Tc} \]

where

\( f_l \) is the fraction of the total root length present in the l'th soil layer.

\( C_{Tc} \) is the current total root conductance calculated as:

\[ C_{Tc} = C_t \cdot FractCover_{canopy} \]

where \( C_t \) is maximum total root conductance. This value can be estimated if a maximum uptake rate is assumed for a fully developed green crop, unstressed, fully watered, with unrestricted root penetration, and under an environment providing large atmospheric evaporative demand. Under this set of conditions, any evaporative demand larger than the maximum uptake rate will only induce stomatal closure.

\[ C_t = \frac{1.5 \cdot WU_{max}}{\psi_{fc} - \psi_{l,sc} \cdot K} \]

where

\( WU_{max} \) (m/day) is the maximum uptake rate crop input parameter.

\( \psi_{fc} \) (J/kg) represents the soil water potential at field capacity.

\( \psi_{[l,sc]} \) (J/kg) is the leaf potential just before the beginning of stomatal closure due to water deficit a crop input parameter.
Leaf area development

Leaf area development depends on daily biomass production. However, because leaf expansion is reduced and stopped earlier than biomass production under water stress conditions, green area index calculations are not directly dependent on above ground biomass production, but rather on an auxiliary variable defined as the leaf area expansion-related biomass production (LAERB). This quantity is only accumulated when the ratio of actual to potential transpiration is greater than the crop water stress threshold defined by the $\frac{\text{Tr}_{\text{act}}}{\text{Tr}_{\text{pot}}}$ ratio where leaf area growth ceases crop parameter.

The value of LAERB is identical to cumulative above ground biomass when the ratio remains above the threshold throughout the growing season.

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>Grain crops (non=legumes)</th>
<th>Legumes</th>
<th>Root crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergence</td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Begin flowering</td>
<td>Plateau</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>End flowering</td>
<td>Plateau</td>
<td>Plateau</td>
<td>Plateau</td>
</tr>
<tr>
<td>Begin Grain filling</td>
<td>Decrease</td>
<td>Decrease</td>
<td>-</td>
</tr>
<tr>
<td>Begin Senescence</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>Physio. Maturity</td>
<td>stop</td>
<td>Stop</td>
<td>Stop</td>
</tr>
</tbody>
</table>

The leaf area expansion-related biomass accumulation (LAERB) is used in determining the green area index (GAI) during the active growth stage.

Both LAI and GAI generally have the same value during the active growth stage, reach a peak near flowering (cereal crops), and start declining during senescence (see the Leaf area index development stages table). When the crop is at physiological maturity, LAI is set a percentage of the peak LAI. Note that some crops will not have all the listed growth stages (see the relevant phenology table).

The leaf area expansion-related biomass produced in a given day, and the accumulated quantity until that day, are used to determine the new green leaf area index produced in the day (GAItoday) as follows:

$$GAI_{\text{today}} = \frac{\text{LAERB}_{\text{today}} \cdot \text{SLA}}{(\text{LeafStemPart} \cdot \text{LAERB}_{\text{cum}} + 1)^2}$$

where

- LAERBtoday (kg/m²) is the daily leaf area expansion-related biomass.
- LAERBcum (kg/m²) is the accumulation of LAERBtoday.
- SLA (m²/kg) is the Specific leaf area crop input parameter.
- LeafStemPart (m²/kg) is the Leaf/stem partitioning coefficient crop parameter.
The fraction of GAI produced in each day is initialized with zero degree-days, and the thermal time during the life of this fraction is calculated daily as follows:

$$GDD_{\text{green}} = CGD_{\text{day}} \cdot \left( 1 + GAI_{\text{sensitivity}} \cdot \text{StressIndex}_{\text{Water}} \right)$$

where

- $CGD_{\text{day}}$ is the **computed accumulated thermal time**.
- $\text{StressIndex}_{\text{water}}$ is the computed **daily plant water stress index**.
- $GAI_{\text{sensitivity}}$ is the **leaf duration sensitivity to water stress crop** input parameter.

When the accumulated thermal time of any given fraction of GAI reaches the thermal time threshold set by the **leaf duration crop input parameter**, this fraction is assumed to senesce and it is subtracted from the total GAI.

The leaf area index (LAI), which includes total leaf area (green or senescent) is equal to GAI during active growth of green area and declines after flowering to reach the value set by the **fraction of maximum LAI at maturity crop input parameter**.
Crop interception

The amount of water intercepted by the crop canopy is estimated from the fraction of canopy cover (fractCover_canopy) and the storage capacity of the canopy for water, assumed to be 1mm for full canopy cover (Campbell and Diaz, 1988):

$$\text{Interception} = 0.001 \cdot \text{fractCover}_{\text{canopy}}$$
Vernalization

Vernalization in crops can be defined as the low temperature promotion of flowering. Winter crops require a period of exposure to temperatures between approximately 0 to 12 °C for a period of time from 10 to 60 days from germination to proceed into the reproductive phase. Vernalization requirements fluctuate significantly among species and cultivars.

Vernalization is simulated by defining a vernalization factor, which fluctuates from 0 to 1 depending on the accumulation of vernalization days. Vernalization is calculated as follows:

\[
 f_{ver} = f_{ver\min} + \left[ 1 - f_{ver\min} \right] \cdot \left[ \frac{VD_{sum} - VD_{start}}{VD_{end} - VD_{start}} \right]
\]

where

- \( f_{ver} \) (0-1) is the vernalization factor.
- \( f_{ver\ min} \) (0-1) is the minimum vernalization factor value at the beginning of the vernalization process. (usually zero) If \( VD_{start} \) is set to zero, \( f_{ver\ min} \) can be specified as zero or greater than zero. For crops insensitive to vernalization, \( f_{ver\ min} \) must be set equal to 1.
- \( VD_{start} \) is the accumulated vernalization-days at which \( f_{ver} \) is set equal to \( f_{ver\ min} \).
- \( VD_{end} \) is the required sum to complete vernalization (at which \( f_{ver} \) reaches a value of 1.0).
- \( VD_{sum} \) is the sum of the currently accumulated vernalization days. The sum of vernalization day is calculated by adding the vernalization contribution of each day \( (V_i) \). The maximum contribution is equal to one vernalization day and the minimum contribution is zero. Accumulation continues until \( VD_{sum} \geq VD_{end} \). \( V_i \) is calculated from average air temperature as follows:

\[
 V_i = \begin{cases} 
 1 - \frac{T_{avg} - T_{high}}{A} & \text{if } T_{avg} \geq T_{high} \text{ and } F_{ver} \leq 0 \\
 1 - \frac{T_{low} - T_{avg} - T_{avg}}{A} & \text{if } T_{avg, media} \leq T_{low} \text{ and } F_{ver} \geq 0 \\
 1.0 & \text{if } T_{high} > T_{avg} > T_{low}
\end{cases}
\]

where

- \( T_{low} \) (°C) is the low end temperature threshold for optimum vernalization.
- \( T_{high} \) (°C) is the high end temperature threshold for optimum vernalization.
- \( A \) is assigned the value of 7.0.
$T_{\text{avg}} \ ^{\circ}\text{C}$ is the average air temperature.
Photo-period

Plant development may respond to the relative lengths of days and nights. Some crops (long-day plants) accumulate physiological time towards flowering when the day length exceeds some minimum threshold (i.e. oats, sugarbeet, winter barley, winter wheat). Some crops accumulate physiological time towards flowering when the day length is shorter than some maximum (i.e. soybeans, maize, rice, etc.). Other crops are insensitive to day length.

The response to photo-period is approximated with a simple linear relation.

For long-day crops (when daylength > daylength_if):

\[ f_{\text{photo}} = \frac{\text{daylength} - \text{daylength}_{\text{if}}}{\text{daylength}_{\text{ins}} - \text{daylength}_{\text{if}}} \]

where

daylength_{ins} (day length for insensitivity) is the crop parameter for day length threshold above which maximum physiological time accumulation occurs.

daylength_{if} (day length to inhibit flowering) is the crop parameter for day length threshold below which no accumulation of physiological time occurs.

For short-day crops (when daylength < daylength_{if}):

\[ f_{\text{photo}} = \frac{\text{daylength}_{\text{if}} - \text{daylength}}{\text{daylength}_{\text{if}} - \text{daylength}_{\text{is}}} \]

In this case, day length for insensitivity is the day-length threshold below which the maximum accumulation of physiological time occurs. Day length to inhibit flowering is the day-length threshold above which no accumulation of physiological time occurs.

As with the vernalization factor, the photoperiod factor takes on values from 0 to 1.
Crop harvest

Crop harvest events usually occur at a specified number of days after maturity. In the case, of perennial crops, harvest events will be periodic based on clipping criteria parameters specified in a management file.

Harvest index and crop yield

Harvest index is defined as the ratio of yield biomass to the total cumulative biomass at harvest (Biomass\textsubscript{hrv}); thus, crop yield can be calculated as:

\[
\text{Yield} = \text{Biomass}_{hrv} \cdot \text{HI}
\]

The harvest index is given by the harvest index crop parameter, adjusted to account for sensitivity to water stress during flowering and/or grain filling.

\[
\text{HI} = \text{HI}_{\text{unstressed}} \cdot (1 - \text{avgStress}_f) \cdot (1 - \text{avgStress}_g)\]

where

- \text{avgStress}_f is the mean water stress index during the period of flowering.
- \text{avgStress}_g is the mean water stress index during the period of grain filling.
- \text{Sf, Sg} are the harvest index adjustment parameters for water stress sensitivity during flowering and grain filling respectively.

In addition, grain yield based on translocation is determined as biomass at flowering, times the translocation factor, times the mean flowering stress:

\[
\text{biomass}_{\text{flower}} \cdot \text{translocation} \cdot \text{avgStress}_f
\]

This is compared with the yield obtained from the biomass harvest index equation. The maximum of the two is compared with the unstressed yield from then biomass harvest index equation and the minimum is taken as the predicted yield.

Non-yield harvest biomass and surface residue addition

All or a fraction of the non-yield above ground biomass may remain in the field after harvest and may be added to any existing surface residue. Residues from each harvest are maintained separately since each crop has its own rate of decomposition, area mass ratio and nitrogen pool.

\[
\text{Residue}_{\text{surface}} = \text{Residue}_{\text{surface}} + F_{BR} (\text{Biomass}_{hrv} - \text{Yield})
\]

where
Residue_{surface} (kg/m²) is the amount of residue on the soil surface.

F_{BR} (0-1) is the crop parameter Fraction of non-grain biomass -> surface residue which selects a fraction of the non-yield above ground biomass to be converted to residue.

Biomass_{hrv} (kg/m²) is the cumulative above ground biomass at harvest.

Yield (kg/m²) is the harvestable biomass.

A portion of the nitrogen stored in the plant is also maintained in the residue. The nitrogen concentration in the stubble is determined as:

\[
N_{\text{stubble}} = N_{\text{stubble max}} \cdot \frac{N_{\text{conc hrv}}}{N_{\text{conc max mature}}}
\]

where

- \(N_{\text{stubble}}\) (kg/kg) is the concentration of nitrogen in the crop stubble which will go into the residue nitrogen pool.
- \(N_{\text{stubble max}}\) (kg/kg) is the Maximum nitrogen concentration of the stubble at harvest crop parameter.
- \(N_{\text{conc max mature}}\) (kg/kg) is the Maximum nitrogen concentration at maturity crop parameter.
- \(N_{\text{conc hrv}}\) (kg N/kg biomass) is the crop nitrogen concentration at harvest.
Fallow cropping conditions

The simulation runs in fallow conditions between the harvest of a crop and the planting of the next crop in the rotation cycle.

Under fallow conditions, the soil water and nitrogen balances for the bare soil plus residue continue to be updated on a daily basis.
Nitrogen-dependent growth

The values of $G_R$ and $G_{Tr}$ are compared and the minimum is used as "potential growth" to determine nitrogen-dependent growth. The nitrogen-dependent growth ($G_N$) ($\text{kg/m}^2/\text{day}$) is a function of potential growth after radiation and water limitations have been applied, the critical and minimum crop nitrogen concentration, and the crop nitrogen concentration expected after new growth, modified from Godwin and Jones (Godwin and Jones, 1991):

$$G_N = G_{Npot} \cdot \left[ 1 - \frac{NC_{crit} - NCONC_a}{NC_{crit} - NC_{min}} \right]$$

where

- $G_{Npot}$ (kg/m$^2$/day) is potential growth after radiation and water limitations have been applied.
- $NC_{crit}$ (kg/kg) is plant critical nitrogen concentration, which is linearly scaled from its value at emergence to its value at flowering, and from its value at flowering to its value at maturity, based on thermal time:

  $$NC_{crit} = NC_{crit \ early} - \frac{(CGD_{day} - CGD_{emerge}) \cdot (NC_{crit \ early} - NC_{crit \ flower})}{CGD_{flower} - CGD_{emerge}}$$

  and similarly for after flowering:

  $$NC_{crit} = NC_{crit \ flower} - \frac{(CGD_{day} - CGD_{flower}) \cdot (NC_{crit \ flower} - NC_{crit \ mature})}{CGD_{mature} - CGD_{flower}}$$

- $NC_{min}$ (kg/kg) is the minimum plant nitrogen concentration at which growth stops, also scaled based on thermal time:

  $$NC_{crit} = NC_{min \ early} - \frac{(CGD_{day} - CGD_{emerge}) \cdot (NC_{min \ emerge} - NC_{min \ flower})}{CGD_{flower} - CGD_{emerge}}$$

- $NC_{crit \ early}$ (kg/kg) is plant critical nitrogen concentration during early growth. It is calculated as 0.65 ($C_3$ species) or 0.35 ($C_4$ species) times the value of plant maximum nitrogen concentration at during early growth crop parameter.

$NC_{crit \ flower}$
\[ \text{NC}_{\text{crit}_\text{flower}} = F_{\text{crit}} \cdot \text{N}_{\text{max}_\text{flower}} \]

\( F_{\text{crit}} \)

is the xxxx 0.65 for C\textsubscript{3} species and 0.35 for C\textsubscript{4} species.

\[ \text{NC}_{\text{min}_\text{early}} \text{ (kg/kg)} \]

**This parameter is obsolete:** is the minimum plant nitrogen concentration at which growth stops at emergence crop parameter.

\[ \text{NC}_{\text{min}_\text{flower}} \]

this is

\[ \text{NC}_{\text{min}_\text{flower}} = f_{\text{min}} \cdot \text{N}_{\text{max}_\text{flower}} \]

\( f_{\text{min}} \)

is the xxxx 0.5 for C\textsubscript{3} species and 0.25 for C\textsubscript{4} species.

\[ \text{NC}_{\text{max}_\text{flower}} \]

is based on the **maximum nitrogen concentration at maturity** and the crop parameters: *translocation factor*, and *harvest index*.

\[ \text{NC}_{\text{max}_\text{flower}} = \frac{\text{N}_{\text{max}_\text{mature}} \cdot (1 - \text{translocation})}{1 - \text{HI}} \]

\[ \text{NC}_{\text{mature}} \text{ (kg/kg)} \]

**This parameter is obsolete:** is the critical plant nitrogen concentration at maturity. It is calculated as \( \text{NC}_{\text{crit}_\text{early}} \) by taking the maximum plant nitrogen concentration at maturity crop parameter as the base.

\[ \text{NC}_{\text{min}_\text{mature}} \]

is the **minimum plant nitrogen at which crop growth stops at maturity**.

\[ \text{N}_{\text{CONC}_\text{a}} \text{ (kg/kg)} \]

is the plant nitrogen concentration after new growth. This is equal to the ratio of crop nitrogen mass to total crop biomass (including new growth). If the plant nitrogen concentration after new growth, calculated in this manner, is less than the critical nitrogen concentration, then potential new growth cannot be supported and both growth and nitrogen concentration after new growth must be corrected according to the following equation:

\[ \text{CNU} \]

\[ \text{N}_{\text{CONC}_\text{a}} = \frac{\text{CTM} + \text{CRM} + G_{\text{Npot}} \cdot \left[ 1 - \frac{\text{NC}_{\text{crit}} - \text{N}_{\text{CONC}_\text{a}}}{\text{NC}_{\text{crit}} - \text{NC}_{\text{min}}} \right]}{\text{CNU}} \]

where
CNU (kg/m²) is cumulative nitrogen uptake.

CTM, CRM (kg/m²) are top and root cumulative biomass.

The third term in the denominator is the nitrogen-dependent new growth (kg/m²). To solve for NCONCa, this equation must be arranged into a quadratic:

\[
NCONCa = \frac{-b + \sqrt{b^2 - 4ac}}{2a}
\]

\[
a = G_{Npot}
\]

\[
b = b \left( NC_{crit} - NC_{min} \right) - \left( CTM + CRM + G_{Npot} \right) - G_{Npot} \cdot NC_{crit}
\]

\[
c = - CNU \cdot \left( NC_{crit} - NC_{min} \right)
\]
Crop nitrogen uptake

Crop nitrogen uptake was modeled by modifying the approach of Godwin and Jones, 1991. Crop nitrogen uptake is determined as the minimum of crop nitrogen demand and potential nitrogen uptake. Crop nitrogen demand is the amount of nitrogen the crop needs to meet its potential growth, as limited by light, temperature and water, plus any deficiency demand.

The deficiency demand is the difference between the crop maximum and actual nitrogen concentration before new growth.

\[ ND = (N_{\text{max}} - N_{\text{CONC}_b}) \cdot (TM + RM) + N_{\text{max}} \cdot (R_{\text{Gpot}} + T_{\text{Gpot}}) \]

where

- \( ND \) (kg/ha) is the crop nitrogen demand.
- \( N_{\text{max}} \) (kg N/kg biomass) is the crop maximum nitrogen concentration.
- \( N_{\text{CONC}_b} \) (kg N/kg biomass) is crop nitrogen concentration before new growth.
- \( TM \) (kg/ha) is the cumulative above ground crop biomass.
- \( RM \) (kg/ha) is the cumulative root biomass.
- \( R_{\text{Gpot}} \) (kg/ha) is the potential new root growth.
- \( T_{\text{Gpot}} \) (kg/ha) is the potential new top growth.

ND represents the deficiency demand, and the second term represents the nitrogen demand for new growth. It is possible to have a negative nitrogen deficiency demand when the supply of nitrogen is sufficient (Godwin and Jones, 1991). This occurs as the plant matures and its maximum nitrogen concentration declines faster than the plant grows.

If the deficiency demand becomes negative, the plant has a nitrogen reserve.

The potential nitrogen uptake is calculated for each soil layer and summed for the soil profile.

\[ N_{\text{upl}} = U_{\text{Pmax}} \cdot RL \cdot N_{\text{avail}} \cdot PAW^2 \]

where

- \( N_{\text{upl}} \) (kg N/ha/day) is the potential nitrogen uptake for layer l.
$UP_{\text{max}}$ (kg N/day/m)

is the maximum nitrogen uptake per unit length of root.

RL (m/ha)

is the root length.

$N_{\text{avail}}$ (0-1)

is a nitrogen availability factor given by Godwin and Jones, 1991:

$$N_{\text{disp}} = 1.0 e^{-a \cdot N_s}$$

where

a

is a constant (0.0275 for nitrate and 0.025 for ammonium).

$N_{S}$ (kg/ha)

is the soil nitrogen concentration. Because the equilibrium between sorbed and solution ammonium is calculated only once a day, $N_S$ for ammonium is taken as total ammonium instead of solution ammonium, i.e., it is assumed that the solution is replenished with new ammonium from the exchange sites as needed for uptake.

PAW

is the plant available water.
Nitrogen fixation

For crops such as legumes, CropSyst decreases nitrogen demand by supplying additional nitrogen produced by nitrogen fixing bacteria.

\[ \text{ND}_{\text{act}} = \text{ND}_{\text{pot}} - N_{\text{fixation}} \]

where

- \( \text{ND}_{\text{pot}} \) (kg/ha) is the nitrogen demand.
- \( \text{ND}_{\text{act}} \) (kg/ha) is the nitrogen demand accounting for nitrogen fixation for legumes and will replace the normal crop nitrogen demand (ND).
- \( N_{\text{fixation}} \) (kg/ha) is the fixed nitrogen.

The rate of nitrogen fixation follows the development of crop growth. The potential amount of fixed nitrogen may be reduced by plant available water, mineral nitrogen content in the root zone and soil temperature.

\[ N_{\text{fixation}} = \min [ \text{ND}_{\text{pot}} \cdot \text{Fix}_r , 6.0 \text{(kgN/ha)/day} ] \]

\[ \text{Fix}_r = \text{Fix}_p \cdot \min(\text{Fix}_w, \text{Fix}_n, \text{Fix}_t) \]

where

- \( \text{Fix}_r \) (0-1) is the fraction of daily nitrogen demand supplied by fixation.
- \( \text{Fix}_p \) (0-1) is the effect of crop development.
  
  \[ \text{Fix}_p = \begin{cases} \frac{\text{CGD}_{\text{day}}}{\text{CGD}_{\text{flowerbegin}}} & \text{if active growth} \\ 1.0 & \text{if senescence (grain filling)} \\ 1.0 - \left[ \frac{\text{CGD}_{\text{day}} - \text{CGD}_{\text{gfbegin}}}{\text{CGD}_{\text{fixend}} - \text{CGD}_{\text{gfbegin}}} \right] & \text{if senescent} \end{cases} \]

During senescence, fixation is reduced from the start of grain filling to a point halfway between grain filling and physiological maturity at which fixation is zero.

- \( \text{Fix}_w \) limits fixation based on plant available water (PAW) in the first 10 to 30 cm of the soil profile.
\[ \text{Fix}_t = \frac{(\text{PAW} - 0.5)}{0.5} \]

\text{Fix}_w \] is constrained to the range \([0,1]\).

\text{Fix}_n \]

limits fixation based on the mineral nitrogen content in the root zone. The rate of bacterial fixation is reduced when nitrogen is already present.

\[
\text{Fix}_n = \begin{cases} 
0.0 & \text{if } N_{\text{rootzone}} > 300 \text{ kgN/ha} \\
1.0 & \text{if } N_{\text{rootzone}} < 100 \text{ kgN/ha} \\
1.0 - \frac{(N_{\text{rootzone}} - 100)}{200} & \text{otherwise}
\end{cases}
\]

where

\(N_{\text{rootzone}} \) (kg N/ha) is the total N content (both as nitrate and ammonium) within the root zone.

\text{Fix}_t (^\circ \text{C})

limits fixation based on the subsurface soil temperature (up to 30cm).

\[
\text{Fix}_t = \begin{cases} 
1.0 & \text{if } t > 30^\circ \text{C and } T < 36^\circ \text{C} \\
0.7 & \text{if } t > 36^\circ \text{C} \\
0.0 & \text{if } t < 0^\circ \text{C} \\
\frac{t}{30^\circ \text{C}} & \text{if } t > 0^\circ \text{C and } T < 36^\circ \text{C}
\end{cases}
\]
Nitrogen Simulations

The components of the nitrogen budget in CropSyst include: transport, transformation, ammonium sorption, crop nitrogen uptake and residue mineralization.

Nitrogen transport in the soil

Nitrogen transport through the soil profile has been modelled many different ways. Complex methods using numerical solutions such as the one described by Murali and Aylmore, 1981, the SHAW model (Flerchinger, 1987), or the LEACHM model (Wagnet and Hutson, 1989) are available.

However, they are not very practical when used within a cropping systems model which simulates many other processes for a large number of crop rotation cycles. Simple approaches are then preferable. Examples of simple but sound approaches are found in the literature (Rose et al., 1982a and Rose et al., 1982b, and Corwin et al., 1991). The method included in CropSyst is adapted from the concepts of Corwin et al., 1991 and implement to transport nitrogen in the soil in one day time step in days when water infiltrates into the soil.

Corwin et al., 1991 proposed a simple mass-balance approach to solute transport. Their approach included a bypass coefficient (BC) to describe the fraction of water in a soil layer that is bypassed, while (1-BC) represents the fraction of the soil water subject to piston-type displacement. The bypass coefficient simplistically accounts for flow through cracks and macropores. The practical effect is to produce the flow of a mobile water phase independent of the immobile phase of water.

The nitrogen concentration of the water remaining within and leaving a layer can be calculated three ways, depending upon the initial water content and the amount of water to reach a layer. As water enters a layer, it first fills the layer to field capacity if enough water is available. Once the layer is at field capacity, the incoming water begins to replace the existing water (excluding bypassed volume) and the existing water is moved out of the layer. The incoming water continues to replace the existing water until all the existing water is replaced and then the incoming water begins to move out of the layer.

If the amount of water to reach a layer is enough to fill the layer to field capacity and replace the existing mobile water, then the nitrogen concentration of the the layer is:

$$C_{\text{out}} = \frac{W_{\text{in}} \cdot C_{\text{in}} - \Delta Z_l \cdot (FC - BC \cdot WC_{\text{bi}}) \cdot C_{\text{in}} + (1 - BC) \cdot \Delta Z_l \cdot WC_{\text{bi}} \cdot C_{\text{bi}}}{W_{\text{out}}}$$

and the layer nitrogen concentration after the water input event is:

$$C_{\text{ai}} = \frac{(FC - BC \cdot WC_{\text{bi}}) \cdot C_{\text{in}} + BC \cdot WC_{\text{bi}} \cdot C_{\text{bi}}}{FC}$$

where
\( C_{\text{out}} \) (kg N/m³ water) is the nitrogen concentration of the water leaving the layer.

\( C_{\text{ai}} \) (kg N/m³ water) is the nitrogen concentration of the water within the layer after a water input event.

\( C_{\text{bi}} \) (kg N/m³ water) is the nitrogen concentration of the water within the layer before a water input event.

\( C_{\text{in}} \) (kg N/m³ water) is the nitrogen concentration of the water that enters the layer.

BC (dimensionless, 0-1) is the bypass coefficient.

\( \Delta Z_l \) (m) is the layer thickness.

\( WC_{\text{bi}} \) (m³/m³) is the volumetric water content before water input.

\( WC_{\text{in}} \) (m) or (m³ water/m² soil) is the water depth entering the layer.

\( WC_{\text{out}} \) (m) or (m³ water/m² soil) is the water depth leaving the layer.

If the amount of water to reach a layer is not enough to completely replace the existing mobile water but is greater than the amount required to fill the layer to field capacity, then:

\[ C_{\text{out}} = C_{\text{bi}} \]

If the amount of water to reach a layer is less than the amount required to fill the layer to field capacity, then:

\[ C_{\text{out}} = 0 \]

**Nitrogen transformations in the soil**

The nitrogen transformations developed for CropSyst include net mineralization, nitrification and denitrification, which are simulated using first order kinetics (Stöckle and Campbell, 1989) and assumed to occur in the to 30 to 50 cm of the soil profile. Net mineralization is the transformation of organic matter nitrogen to ammonium, resulting from the opposite process of mineralization and immobilization. Nitrification is the process that transforms ammonium to nitrate. Denitrification converts nitrate to gaseous nitrogen, which is lost to the atmosphere. Because these transformations are temperature dependent, soil temperature simulation is included in the model using a method similar to that proposed by Sharpley and Williams, 1990).

**Mineralization**

The amount of organic matter nitrogen mineralized is calculated by:

\[ \text{MIN} = \text{MIN}_{\text{pot}} \cdot (1 - \text{MF} \cdot e^{(-\text{MRATE} \cdot \Delta t)} ) \]

where

MIN (kg/ha) is the amount of organic matter nitrogen mineralized to ammonium in time \( t \) (one day).

MINpot (kg/ha) is the potential amount of organic matter nitrogen available to mineralize.
MRATE (1/day) is mineralization rate constant found by:

\[
MRATE = \frac{1}{7} \cdot e^{\left[\frac{17.753 - 6350.6}{T_s - 273}\right]}
\]

where

- \( T_s \) (°C) is the soil temperature.
- -273 converts to degrees Celcius to Kelvin.

MF is a soil moisture function dependent on the fraction of pore space containing water.

\[
MF = \begin{cases} 
1.11 & \text{if } DS \leq 0.9 \\
10.0 - 10.0 \cdot DS & \text{if } DS > 0.9 
\end{cases}
\]

where DS is the degree of saturation (0-1) obtained by:

\[
DS = \frac{WS}{1 - BD/2.56}
\]

**Nitrification**

The daily amount of nitrified ammonium is found using:

\[
NIT = NH_4 \cdot \left(1 - e^{-NRATE \cdot \Delta t}\right) \cdot MF
\]

where

- NIT (kg NH_4 / ha) is the amount of ammonium nitrogen transformed to nitrate in time \( t \) (one day).
- NH_4 (kg / ha) is the amount of ammonium nitrate available for nitrification.
- NRATE (1 / day) is the nitrification rate constant, and MF is the soil moisture function.

The nitrification rate constant is given by the nitrification rate constant at 35 °C multiplied by a function of soil temperature.

\[
NRATE = \begin{cases} 
(0.0105 \cdot Ts + 0.00095 \cdot Ts^2 \cdot NRATE_{35}) & \text{if } 10^\circ \text{C} \geq Ts \\
(0.032 \cdot Ts - 0.12) \cdot NRATE_{35} & \text{if } 35^\circ \text{C} \geq Ts > 10^\circ \text{C} \\
(-0.1 \cdot Ts + 4.5) \cdot NRATE_{35} & \text{if } Ts > 35^\circ \text{C}
\end{cases}
\]

where
NRATE\textsubscript{35} = 0.8 (1/day) is the nitrification rate constant at 35 °C.

\( T_s \) (°C) is the soil temperature.

**Denitrification**

The daily amount of denitrification that occurs is determined by:

\[
DEN = NO_3 \cdot (1 - e^{-\text{DRATE} \cdot \Delta t})
\]

where

- \( DEN \) (kg N/ha) is the amount of nitrate nitrogen that denitrifies to gaseous nitrogen in time \( t \) (one day).
- \( NO_3 \) (kg/ha) is the amount of nitrate available for denitrification.
- \( \text{DRATE} \) (1/day) is the denitrification rate constant determined from the denitrification rate value at 15 °C modified by a soil temperature function and a soil water function.

\[
\text{DRATE} = \begin{cases} 
0.67 \cdot e^{(0.43 \cdot (\text{T}_s - 10))} \cdot \text{DRATE}_{15} \cdot \text{WCCF} & \text{if } \text{T}_s \leq 10^\circ \text{C} \\
 e^{(0.08 \cdot (\text{T}_s - 15))} \cdot \text{DRATE}_{15} \cdot \text{WCCF} & \text{if } \text{T}_s > 10^\circ \text{C}
\end{cases}
\]

where

- \( \text{T}_s \) (°C) is the soil temperature.
- \( \text{DRATE}_{15} \) (1/day) is the denitrification rate constant 15 °C.
- \( \text{WCCF} \) is a water content correction function, given by:

\[
\text{WCCF} = e^{(0.304 + 2.94 \cdot \text{WC}_{\text{sat}} - \text{WC}) - 47 \cdot (\text{WC}_{\text{sat}} - \text{WC})^2}
\]

where

- \( \text{WC}_{\text{sat}} \) (m\(^3\)/m\(^3\)) is volumetric water content at saturation.
- \( \text{WC} \) (m\(^3\)/m\(^3\)) is the current volumetric water content.

**Ammonium Sorption**

Ammonium in the soil is either sorbed to the soil solid phase or in the solution soil water, and therefore available to move with water.

A Langmuir relationship is used to relate ammonium in solution and ammonium in the soil matrix (Campbell, 1985).

\[
\text{NH}_4^x = \frac{C \cdot Q \cdot \text{NH}_4^s}{1 + C \cdot \text{NH}_4^s}
\]
where

\( \text{NH}_4X \) (\( \text{kg NH}_4/\text{kg soil} \)) is the ammonium held on the exchange sites.

C, Q (kg/kg) are constants for different soils and solutes.

\( \text{NH}_4S \) (\( \text{kg NH}_4/\text{kg H}_2\text{O} \)) is the ammonium in the soil solution.

The total amount of ammonium in the soil layer is related to the ammonium in solution and the ammonium sorbed by:

\[
\text{NH}_4 = (\text{NH}_4XS + \text{WC}_{\text{wt}} \cdot \text{NH}_4S) \cdot \rho_b
\]

where

\( \text{NH}_4 \) (\( \text{kg} \text{ N/m}^3 \text{ soil} \)) is the total amount of ammonium in the soil.

\( \text{NH}_4XS \) (\( \text{kg N/kg soil} \)) is the amount of sorbed ammonium.

\( \text{WC}_{\text{wt}} \) ((\( \text{kg H}_2\text{O}/\text{kg soil} \)) is the gravimetric water content.

\( \text{NH}_4S \) (\( \text{kg/m}^3 \)) is the soil solution ammonium concentration.

\( \rho_b \) (tonne/cm\(^3\)) is the soil bulk density.

Combining equations for \( \text{NH}_4X \) and \( \text{NH}_4 \), a quadratic equation is obtained to solve for the ammonium in soil solution.

**Crop nitrogen uptake**

Crop nitrogen uptake is a function of the crop.

**Nitrogen Fixation (legumes)**

Nitrogen fixation is a function of legumes and other crops supporting nitrogen fixation.

**Residue nitrogen net mineralization**

Residue nitrogen net mineralization is a function of residue decomposition.
Actual residue evaporation

Actual residue evaporation is assumed to be proportional to the ratio of residue water content to residue water holding capacity \((3 \text{ kg H}_2\text{O})/(\text{kg Residue})\) when residue water content is lower than its water holding capacity; otherwise it is assumed to be at its potential rate.
Residue redistribution occurs when management events (such as tillage, residue removal, or other management operations involving machinery) disturb the residue and soil surface.

### Redistributing the soil surface residue

Warning this needs to be updated Surface residue is recomputed as:

\[ \text{Residue}_{\text{surface}} = \text{Residue}_{\text{surface}} \cdot \text{Tillage}_{\text{surface}} / 100 \]

where

- \( \text{Residue}_{\text{surface}} \) (kg/m²) is the surface residue.
- \( \text{Tillage}_{\text{surface}} \) (%) is the percentage of surface residue remaining on the surface after the tillage operation.

Shallow incorporated residue is accumulated when a portion of the surface residue is buried. The total shallow incorporated residue after each tillage operation is estimated by:

\[ \text{Residue}_{\text{shallow}} = \text{Residue}_{\text{shallow}} + \text{Residue}_{\text{surface}} \cdot \text{Tillage}_{\text{shallow}} / 100 \]

where

- \( \text{Residue}_{\text{shallow}} \) (kg/m²) is the incorporated shallow residue.
- \( \text{Tillage}_{\text{shallow}} \) (0-1) is the fraction of surface residue that is buried at 5 to 8 cm by the tillage operation.
Residue decomposition

The residue left on the ground is buried by tillage operations and gradually decomposes.

The modeling of these processes is important because the residue mulch reduces erosion and helps the soil retain water. The daily residue loss is simulated in the program.

A simple model for simulating residue decomposition is based on the work of Bristow et al., 1986 and Stroo et al., 1989. Soil moisture, temperature and residue endurance factors are taken into account in the calculation of the rate of residue decomposition.

Residue loss

It is assumed that the rate of residue loss is directly proportional to the mass of residue present:

$$\Delta R = R_d - R_{d-1} = -R_{d-1} \cdot \Delta t / \tau$$

where

- $\Delta R$ (kg/m²) is the residue loss (decomposed).
- $R_d$ (kg/m²) is today's residue mass.
- $R_{(d-1)}$ (kg/m²) is yesterday's residue mass.
- $t$ (day) is the time step.
- $\Delta t$ (day) is the time constant of the residue input parameter.

After the residue has decomposed by 90%, this is set to 105 days (for the decomposition of lignins).

This equation can be rearranged to give:

$$R_d - R_{d-1} \cdot \left[ 1 - \frac{\Delta t}{\tau/f(CN_{R&S})} \right]$$

The time step, $t$, under ideal laboratory conditions, is related to the time step in the field, $t_{field}$, by:

$$\Delta t = f(W,T) \cdot \Delta t_{field}$$

so, considering that the time interval for the simulation (which is equivalent to $t_{field}$) is one day, then by combining equations for $\Delta R$ and $\Delta t$ the following expression is obtained:

$$R_d - R_{d-1} \cdot \left[ 1 - \frac{f(W,T)}{\tau} \right]$$

where

- $t_{field}$ (daily simulation time step)
corresponds to 1 day.

\[ f(W,T) = \min[f(W), f(T)] \]

is a residue loss rate factor dependent on the temperature and the soil water content.

\( f(W), F(T) \)

are moisture and temperature factors respectively, and the minimum of the two will be chosen for \( f(W,T) \). The range of both \( f(W) \) and \( f(T) \) is 0.1 to 1.0 (Stroo et al., 1989).

\( f(CN_{R&S}) \)

is a function of the current residue carbon/nitrogen ratio, calculated by including the current soil mineral nitrogen as part of the potential residue nitrogen:

\[ f(CN_{R&S}) = e^{-0.693 \cdot (CN_{R&S} - 25) / 25} \]

\[ CN_{R&S} = \frac{\text{carbon}_{OM} \cdot R_d}{(N_{\text{residue}} + N_{\text{asNO}} + N_{\text{asNH}})} \]

where

\( \text{carbon}_{OM} \) is the fraction of carbon in organic matter.

\( N_{\text{residue}} \) (kg/m²) is the residue nitrogen content.

\( N_{\text{asNO}} \) and \( N_{\text{asNH}} \) (kg/m²) are the soil respective soil layer nitrogen contents.

The value of \( f(CN_{R&S}) \) is set equal to 1 when the nitrogen simulation option is disabled.

**Moisture factor**

The general algorithm of the moisture factor (Bristow et al., 1986) is:

\[ f(W) = \begin{cases} 1.0 & \text{if } WC \geq WC_{opt} \\ \frac{WC}{WC_{opt}} & \text{otherwise} \end{cases} \]

where for surface residues:

\( WC \) (m³ H₂O/kg Residue) is the residue water content.

\( WC_{opt} \) (0.003 m³ H₂O/kg Residue) is residue water holding capacity.

and for subsurface residues:

\( WC \) (m³/m³) is the water content of the respective soil layer.

\( WC_{opt} \) (m³/m³) is the field capacity water content of the respective soil layer.
**Temperature factor**

The temperature factor, $f(T)$, is calculated with an empirical equation (Stroo et al., 1989):

$$\begin{align*} f(T) &= 1.32 \cdot \frac{2 \cdot [(T_{\text{max}} + T_{\text{min}})/2 + a]^2 \cdot (T_{\text{m}} + a)^2 - [(T_{\text{max}} - T_{\text{min}})/2 + a]^4}{(T_{\text{m}} + a)^4} \end{align*}$$

where

- $T_{\text{max}}$, $T_{\text{min}}$ (°C) are the daily maximum and minimum temperatures respectively.
- $T_{\text{m}}$ (30 ºC) is the optimal temperature for residue decomposition.
- $a$ (6.1 ºC) is an empirical constant.
Residue nitrogen net mineralization

Decomposition of residues may release nitrogen (mineralization). Nitrogen is either taken up from or released to the soil, depending on Carbon/Nitrogen ratio of the residue.

The net residue nitrogen mineralization can be computed using the following expression (Shaffer et al., 1991):

\[ R_{\text{N net}} = \Delta R \cdot \text{carbonOM} \cdot (1/\text{CN}_R - 0.042) \]

where

\( \Delta R \) ((kg/m²)/day) is the amount of residue decomposed during the day.

\( R_{\text{N net}} \) ((kg/m²)/day) is the daily net residue nitrogen mineralized.

0.042 is the inverse of a carbon/nitrogen ratio equal to 24.

\( \text{CN}_R \) is the carbon/nitrogen ratio of the residue:

\[ \text{CN}_R = \frac{\text{carbonOM} \cdot R_d}{N_{\text{residue}}} \]

where

\( \text{carbonOM} \) (taken as 0.4) is the fraction of carbon in organic matter.

\( N_{\text{residue}} \) (kg/m²) is the residue nitrogen content.

\( R_d \) (kg/m²) is today's residue mass.

The net residue nitrogen mineralization assumes that net mineralization is negative or equal zero at a Carbon/Nitrogen ratio larger or equal to 24 respectively and that the Carbon/Nitrogen value for soil microbes is 6 (Shaffer et al., 1991). If \( R_{\text{N net}} \) is negative, nitrogen must be subtracted from the soil mineral nitrogen pool, which has the limit given by the actual amount of mineral nitrogen available in the soil. Negative net residue nitrogen mineralization tends to occur early in the decomposition process of fresh residues which are poor in nitrogen content (large carbon/nitrogen ratios). As the residue decomposition progresses and the growth of microbial population responsible for such decomposition stabilizes, carbon/nitrogen ratios decrease and mineralizable nitrogen starts to be released from the residues.

Each day (t = 1 day), the nitrogen content of the residue needs to be updated:

\[ N_{\text{residue}} = N_{\text{residue}} - R_{\text{N net}} \]

80% of the nitrogen released from decomposed residues is distributed to the soil ammonium pool and the remaining 20% goes to the nitrogen pool associated with stable organic matter.
Irrigation management simulation

Automatic irrigation application simulation

When the simulation applies water in an automatic irrigation event, it uses the following formula to determine the amount of water to be applied:

$$\sum_{l=1}^{n_l} (WC_{\text{new}} - WC_l) \cdot RD_l \quad \text{if} \ PAW_l < PAW_{\text{refill}}$$

where

- $n_l$ is the number of soil layers.
- $WC_l$ (m³/m³) is the water content of layer $l$.
- $RD_l$ (m) is the root depth into layer $l$ (If the root grows through the layer, $RD_l$ is equal to the thickness of the layer).
- $PAW_l$ (0-1) is the current plant available water for layer $l$ calculated as:
  $$PAW_l = \frac{WC_l - PWP_l}{FC_l - PWP_l}$$
- $PAW_{\text{refill}}$ (0-1) is the point of plant available water to refill to.
- $WC_{\text{new}}$ (m³/m³) is the water content when the soil layer is refilled to $PAW_{\text{refill}}$. It is determined by the equation:
  $$WC_{\text{new}} = PAW_{\text{refill}} \cdot (FC_l - PWP_l) + PWP_l$$
- $FC_l$ (m³/m³) is the field capacity of layer $l$.
- $PWP_l$ (m³/m³) is the permanent wilting point of layer $l$.

Specific irrigation application simulation

need to discuss
Nitrogen fertilizer application

Nitrogen fertilizer may be applied in any combination of the following forms:

- organic manure
- organic NH3
- NH4 preparation
- NO3 preparation

The application events may occur at times as specified in the management events table or automatically as determined by the simulation based on one of three sets of specified criteria:

- Based on optimal nitrogen allocation to plant tissues
- Based on nitrogen balance
- Based on local calibration

Specific nitrogen application

The user may specify any number of nitrogen application events either in the form of organic material or inorganic (commercial) fertilizer.

This section needs further development

Automatic optimal nitrogen allocation

When automatic nitrogen fertilization is enabled growth will not be limited by nitrogen.

The simulation will maintain the daily additional nitrogen requirements. This information is available in the daily report, and the accumulated value is available in the harvest report.

Automatic based on nitrogen balance

Automatic based on local calibration

NEED TO DISCUSS ORGANIC, INORGANIC, VOLATILIZATION etc...
Simulation of the affects of tillage operations

Tillage, residue, and other management operations affect the redistribution of residues and change the soil surface characteristics.

Residue redistribution

Residue redistribution factors are used to estimate the amounts of surface and shallow incorporated residues following a tillage operation or other residue treatment practices.

On the day when a tillage operation is performed, surface residue is redistributed. A part of it remains on the surface, a part is buried at 5 to 8 cm soil depth (defined as incorporated residue), and the rest is lost to deeper depths in the soil. The portion of residue buried below 8 cm soil depth is considered to have little or no contribution to erosion control.

A code for each tillage operation as well as the redistribution factors for surface and incorporated residue has been tabulated by the USDA-SCS Spokane, WA office (personal communication, 1987). When the simulation day matches the date that a tillage operation is assigned, the code of the operation is invoked and the amount of current surface residue is set. Residue redistribution occurs for each residue pool.

Soil surface detachability and roughness

The surface soil detachability and roughness factor (SDR) is evaluated after each tillage operation.

The data relating SDR and tillage operations are from the USDA/SCS National Engineering Handbook (USDA-SCS, 1988a).

Depressional storage

Need description This affects water storage in the finite difference numerical runoff simulation mode.
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