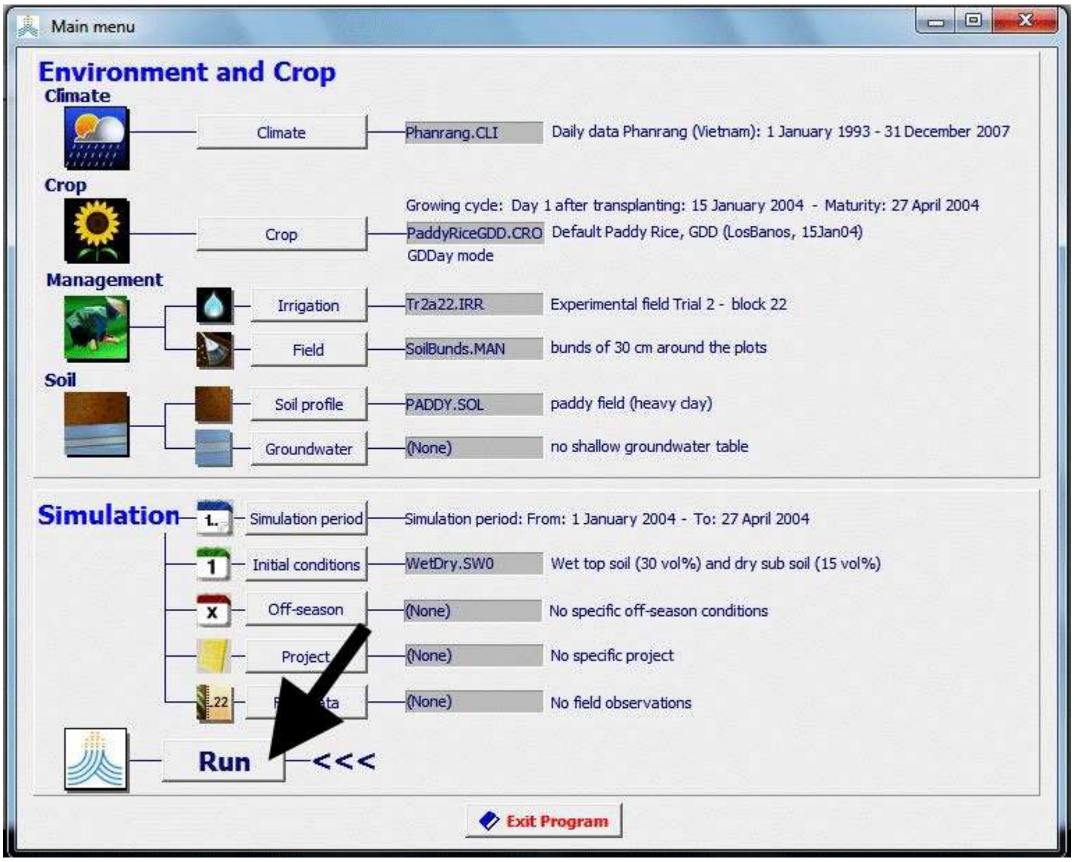
Food and Agriculture Organization
of the United Nations

AquaCrop training handbooks



Book II.
Running AquaCrop

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Table of Contents

AquaCrop training handbooks
Book II. – Running AquaCrop
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Prepared by Dirk Raes and Hanne Van Gaelen

Contributions by Kristine De Schamphelaere, Marga Garcia Vila, Emmanuel Kipkorir, Patricia Mejias Moreno, Reinout Reggers and Eline Vanuytrecht

The handbook explains step by step how to use AquaCrop (Part A), and is illustrated with a set of exercises (Part B). The content and learning objectives of the exercises are listed in Annex I, with reference to different sections of the handbook.

After the introduction to the software in AquaCrop training handbook I, the second handbook focuses on the practical part on how to run simulations with AquaCrop (Version 6.0). It consists of two parts:

Part A 'Menu references' explains how to use the AquaCrop software. The first chapter introduces the user to the file management. The next chapters cover respectively the climate, soil, crop, soil and management files. Each chapter, explains step by step how to select and create files, and how to update the characteristics. The last chapter deals with the settings required for running a simulation. The concepts and underlying principles for each of those themes are explained in the corresponding chapters of AquaCrop training handbook I 'Understanding AquaCrop';

Part B 'Exercises' is composed as an exercise book. Exercises cover rainfed agriculture and irrigated crop production in the region of Tunis (Tunisia), Hyderabad (India) and Brussels (Belgium). Each exercise contains an assignment as well as a list of steps that could be followed to complete the assignment. Part A of the handbook can be consulted for additional help to complete each step. At the end of each exercise, a solution sheet is presented to note the exercise results.

Part A – Menu references

Chapter 1. File management

1.1 Main menu

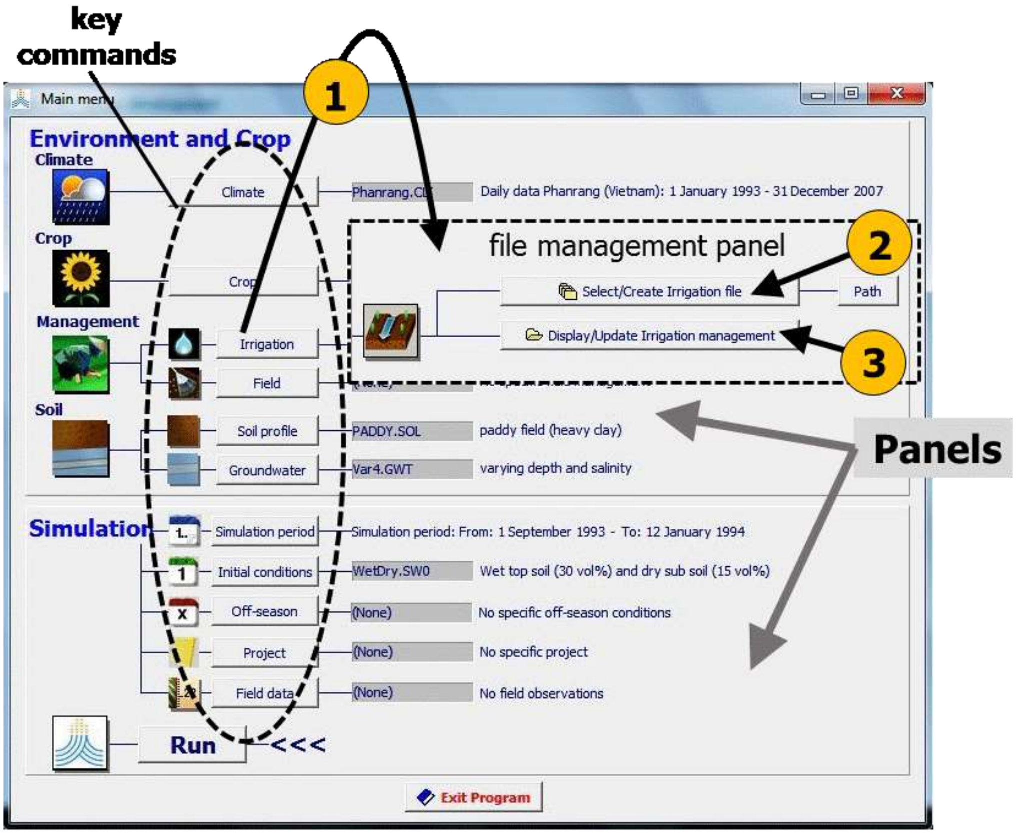


Figure 1.1 – *Main menu* of AquaCrop. By selecting (1) one of the key commands, the user gets access to the file management panel from which (2) files can be selected or created and (3) the input characteristics can be displayed and updated.

The ***Main Menu*** consists of 2 panels where the names and descriptions of the selected input files are displayed (Fig. 1.1):

- ☐ **Environment and Crop panel:** where the user:
  - (1) selects or creates **Climate**, **Crop**, **Irrigation** and **Field** management, **Soil profile** and **Groundwater** table files and displays or updates the corresponding characteristics;
  - (2) specifies the start of the growing cycle;
- ☐ **Simulation panel:** where the user:
  - (3) specifies the **Simulation period**;
  - (4) selects or creates **Initial conditions, Off-season** conditions, **Project** and **Field data** files and displays or updates the corresponding characteristics;
  - (5) **Run** a simulation for the specified environment, crop and simulation settings.

1.2 Selecting files, undoing the selection and default settings

When AquaCrop is launched, default settings are assumed (Tab. 1.1). By means of the **<Select/Create>** commands available in the file management panel of the ***Main menu*** the user has access to the data base from which input files can be selected (Fig. 1.2). The files are stored in the default data base, which is the DATA subdirectory of the AquaCrop folder. With the **<Path>** command the user can select another directory.

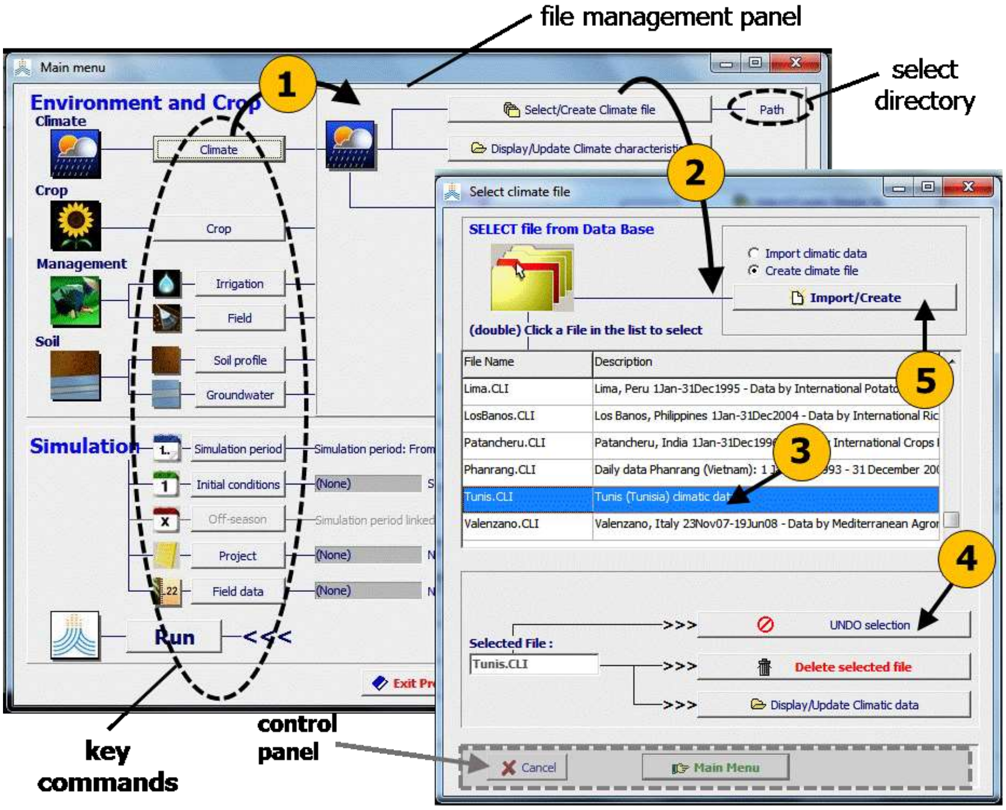


Figure 1.2 – By selecting (1) one of the key commands and subsequently (2) the corresponding <Select/Create> command in the file management panel in the *Main menu*, the user gets access to the *Select file* menus in which (3) one of the available files can be selected, (4) the selection can be undone, and (5) new files can be created.

A file is selected by clicking or double clicking the file name in the list displayed in the ***Select file*** menu. With the <**UNDO selection**> command in the ***Select file*** menu, the file selection is undone, and AquaCrop returns to the default settings for that file (Tab. 1.1).

Table 1.1 – Default settings

Subject	File	Remarks
Climate	(None)	A default minimum and maximum air temperature, ETo, rainfall (none), and CO_2 concentration are assumed. When running a simulation, other values for ETo and rainfall can be specified
Crop	DEFAULT.CRO	Generic crop data with planting at 22 March
Irrigation management	(None)	Rainfed cropping is assumed. When running a simulation, irrigation characteristics (quality and amount) can be specified

Field management	(None)	Optimal field management conditions are assumed
Soil profile	DEFAULT.SOL	Soil physical characteristics of a deep loamy soil
Groundwater	(None)	Absence of a shallow groundwater table
Simulation period		Simulation period covers the growing cycle
Initial conditions	(None)	Soil water content is at field capacity and salts are absent
Off-season	(None)	Optimal field management conditions are assumed

1.3 Displaying and updating characteristics

From the ***Main menu*** the user has access to a set of menus in which characteristics are grouped in tabular sheets. Distinction is made between:

1. menus where characteristics are only displayed but cannot be altered. The **'display'** menus become available by clicking on the file name or the corresponding icon in the ***Main menu***;
2. menus where characteristics are displayed and can be updated. The **'display/update'** menus become available by selecting the <**Display/Update characteristics**> commands in the file management panel of the ***Main menu***. The updates can be saved when returning to the ***Main menu*** (see 1.4).

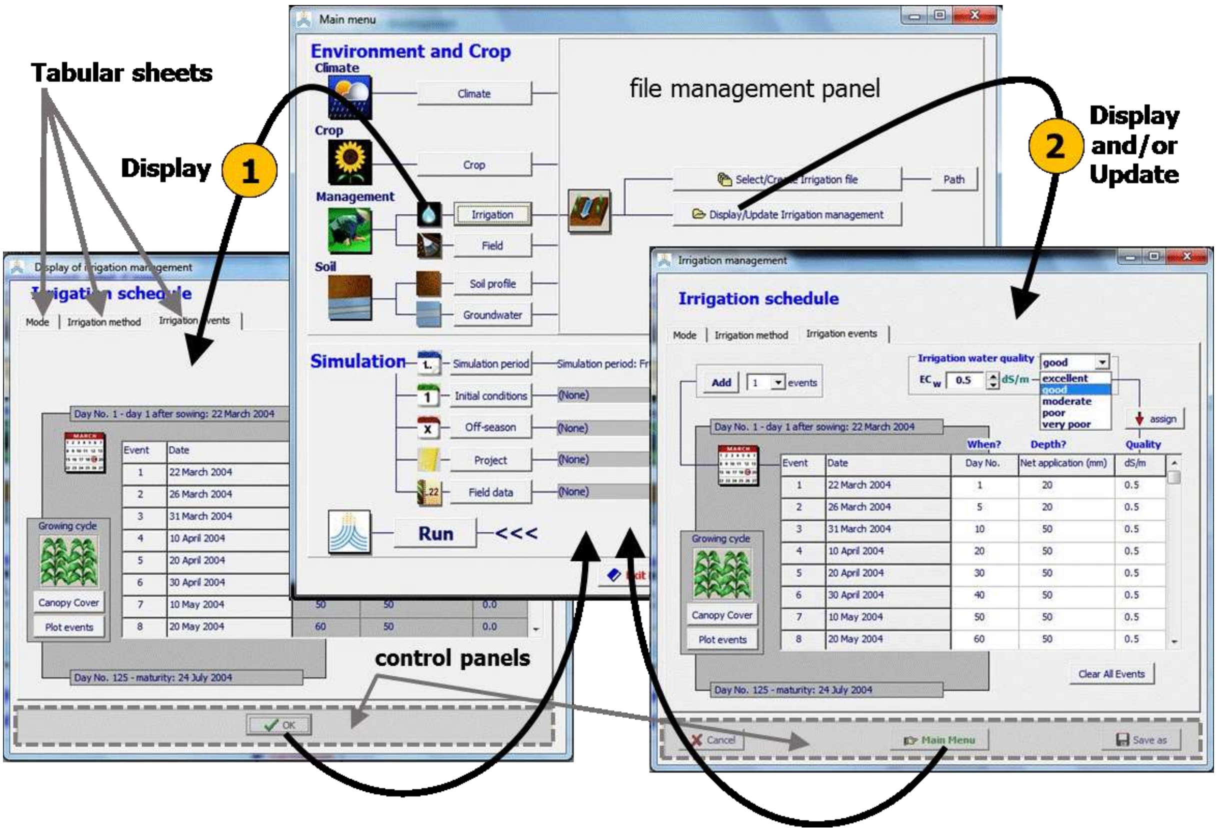


Figure 1.3 – From the *Main menu*, the user has the option (1) to only display the characteristics or (2) to display and update the characteristics of a file

1.4 Creating files

Several options to create a file are available (Fig. 1.4):

- from the ***Select file*** menu (example in Fig. 1.2):
  Create file menus becomes available by selecting the <**Create file**> command in the ***Select file*** menu. In the created files, characteristics of the climate, crop, irrigation or field management, soil profile, groundwater, initial conditions, project or field data are stored;
- after updating the characteristics in one of the menus (example in Fig. 1.3 - 2) new input files can be created by saving the update in a file. Distinction is made between:
  Save on disk: This is the option when the characteristics were not retrieved from a file, but consisted of an update of the default settings. An input file is created by selecting the <**Save on disk**> command in the control panel at the bottom of the ***Display/Update characteristics*** menu.
  Save as: This is the option when the characteristics were retrieved from an input file (as in Fig. 1.3 - 2). A copy of the file will be created by clicking on the <**Save as**> command in the control panel at the bottom of the ***Display/Update characteristics*** menu. This option allows the user to create various copies of a dataset which may differ only in one particular setting. This might be useful for the analysis of one or another effect on crop development or water productivity.

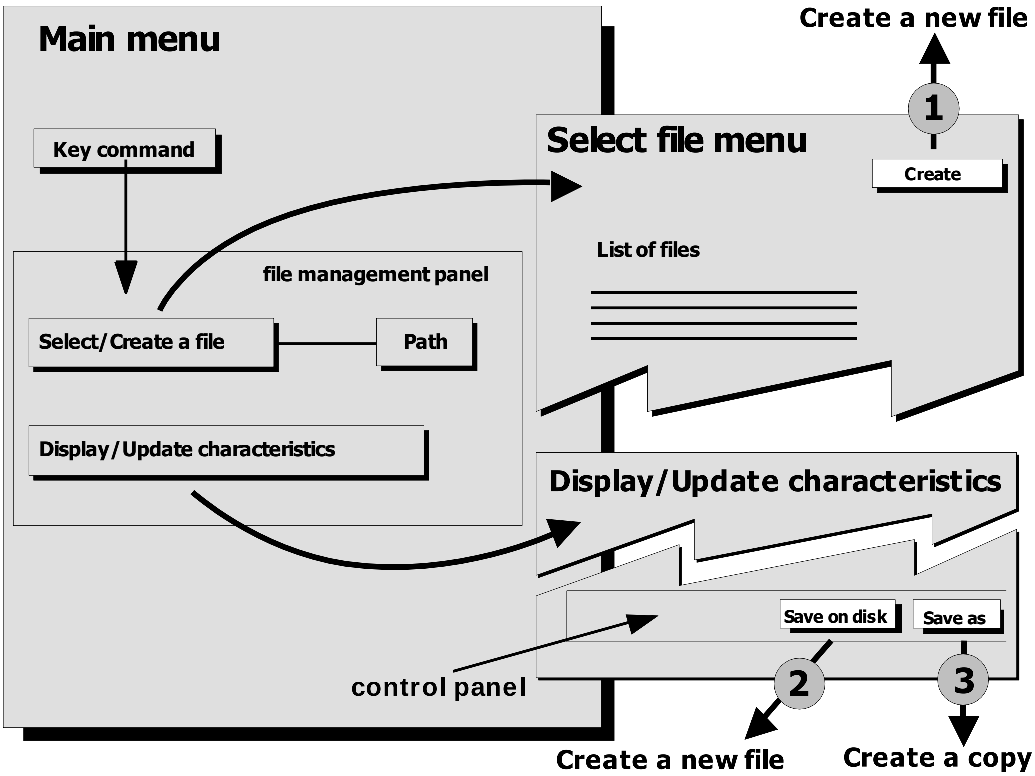


Figure 1.4 – Options to create a new file by selecting (1) the <Create> command at the top of the *Select file* menu, and (2) the <Save on disk> command (if the characteristics were not retrieved from a file) or (3) the <Save as> command (if the characteristics were retrieved from a file), in the control panel at the bottom of the *Display/Update* menu.

1.5 Ways to exit and close a menu

Different commands to exit a menu are available in the control panel at the bottom of each of the AquaCrop menus (Fig. 1.1, 1.2, 1.3 and 1.4). On exit, the window will be closed and the control is returned to the ***Main menu***. The type of exit mode is determined by the selected command. The following options to exit a menu are generally available (Fig. 1.5):

- **<Cancel>** All changes made to the data displayed in the menu are canceled when returning to the ***Main menu***;
- **<Return to Main menu>** Before returning to the ***Main menu***, the program checks if data were changed or settings were altered in the menu. The changes will be saved upon confirmation of the user;
- **<Save on disk>** When data were not retrieved from an input file but consists of an update of the default settings (Tab. 1.1), the user can select this option to save the data on disk before returning to the ***Main menu***;
- **<Save as>** When data were retrieved from an input file, the user can select this option to save the data in a different file from which it was retrieved before returning to the ***Main menu;***
- **<OK>** This is the command to close a menu in which only data or information is displayed that cannot be altered (Fig. 1.3 – 1).

By clicking on the "X" symbol at the upper right corner of a menu, the window is closed as well. This option is however not recommended since the type of exit mode cannot be specified.

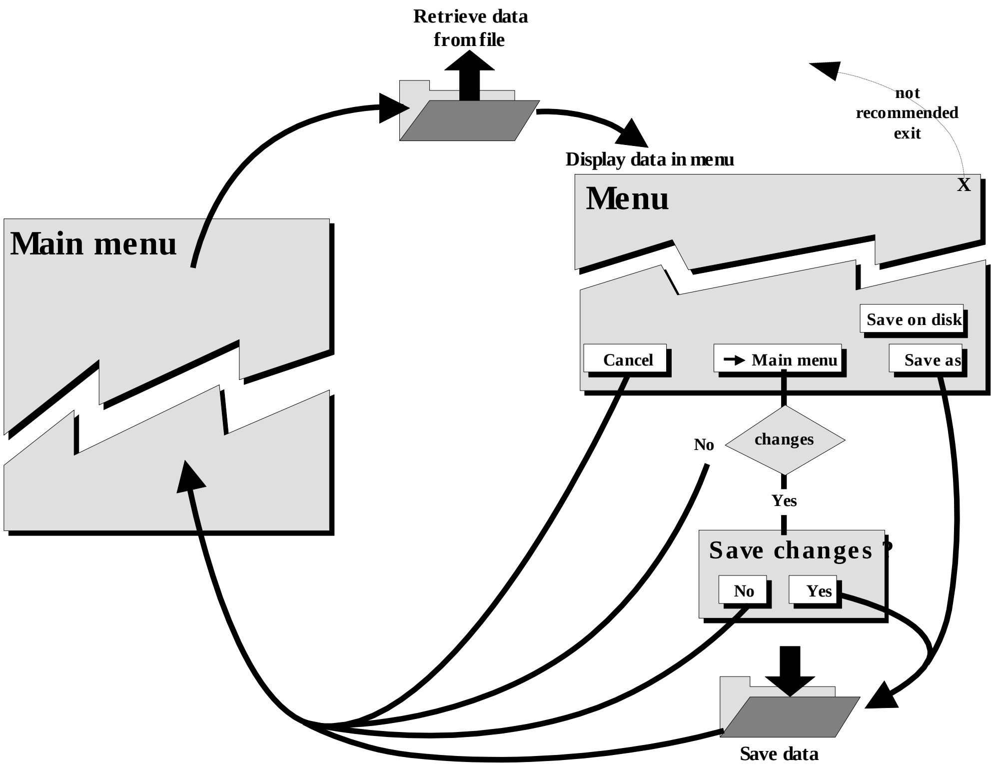


Figure 1.5 – Options to exit and close a menu

Chapter 2. Climate

2.1 Climatic data required by AquaCrop

For each day of the simulation period, AquaCrop requires:

- the minimum (Tn) and maximum (Tx) air temperature,
- the reference evapotranspiration (ETo),
- the rainfall data, and
- the mean annual atmospheric CO_2 concentration.

The required climatic data are stored in respectively:

- temperature files (files with extension '.Tnx'),
- ETo files (files with extension '.ETo'),
- rainfall files (files with extension '.PLU') and
- CO_2 files (files with extension '.CO2').

A covering climate file (file with extension '.CLI') contains the names of the Tnx, ETo, PLU and CO2 file (Fig. 2.1). The climatic data itself is stored in the Tnx, ETo, PLU and CO2 files.

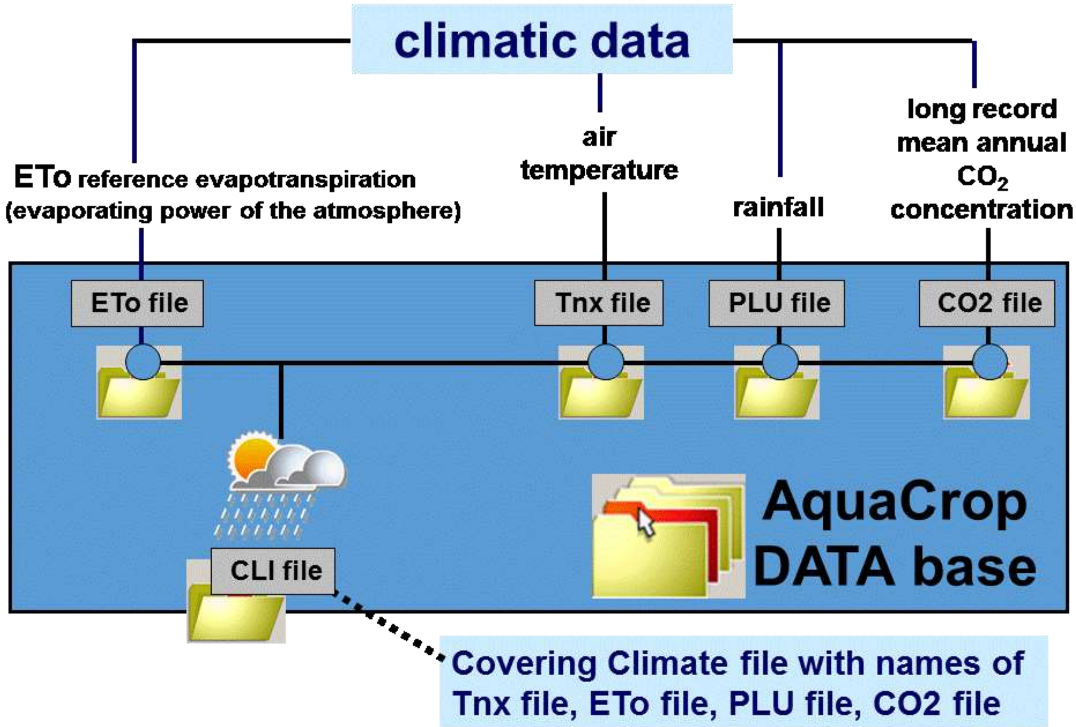


Figure 2.1 – Climate files (*.CLI) and files with climatic data (*.ETo, *.Tnx, *.PLU, *.CO2) stored in AquaCrop data base.

2.2 Creating air temperature, ETo and rainfall files

2.2.1 Text files with climatic data

In the ***Select climate file*** menu, the user has the option to 'Import climatic data' from a text file (Fig. 2.2).

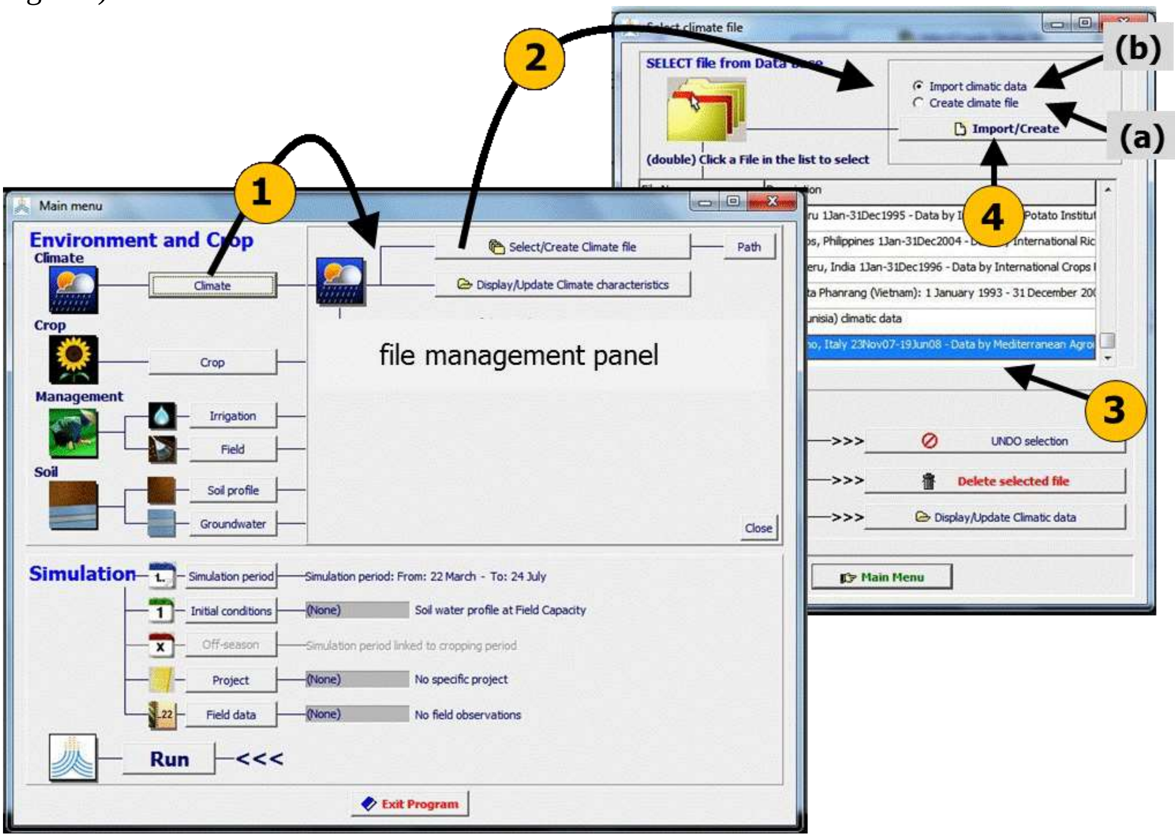


Figure 2.2 – By selecting (1) the <Climate> command and subsequently (2) the <Select/Create Climate file> command in the file management panel in the *Main menu*, the user gets access to the *Select climatic file* menu, in which (3) one of the available CLI files, or (4) the command (a) to <Create a climate file> (new CLI file) or (b) to <Import climatic data> (by creating air temperature, ETo and or rainfall files) is selected.

☐ **Type of data**

Data that can be imported, consist of air temperature, ETo, or rainfall data, and/or other climatic data with which ETo can be calculated. By importing the data, AquaCrop will create the corresponding files containing the climatic data (files with extension '.Tnx', '.ETo' and/or '.PLU'). Data of climatic parameters, expressed in one of the units listed in Table 2.1, can be imported by AquaCrop.

☐ **Free format text files with climatic data (files with extension '.txt' or '.cxt')**

The text file is a file with extension '.txt' (as created by Notepad), in which climatic data for a specific time range are saved in columns (example in Tab. 2.2). It is typically a copy from a spreadsheet but contains only the numerical values: no headings, units, line numbers, or dates!

Table 2.1 – Climatic parameters and units which recognized by AquaCrop for import.

Climatic parameter and Symbol	Possible units
Air temperature data	
Maximum air temperature (Tmax)	°C or °F
Mean air temperature (Tmean)	°C or °F
Minimum air temperature (Tmin)	°C or °F
Air Humidity data	
Maximum Relative Humidity (RHmax)	%
Mean Relative Humidity (RHmean)	%
Minimum Relative Humidity (RHmin)	%
Dewpoint temperature (Tdew)	°C or °F
Actual vapour pressure: e(act)	kPa, mbar, psi, atm or mmHG
Temperature of dry bulb (Tdry)	°C or °F
Temperature of wet bulb (Twet)	°C or °F
Wind speed data	
Wind speed at x m above soil surface: u(x)	m/sec, km/day, knot or ft/sec
Radiation and sunshine data	
Actual duration of sunshine in a day (n)	hour
Relative sunshine duration (n/N)	-
Solar or shortwave radiation (Rs)	MJ/m^2.day, W/m^2, J/cm^2.day, mm/day, cal/cm^2.day
Net radiation (Rn)	MJ/m^2.day, W/m^2, J/cm^2.day, mm/day, cal/cm^2.day
ETo, Reference crop evapotranspiration	
Direct import of reference crop evapotranspiration (ETo)	mm/day
Rainfall data	
Rainfall (Rain)	mm or inch

Table 2.2 - Example of a text file containing climatic data. It consists of daily data, which are (column 1) rainfall in mm, (column 2) minimum and (column 3) maximum air temperature in °C, (column 4) hours of bright sunshine in hours/day, and (column 5) wind speed in m/sec.

```
0      18    30   6.5  4.2
0      19    29.7 5.8  2.9
55.6   16.8  29.4 5.5  2.5
2.2    15.5  26.2 2.7  2.7
0      14.5  28.9 9.4  1.1
0      11.3  30.2 10.2 1.3
0      12.7  31.2 11   1.4
0      15.1  33.4 10.7 1.5
0      15.7  34.8 10.7 1.8
0      15.2  34.8 10.5 1.7
0      15.9  35.7 10.7 1.8
```

The file may contain daily, 10-daily or monthly climatic data. The text file consists of climatic data recorded in a specific time range (ranging from a few days up to several years) or of calculated averages for a number of years. Missing data has to be identified by a specific value. The default, which is -999.000, can be altered in the 'Climatic parameter' tabular-sheet of the ***Import climatic data*** menu (Fig. 2.5). The text file has lines and columns:

– Lines: There are as many lines (rows) as day's, 10-day's or months in the imported time range. Each line contains the climatic data (or average) for only one day, 10-day or month of the time range, and this in successive order;
– Columns: The text file can contain up to 10 columns. Each column contains the data of one of the climatic parameters listed in Table 2.1.

2.2.2 Importing climatic data

The ***Import climatic data*** menu contains 5 tabular sheets (Fig. 2.3);

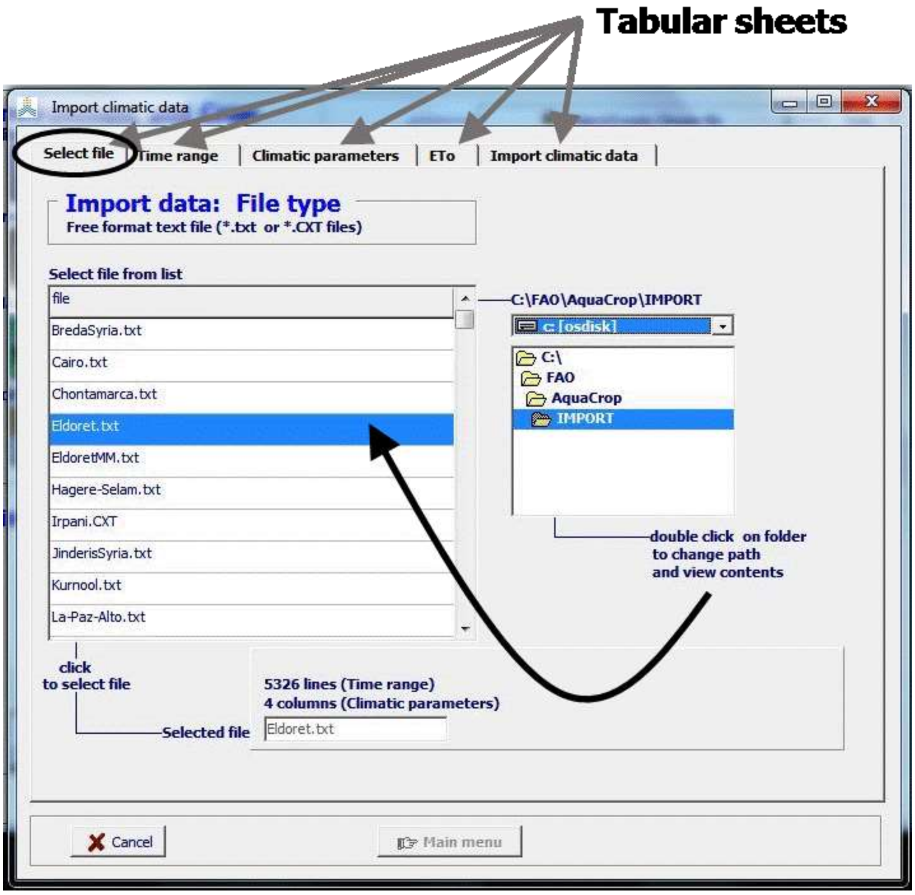


Figure 2.3 – *Import climatic data* menu with its tabular sheets: 'Select file' (displayed), 'Time range', 'Climatic parameters', 'ETo', and 'Import climatic data'.

- **'Select file'**: to select the text file, containing the climatic data to be imported;
- **'Time range'**: to specify the time range of the imported climatic data (lines in text file);
- **'Climatic parameters'**: to specify the climatic parameters and their units of the imported data (columns of text file);
- **'ETo'**: to specify coefficients for ETo calculation (if relevant);
- **'Import climatic data'**: to create '.Tnx', '.ETo', and/or '.PLU' files (containing the imported climatic data), and to save the created file(s) in the AquaCrop data base.

☐ **Tabular sheet: ‘Select file’**

In the tabular sheet ‘Select file’ (Fig. 2.3) the user selects the text file containing the climatic data. All text files (files with extension ‘.txt’ or ‘.CXT’) stored in the IMPORT sub directory of the AquaCrop folder are listed. By altering the path, the user can retrieve text files from other directories. Once a text file has been selected, the program displays the number of:

- Data lines (rows), which corresponds with the number of days, 10-day’s or months in the time range covering the climatic data;
- Columns of the text file, which corresponds with the number of climatic parameters available in the text file.

In the example (Fig. 2.3), the ‘Eldoret.txt’ file has been selected, which contains 5,326 lines and 4 columns with climatic data (i.e. a long record of daily minimum, maximum and average air temperature and rainfall data for several years). The time range and climatic parameters are specified respectively in the ‘Time range’ and ‘Climatic parameters’ tabular sheets.

☐ **Tabular sheet: ‘Time range’**

In the tabular sheet ‘Time range’ (Fig. 2.4), the user specifies the Type of data (daily, 10-daily or monthly) and the Time range (from date - to date). If the climatic data consists of averages of several years, the data should not be linked to a specific year and the year has not to be specified.

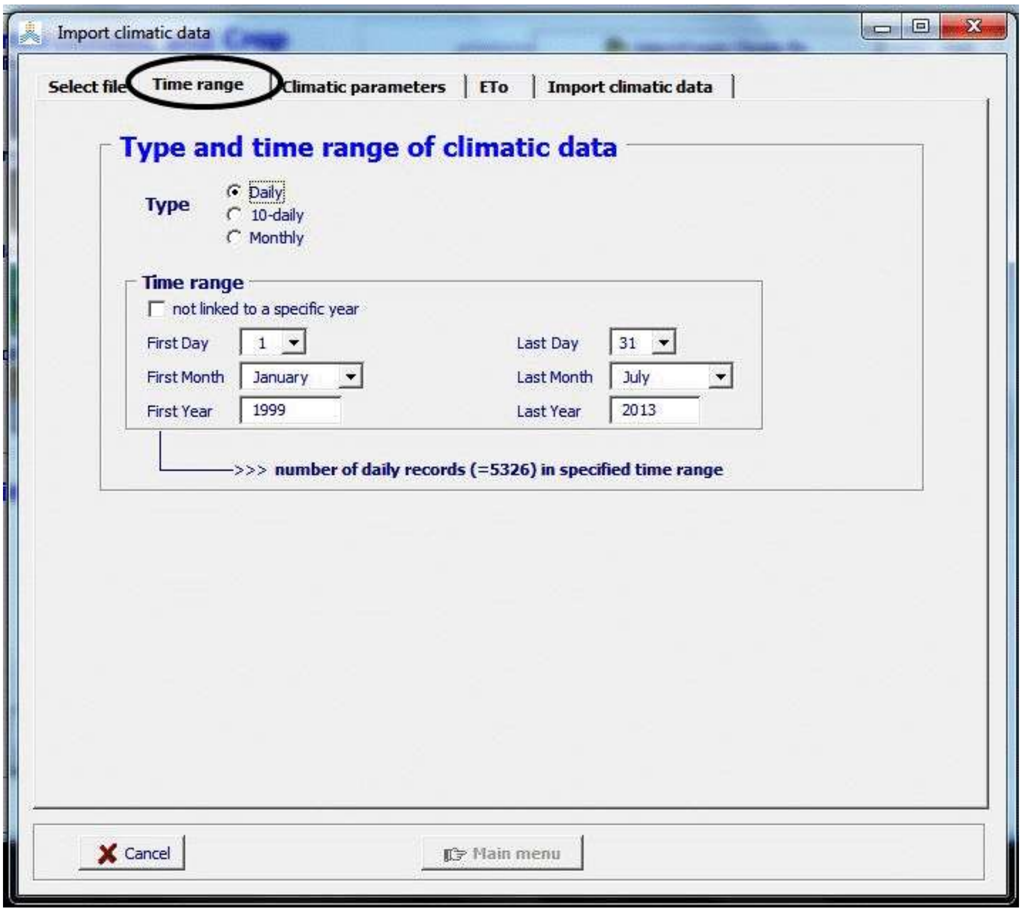


Figure 2.4 – The ‘Time range’ tabular sheet of the *Import climatic data* menu: for ‘Eldoret.txt’ (containing a long record of daily temperature and rainfall data).

By adjusting the time range in the tabular sheet, the program displays the corresponding number of data records within this range. The number of records should match with the number of rows of the text file containing the meteorological data. For the example of the selected 'Eldoret.txt' file with its 5,326 lines in Fig. 2.3, there are indeed 5,326 days between the specified start (1 January 1999) and end (31 July 2013) of the time range (Fig. 2.4).

If the number of records does not match with the number of rows in the text file, a warning ('Adjust time range') is displayed and the climatic data cannot be imported.

☐ **Tabular sheet: 'Climatic parameters'**

In the tabular sheet 'Climatic parameters' (Fig. 2.5) the user specifies the climatic parameters and its units (the data stored in the columns).

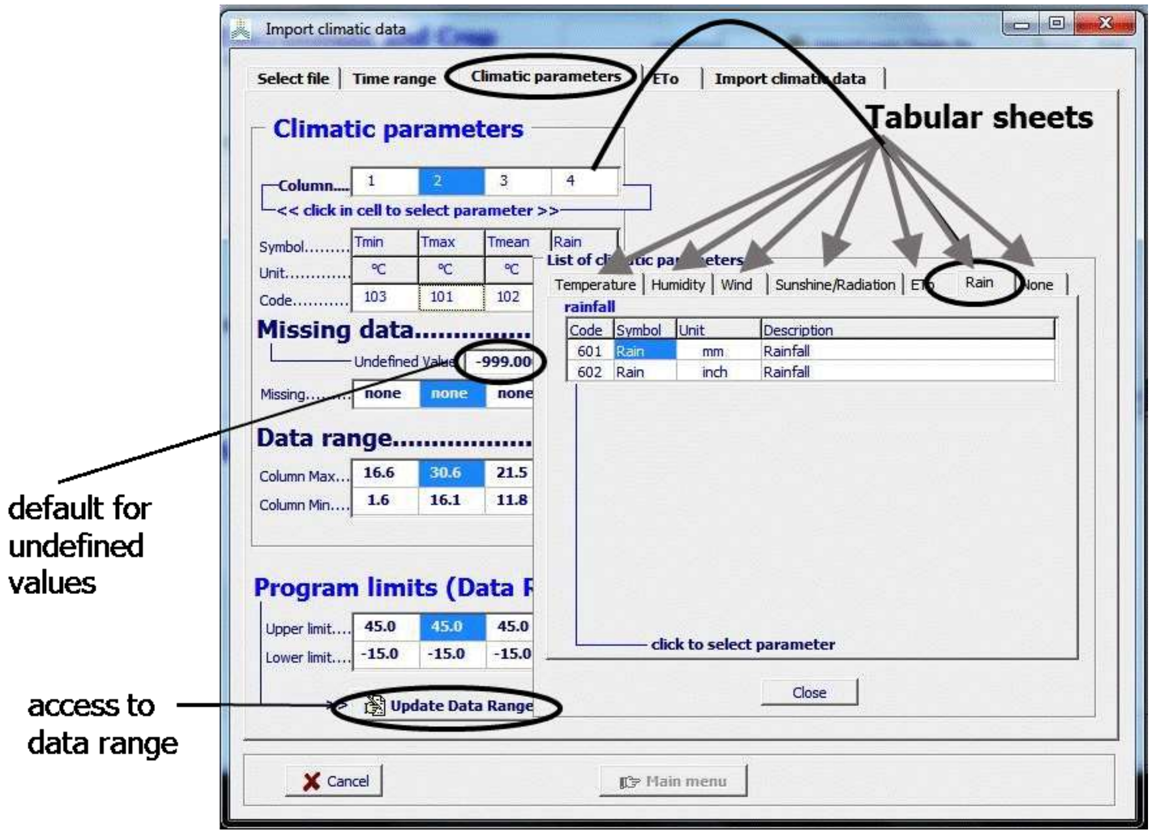


Figure 2.5 – The 'Climatic parameters' tabular sheet of the *Import climatic data* menu for 'Eldoret.txt' (containing a long record of daily temperature (minimum, maximum and average) and rainfall data).

By selecting one of the column numbers, a list pops up containing the climatic parameters which are recognized by AquaCrop (Tab. 1.1). The parameters are stored in 6 tabular sheets grouping them in 'Temperature', 'Humidity', 'Wind speed', 'Sunshine/Radiation', 'ETo', and 'Rain' data. An additional tabular sheet 'None' is available, to specify that the column contains irrelevant data. The data in the column will be disregarded and cannot be imported.

When a climatic parameter is specified for a column, the program displays:
- **Symbol, Unit** and program **Code** for the selected climatic parameter;
- Number of **Missing data** in each column of the text file. The default value (-999.000) will be used to identify missing data. This default value for missing data can be adjusted to the undefined value used in the specific text file. Procedures are available in AquaCrop to estimate ETo with missing air humidity, radiation, sunshine and/or wind speed data. Such procedures are not available to estimate missing minimum and maximum air temperature data, rainfall data and directly imported ETo data. Hence, records with missing Tmax, Tmin, Rain and ETo data cannot be imported if they contain missing values;
- **Data range** (minimum and maximum value) for the selected climatic parameter as found in the text file. These should be within the program limits. If the program limits are smaller than the detected data range the data cannot be imported by the program;
- **Program limits** (upper and lower limit) used by the program for each of the selected climatic parameters. This feature allows for a range check of the imported data. If the user believes that the program limits are too narrow or too broad, the user can alter the limits in the ***Limits of climatic data*** menu (Fig. 2.8). This menu is displayed by clicking on the **<Update Data Range**> command key at the bottom of in the 'Climatic parameters' tabular sheet.

☐ **Tabular sheet: 'ETo'**

If sufficient data is available to calculate ETo with the imported climatic data, information about its calculation and data required for its calculation, are specified in the tabular sheet 'ETo' (Fig. 2.6). It consists of:
- **Coordinates of Meteorological station** (Altitude and Latitude). They are required for the calculation of the psychrometric constant (γ), extra-terrestrial radiation (Ra) and maximum hours of bright sunshine or day length (N). As long as the Altitude and Latitude are identical to their default settings (i.e. 222 m.a.s.l. and 22°22' N), a warning to 'adjust the coordinates' is displayed and the climatic data cannot be imported for ETo calculation;
- **Climatic data considered for ETo calculation.** ETo is calculated with the FAO Penman-Monteith method according to the calculation procedures outlined in the FAO Irrigation and Drainage paper Nr. 56 (Allen et al. 1998). To compute ETo, (i) air temperature, (ii) air humidity, (iii) radiation and (iv) wind speed data are required. The data considered for its calculation are displayed. For the example in Fig. 2.6 (for 'Eldoret.txt', a text file containing a long record of daily temperature and rainfall data), only Tmin and Tmax are available (columns 1 and 2). The required vapour pressure will be estimated from Tmin, and the required solar radiation, will be estimated from the (Tmax-Tmin) difference. For wind speed, the specified average wind speed value will be used;
- **Coefficients required to estimate ETo when solar radiation, wind speed and/or air humidity data are missing**. Calculation procedures as outlined in the FAO Irrigation and Drainage paper Nr. 56 are used to estimate missing radiation, wind speed and air humidity data. Default values can be assigned to the coefficients by specifying the 'Location' of the meteorological station by means of the radio buttons (Fig. 2.6). The calculation procedures consist of:
  - Temperature difference method (using the square root of the difference between the maximum and minimum air temperature) to estimate **missing solar radiation** (Rs). The adjustment coefficient (k_{Rs}) is empirical and differs for 'interior' or 'coastal' regions. In the absence of a calibrated k_{Rs} value, the default value can be used by selecting the appropriate radio button for the location of the meteorological station (Tab. 2.3);

- Selecting a general class of average wind speed, for **missing wind speed**. Enter a general value in the 'Edit' field or select an appropriate radio button for the location of the meteorological station (Tab. 2.3);
- Estimating the actual vapour pressure, by assuming that dewpoint temperature (Tdew) is near the daily minimum air temperature (Tmin). This method can be used where **humidity data are lacking** or are of questionable quality. The relationships Tdew ≈ Tmin holds for humid and sub-humid locations. For arid regions, the air might not be saturated when its temperature is at its minimum. In these situations, Tdew might be better approximated by subtracting 2 up to 3°C from Tmin. In the absence of a calibration, the default values for the region can be used by selecting the appropriate radio button for the location of the meteorological station (Tab. 2.3).

- **Coefficients of the Angstrom formula** for the calculation of solar radiation if different from the default setting. When net radiation (Rn) is not specified, AquaCrop uses the Angstrom formula to estimate incoming solar radiation (Rs). When no calibration has been carried out for improved 'a' and 'b' constants of the formula, the default values (a = 0.25 and b = 0.50) are recommended. To estimate outgoing long wave radiation the ratio between the incoming solar radiation (Rs) and the clear sky solar radiation (Rso) is required. The adjustment for station elevation in the calculation of Rso, is recommended in the absence of calibrated 'a' and 'b'. If calibrated values for 'a' and 'b' are available they can be specified (Fig. 2.6).

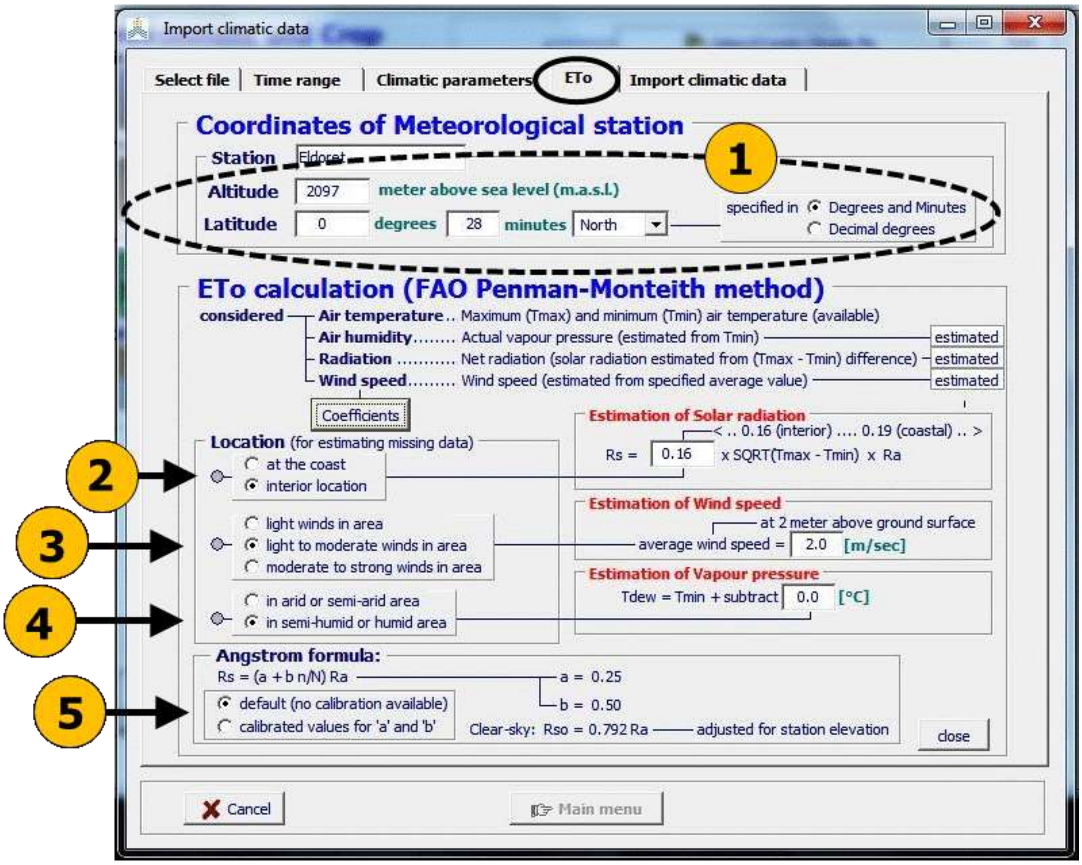


Figure 2.6 – The 'ETo' tabular sheet of the *Import climatic data* menu for 'Eldoret.txt' (containing a long record of daily temperature and rainfall data), with (1) specification of the coordinates; choices made for estimating missing (2) solar radiation, (3) wind speed, and (4) vapour pressure; and (5) values for coefficients of the Angstrom formula.

Table 2.3 – Default values for estimating missing climatic data

Missing parameter	Location of meteo-station	Default values	
Solar radiation (Rs)	- at the coast - interior location	k_{Rs} = 0.19 k_{Rs} = 0.16	temperature difference method
Wind speed at 2 meter above ground surface (u_2)	- light winds - light to moderate winds - moderate to strong winds	u_2 = 0.5 m/sec u_2 = 2.0 m/sec u_2 = 4.0 m/sec	
Vapour pressure: dewpoint temperature	- in arid or semi-arid area - in semi-humid or humid area	Tdew ≈ Tmin – 2°C Tdew ≈ Tmin	

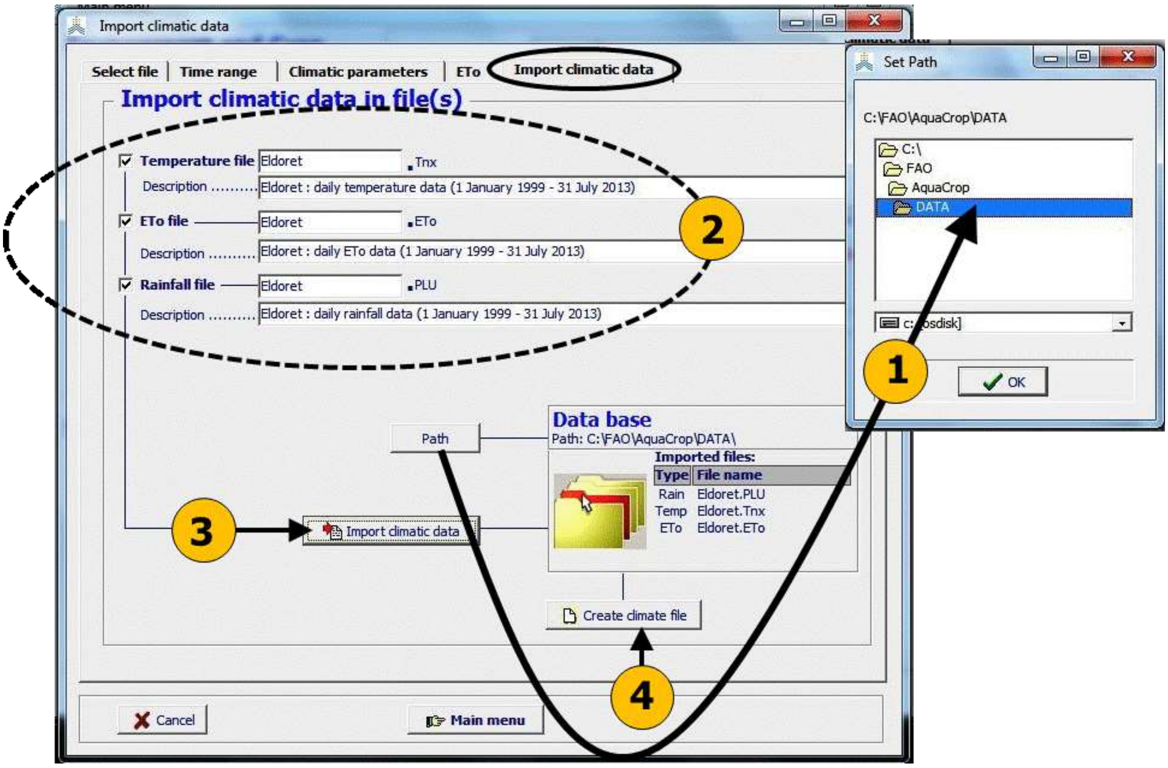


Figure 2.7 – The 'Import climatic data' tabular sheet of the *Import climatic data* menu for 'Eldoret.txt' (containing a long record of daily temperature and rainfall data), with specification of (1) folder, and (2) names and description of files with climatic data. By selecting (3) the <Import climatic data> command the climatic data is imported in the required format, and (4) a covering climate file can be created.

☐ **Tabular sheet: 'Import climatic data'**

In the tabular sheet 'Import climatic data' (Fig. 2.7), the user can adjust:

- Folder in which the files with climatic data needs to be stored. By selecting the **<Path>** command, the user can alter the directory from its default path which is the 'DATA' subdirectory of the AquaCrop folder;
- Default file names and description for Temperature (file with extension '.Tnx'), ETo (extension '.ETo'), and Rainfall (extension '.PLU') files. These files can only be created if (i) the Time range is well set, (ii) sufficient climatic data is available, (iii) the climatic data is within the program limits, and (iv) the coordinates of the meteorological station are adjusted (only required when ETo is calculated);
- By selecting the <**Import climatic data**> command, the selected files (with the imported data) are created, and stored in the specified folder (default is the data base 'DATA' of AquaCrop).

For the example in Fig. 2.7, for 'Eldoret.txt' (a text file containing a long record of daily temperature and rainfall data): a **temperature file** ('Eldoret.Tnx' containing the imported daily Tmin and Tmax values), an **ETo file** ('Eldoret.ETo' containing calculated daily ETo estimates), and a **rainfall file** ('Eldoret.PLU' containing the imported daily rainfall data) were created. With the imported Tnx, ETo and PLU file a **covering climate file** ('Eldoret.CLI') can be created (see section 2.4).

2.2.3 Data range

The ***Limits of climatic data*** menu (Fig. 2.8) contains the data range (lower and upper limit) assigned by the program to the various climatic parameters that can be imported (Tab. 2.4).

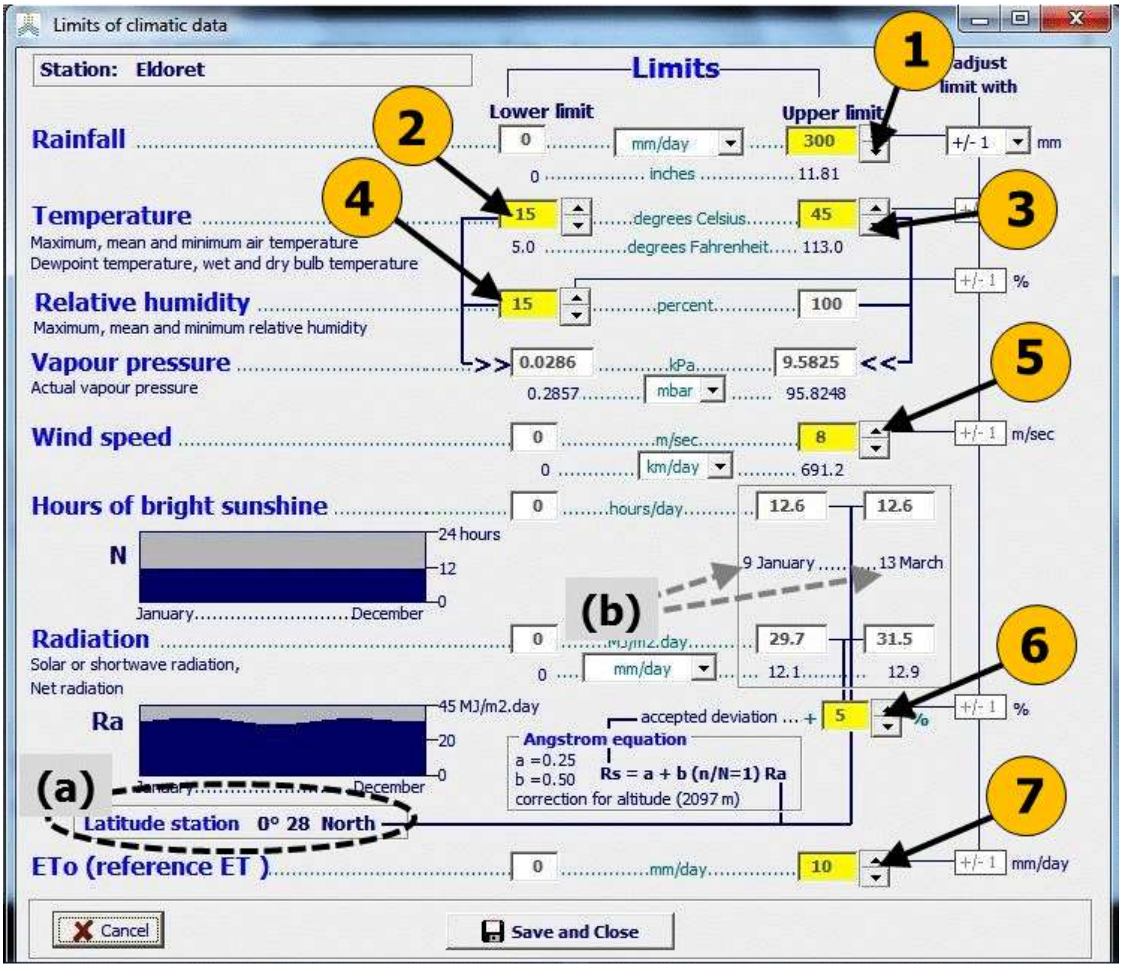


Figure 2.8 – The *Limits of climatic data* menu in which upper and/or lower limits can be adjusted for (1) total rainfall, (2) and (3) air temperature, (4) relative humidity, (5) daily wind speed, (6) deviation from maximum possible daily radiation (given by (a) latitude and (b) time of the year), and (7) daily ETo.

The following limits can be adjusted to obtain a more refined or flexible range check of the imported data:

- **Upper limit for rainfall data.** The upper limit for rainfall data differs with the type of rainfall data (daily, 10-daily or monthly values).

- **Limits for air temperature, relative humidity and vapour pressure.** Since these limits are linked, changing the limits for one parameter will alter the limits for the linked climatic parameters.
- **Upper limit for wind speed.** Daily, 10-daily and monthly wind speed are always expressed as the average daily value.
- **Upper limits for sunshine and radiation data.** The upper limits are determined by the latitude of the station and the time of the year. However a degree of over-estimation, that the user still finds acceptable, is allowed. The latitude and altitude are specified in the 'ETo' tabular sheet of the ***Import climatic data*** menu (Fig. 2.6).
- **Upper limit for direct imported ETo values.** Daily, 10-daily and monthly ETo are always expressed in AquaCrop as the average daily value.

Table 2.4 – Defaults for range check of climatic data

Climatic parameter	Lower limit	Upper limit
Total rainfall	0 mm	300 mm/day 1,000 mm/10-day 2,000 mm/month
Air temperature	-15 °C	+ 45 °C
Relative humidity	15 %	100%
Average daily wind speed	0 m/sec	8 m/sec
Deviation from maximum possible daily radiation (given by latitude and time of year)	0 %	5 %
Average daily ETo	0 mm/day	10 mm/day

2.3 CO2 files

Mean annual atmospheric CO_2 concentrations are stored in CO2 files. The CO2 file that needs to be created or can be used depends on the type of application:

- **Running simulations with historical climatic data or for the near future:**
  When running simulations with historical climatic data, or for the near future (next 10 year), there is no need to create a CO2 file, since the (default assigned) 'MaunaLoa.CO2' file (stored in the SIMUL subdirectory of AquaCrop) can be used. It contains the mean annual atmospheric CO_2 concentration measured at Mauna Loa Observatory since 1958. For earlier years, data obtained from firn and ice samples are used, and for future estimates an increase of 2.0 ppm is considered (which can be assumed to be valid for the next 10 years);

- **Running simulations for future years:**
  - For crop yield estimates for future years, CO2 files from SRES (Special Report on Emissions Scenarios), containing data derived from emissions scenarios are available in the DATA subdirectory of AquaCrop ('A1B.CO2', 'A2.CO2', 'B1.CO2' and 'B2.CO2'). The CO_2 projections presented in those files assume different socio-economic storylines;
  - Next to the 4 CO2 files from SRES, four different RCP's ('RCP2-6.CO2', RCP4-5.CO2', 'RCP6-0.CO2' and 'RCP8-5.CO2') are available in the data base of AquaCrop (Fig. 2.9). As the SRES set, the RCPs (Representative Concentration Pathways) represent a broad range of climate outcomes. Each RCP results from different combinations of economic, technological, demographic, policy, and institutional futures;

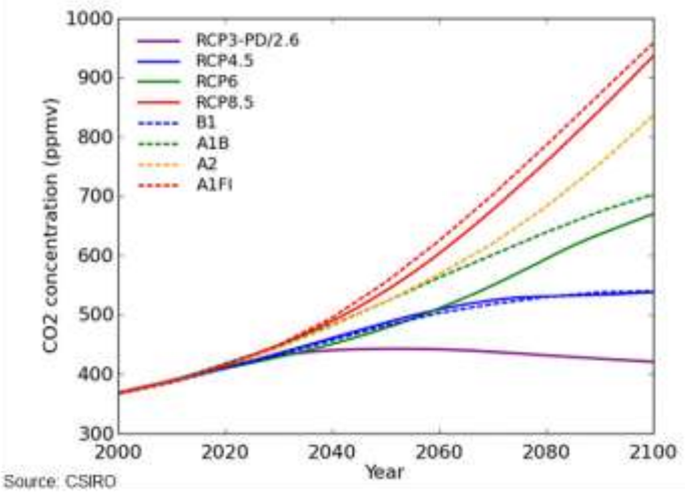


Figure 2.9 – Different SRES and RCP's scenarios available in AquaCrop data base

- The user can also create:
  - CO2 file containing (observed and/or projected) annual atmospheric CO_2 concentrations for a number of years;
  - CO2 file containing only one specific annual atmospheric CO_2 concentration (e.g. 550 ppm) for testing its effect on crop production (Tab. 2.6).

<u>Structure of a CO2 file and rules applied when running a simulation</u>

A CO2 file contains mean annual atmospheric CO_2 data (in ppm) for a series of years arranged in chronological order (Tab. 2.5 and 2.6). The following rules apply:

- for years not specified in the file, AquaCrop will derive at run time the CO_2 concentration by linear interpolation between the specified CO_2 values for an earlier and later year;
- for years out of the listed range, the atmospheric CO_2 concentration is assumed to be equal to the specified value of the first year (for earlier years) or the specified value of the last year (for later years).

Table 2.5 – Structure of a CO2 file containing annual [CO_2] of different years

Line	File content	Explanation
1	First line is a description	description
2	Year CO2 (ppm by volume)	title
3	============================	title
4	1940 310.5	year(1) and corresponding [CO_2]
5	1960 316.91	year(2) and corresponding [CO_2]
6	1961 317.65	year(3) and corresponding [CO_2]
...	... .	....
n-1	2007 383.72	year(n-1) and corresponding [CO_2]
n	2020 409.72	year(n) and corresponding [CO_2]

Table 2.6 – Example of a CO2 file containing only one specific annual atmospheric [CO_2] for testing its effect on crop production in any year of the simulation period.

Constant CO2 concentration of 550 ppm
Year CO2 (ppm by volume)
============================
2050 550

2.4 Creating covering climate files

With climatic data stored in Tnx, ETo, PLU and CO2 files, a covering climate file (extension '.CLI') can be created:

- by selecting the option 'Create climate file' in the ***Select climatic file*** menu (Fig. 2.2 – 4a), or
- by selecting the command <**Create climate file**> in the 'Import climatic data' tabular sheet of the ***Import climatic data*** **menu** (Fig. 2.7 – 4).

The CLI file is composed in the ***Create climate file*** menu by selecting (a) a Rainfall, (b) ETo, (c) air Temperature, and (d) CO2 file from the Data Base (Fig. 2.10).

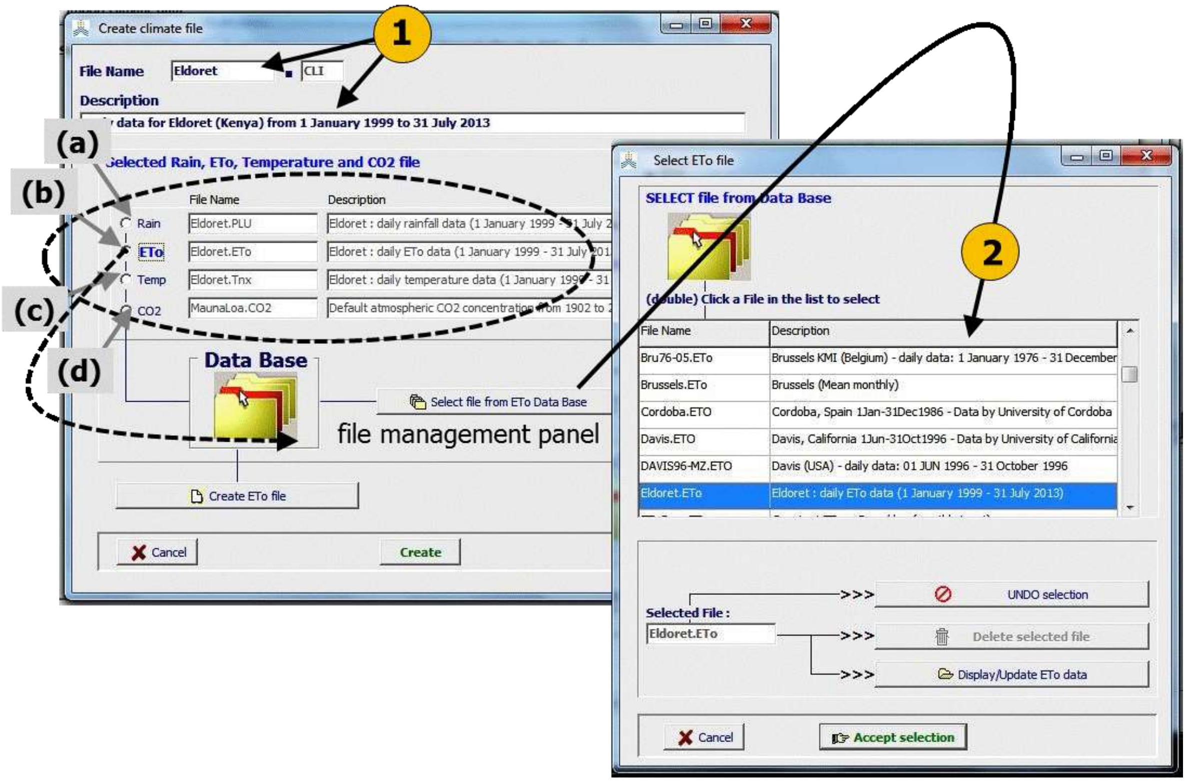


Figure 2.10 – *Create climate file* menu in which the user composes the covering climate file (1) by specifying its name and description, and (2) by selecting a (a) rainfall, (b) ETo, (c) air temperature and (d) CO2 file from the Data Base.

Chapter 3. Soil

3.1 Creating soil profile files

In the ***Create soil profile file*** menu, the user specifies (Fig. 3.1):

a) File **name**;
b) File **Description**;
c) **Number of Soil horizons** (from 1 to 5);
d) **Soil textural class** and (e) **Thickness** of each of the horizons. The classes are selected from a list, which contain data for a set of soil textural classes. From the data, default values for the required soil physical characteristics of each layer and the soil surface are derived.

After creating the file, the ***Soil profile characteristics*** menu is displayed (Fig. 3.2), in which the user can fine-tune the soil physical characteristics.

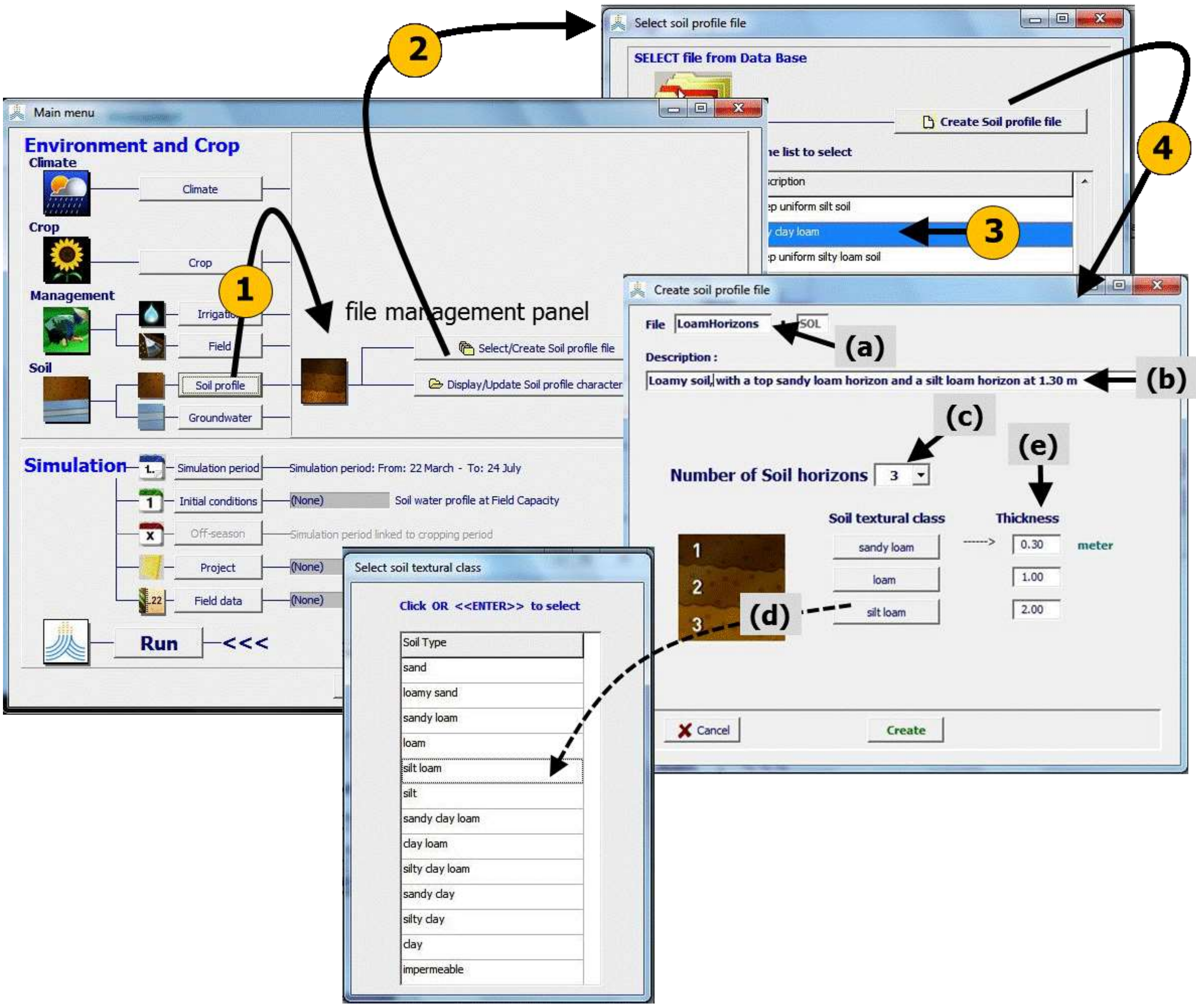


Figure 3.1 – By selecting (1) the <Soil profile> command and subsequently (2) the <Select/Create soil profile file > command in the file management panel of the *Main menu*, the user gets access to *Select soil profile file* menu, in which (3) one of the available soil profile files or (4) the command to <Create a soil profile file> is selected.

3.2 Soil profile characteristics

The soil physical characteristics of the different soil horizons and soil surface layer (Tab. 3.1) are displayed and can be updated in the various tabular sheets of the ***Soil profile characteristics*** menu:

- **Description**: to adjust the description of the soil profile file;
- **Characteristics of soil horizons** (Fig. 3.2): to alter the number of horizons and to adjust their thickness, and (A) – 'Soil water': to alter the soil water content at permanent wilting point (PWP), field capacity (FC) and at saturation (SAT), and the saturated hydraulic conductivity (Ksat); (B) – 'Stoniness': to specify mass percentages of gravel; and (C) – 'Penetrability': to specify root zone expansion rates in the various horizons (if restrictive);
- **Soil surface**: to adjust the Curve Number (CN) and the Readily Evaporable Water (REW);
- **Capillary rise**: to calibrate the maximal amount of water that can be transported upwards by means of capillary rise.

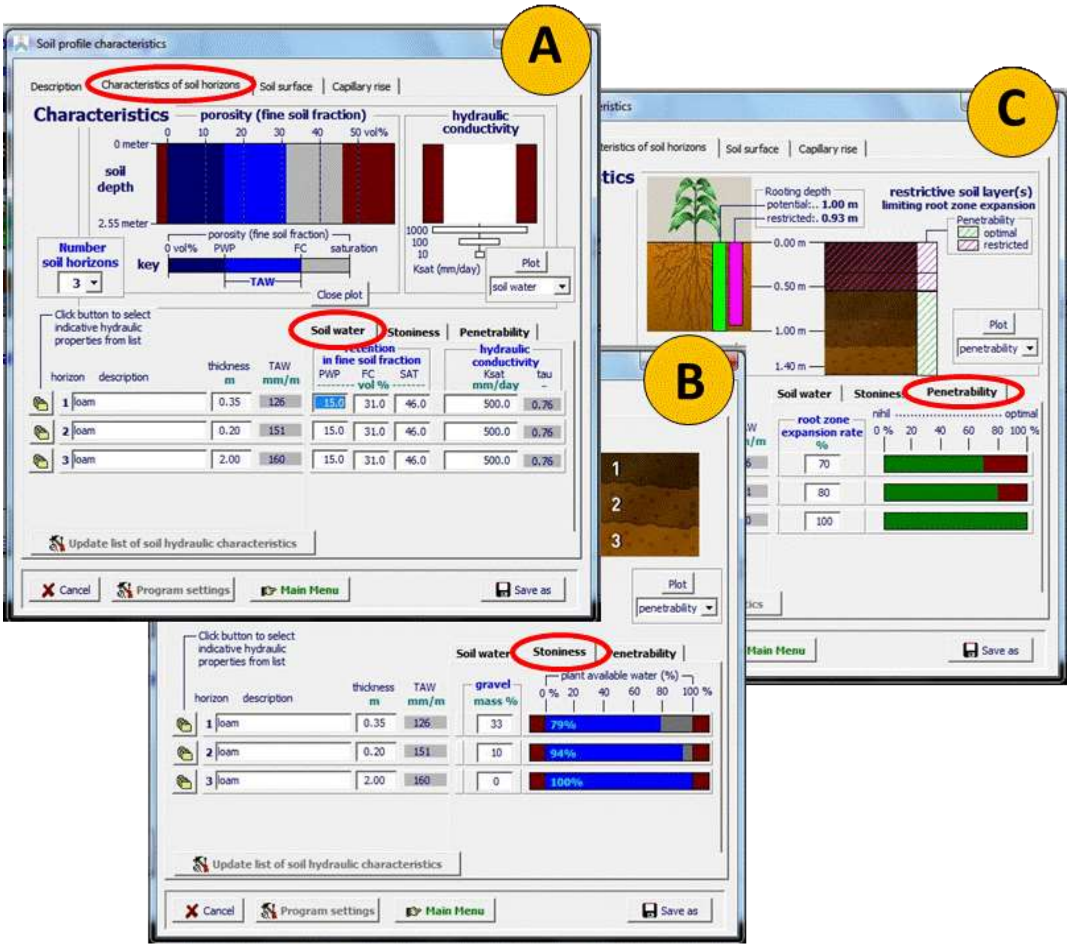


Figure 3.2 – Specification of physical characteristics of the various soil horizons in the (A) 'Soil water', (B) 'Stoniness' and (C) 'Penetrability' tab-sheet in the *Soil profile characteristics* menu.

Table 3.1 – Comments when specifying soil profile characteristics

Number of horizons: Different soil horizons need only be considered if there is a substantial difference in TAW (differences larger than 10 mm/m), in Ksat, presence of gravel or penetrability between the horizons

Soil water content at permanent wilting point (θ_{PWP}), field capacity (θ_{FC}) and at saturation (θ_{SAT}):

- Together with the depth of the root zone (which is a crop characteristic), the difference between the θ_{FC} and θ_{PWP} determines the size of the root zone reservoir (expressed by TAW). The larger the TAW, the more water can be retained in the root zone, and the less drought stress will appear during the dry spells;
- In the absence of locally determined values for θ_{PWP}, θ_{FC} and θ_{SAT} use the indicative values provided by AquaCrop for the various soil textural classes, or derive data from soil texture with the help of pedo-transfer functions.

Saturated hydraulic conductivity (Ksat):

- Indicative values provided by AquaCrop for the various soil textural classes can be used;
- Simulation of infiltration and internal drainage are not very sensitive to Ksat, unless its value becomes small (Ksat less than 50 mm/day).

Gravel: The reduction of the total available water (TAW), due to gravel, is displayed.

Penetrability: Compacted layers (e.g. hardpan) limits the root zone expansion rate.

Curve Number (CN):

- CN is required for the simulation of the surface runoff. The larger the CN the more important the runoff. The default value is derived from the Ksat of the top horizon;
- Field surface practices and land use affecting runoff and CN, have to be specified as Field management characteristics (see Chapter 5).

Readily Evaporable Water (REW). It expresses the amount of water that can be evaporated from the soil surface in the energy limiting stage.

Restrictive soil layer: The presence of the restrictive soil layer will only block root zone expansion. The effect on soil water movement is determined by the Ksat of the soil horizon. Very low Ksat (as 1 mm/day) strongly restricts water movement in that horizon.

Capillary rise:

- The default values for the parameters used for the simulation of capillary rise for each soil horizon, are obtained by considering θ_{PWP}, θ_{FC}, θ_{SAT} and Ksat;
- With the help of 'spin' buttons the user can calibrate the maximum amount of water that can move upwards to the root zone from a groundwater table at a selected depth. For the example in Fig. 3.3: if for the soil characteristics of the soil horizons, the maximal capillary rise to the root zone (thickness of 1 m, which is a crop characteristic) is known to be only 1 mm/day (instead of the displayed 1.8 mm/day) for a groundwater table depth at 2 meter, (i) set the depth of the water table at 2 m, and (ii) use the spin button of the horizons (mainly horizon 3 in this case), to reduce the capillary rise to the bottom of the root zone to 1.0 mm/day;
- By means of the **<Reset>** command, the parameters used for the simulation of capillary rise can be reset to their default values (Fig. 3.3);
- When running a simulation, the magnitude of the capillary rise can differ from the calibrated maximum value:
    - Capillary rise will be smaller if the soil water content in the root zone is at or above field capacity (no driving force) or close to wilting point (hydraulic conductivity too small to move water upwards);
    - If the depth of the groundwater is different from the one selected in the ***Soil profile characteristics*** menu for calibration, capillary rise will be different. The depth (and water quality) of the groundwater table for the simulation are specified in the ***Groundwater characteristics*** menu.

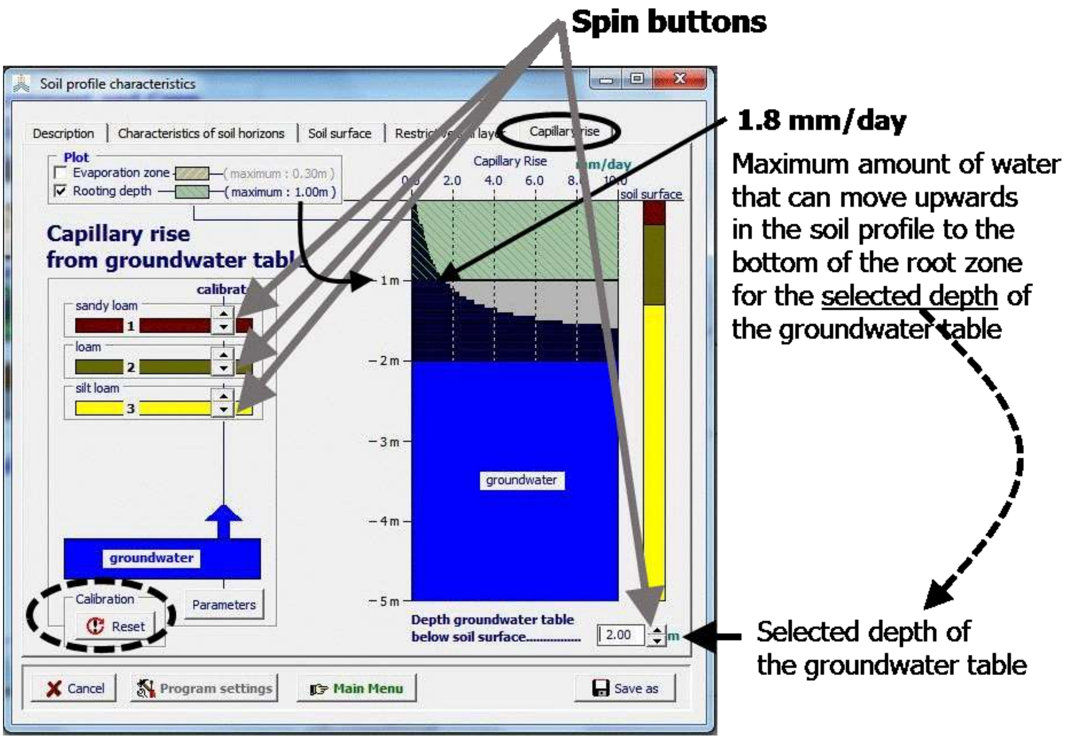


Figure 3.3 – The 'Capillary rise' tabular sheet of the *Soil profile characteristics* menu in which the maximum amount of water that can be transported upwards to the bottom of the root zone (for the specified crop), can be calibrated with the help of spin buttons, for a selected groundwater table depth.

3.3 Creating groundwater table files

When creating a groundwater table file, the type of file has to be selected in the ***Select groundwater file*** menu (Fig. 3.4): (a) Constant depth and water quality; or (b) Varying depth and/or water quality. Subsequently the user specifies the characteristics (depth and water quality) of the groundwater table, which can be displayed and updated in the ***Groundwater characteristic*** menu (Fig. 3.5).

If the groundwater table is not shallow (more than 4 meter below the root zone), there is no need to specify a groundwater table, since capillary rise can be disregarded;

3.4 Groundwater table characteristics

The characteristics of the groundwater table (depth and water quality) are displayed and can be updated in the ***Groundwater characteristics*** menu:

- If the characteristics vary in time, the characteristics are specified for various instants in the (successive) season(s) with reference to the 'First day of observations' (Fig. 3.5 – A);
- If the characteristics of the groundwater table are valid for each year, do not specify the year of the 'First day of observation'.

At run time, AquaCrop will derive the depth and water quality of the groundwater table for each day, by linear interpolation between the specified values (Fig. 3.5 – B). For moments out of the listed period, the depth and soil water quality is assumed to be equal to the 1st value in the list (for earlier dates) or the last value in the list (for later dates).

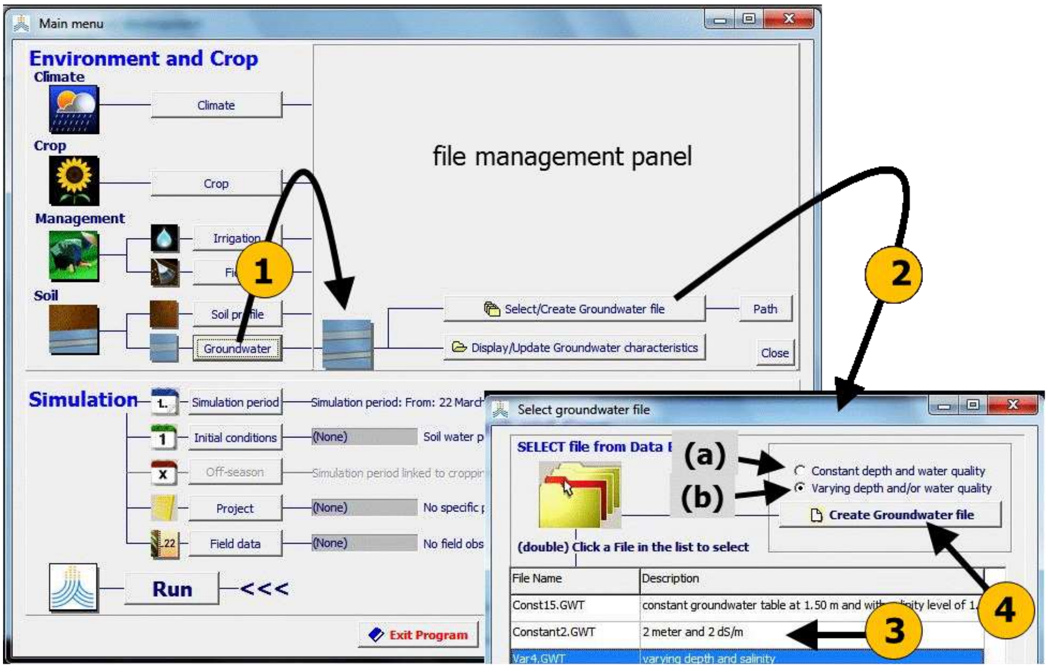


Figure 3.4 – By selecting (1) the <Groundwater> command and subsequently (2) the <Select/Create Groundwater file> command in the file management panel of the *Main menu*, the user gets access to the *Select groundwater file* menu, in which (3) one of the available groundwater table files or (4) the command to <Create Groundwater file> (by specifying its type: 'a' or 'b') is selected.

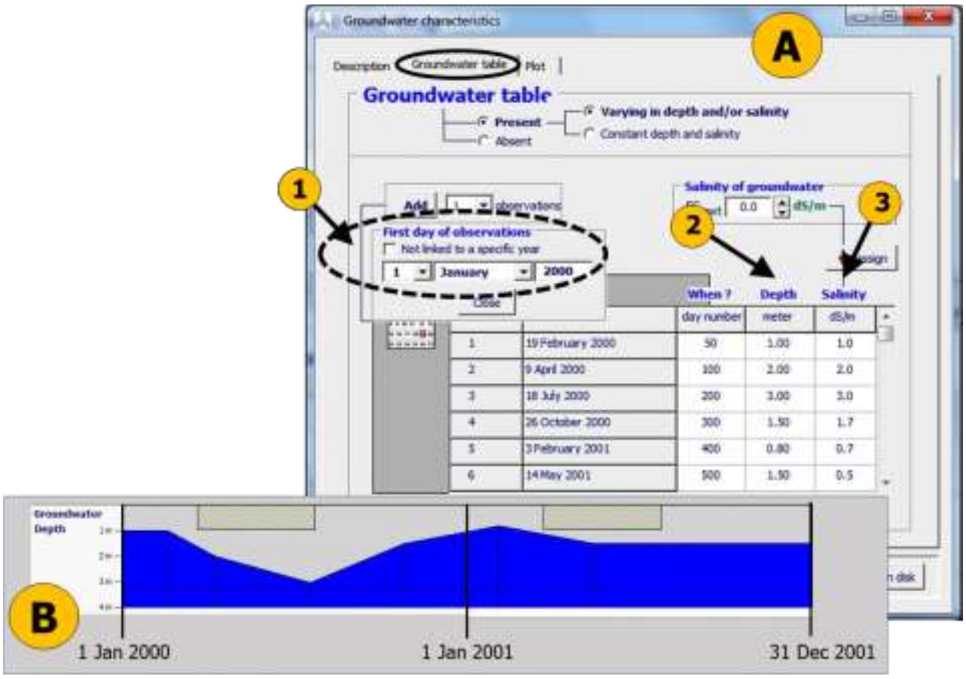


Figure 3.5 – (A) Specifying (1) the first day of observations and the (2) depth and (3) salinity of the groundwater table at specific days in the *Groundwater characteristics* menu. (B) Plot of the groundwater table depth below the soil surface in 2000 and 2001 corresponding to the specifications in A.

Chapter 4. Crop

4.1 Planting/sowing date

4.1.1 Specifying the planting/sowing date

When the crop is selected, the planting/sowing date can be specified (Fig. 4.1):

A. When selecting a crop in the ***Select crop file*** menu, the ***Planting date*** menu pops up, in which the planting or sowing date needs to be specified (Fig. 4.1A).

B. Once a crop is already selected, the planting date can still be adjusted in the ***Main menu*** (Fig.4.1B).

To specify or alter the year in which the planting/sowing takes place, a climate file needs to be selected.

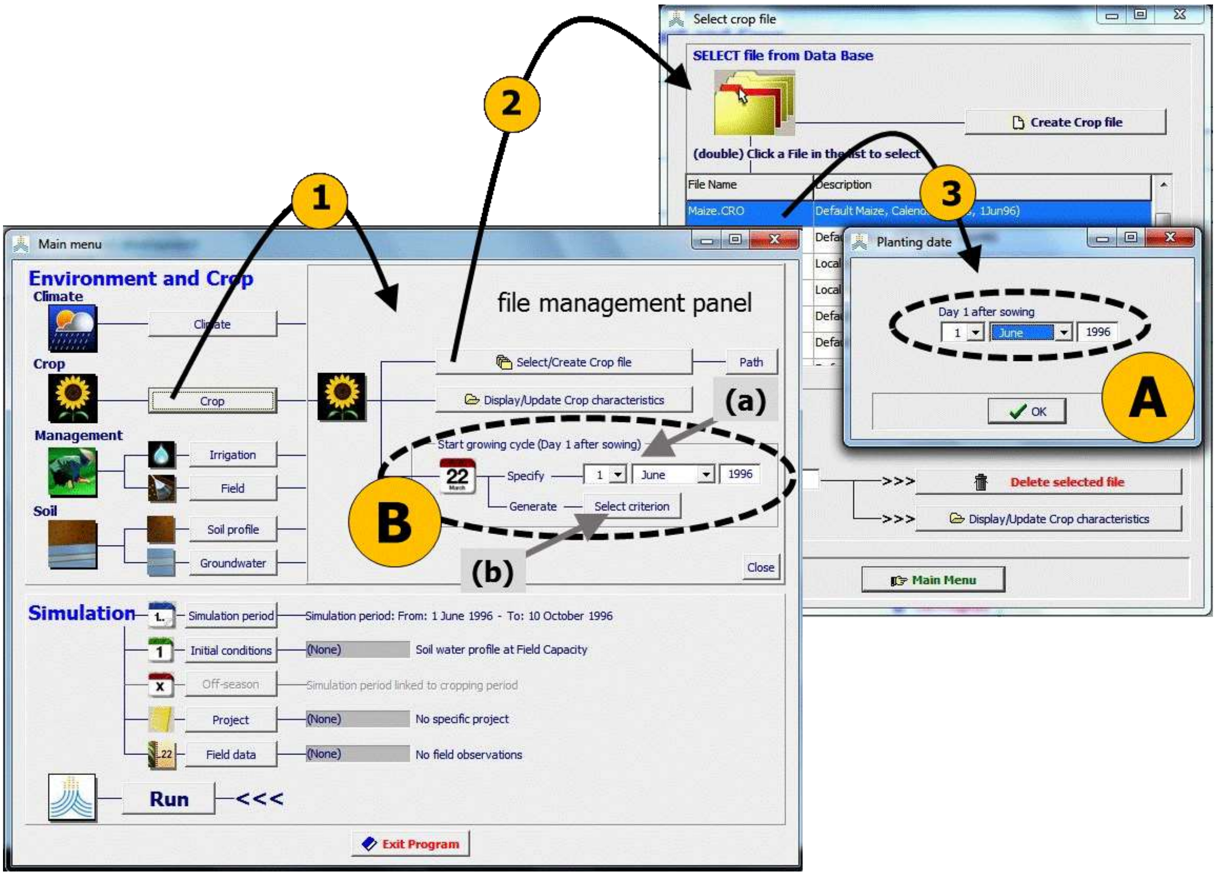


Figure 4.1 – (A) When selecting a crop file (steps 1 to 3), the planting/sowing day needs to be specified. (B) When a crop file is already selected the planting/sowing day can still be altered (a) by specifying another date, or (b) by generating a date based on climatic data.

4.1.2 Generating the planting/sowing date

In case the planting/sowing date is unknown, AquaCrop offers the possibility to generate a date, based on climatic data (Fig 4.1B, b). By selecting a criterion in the ***Onset based on rainfall or temperature*** menu an onset date is determined by automatic assessment of the rainfall or the temperature data before planting/sowing (Fig. 4.2). By specifying the first and last day in the 'Search window', only rainfall or air temperatures within the specified window are evaluated.

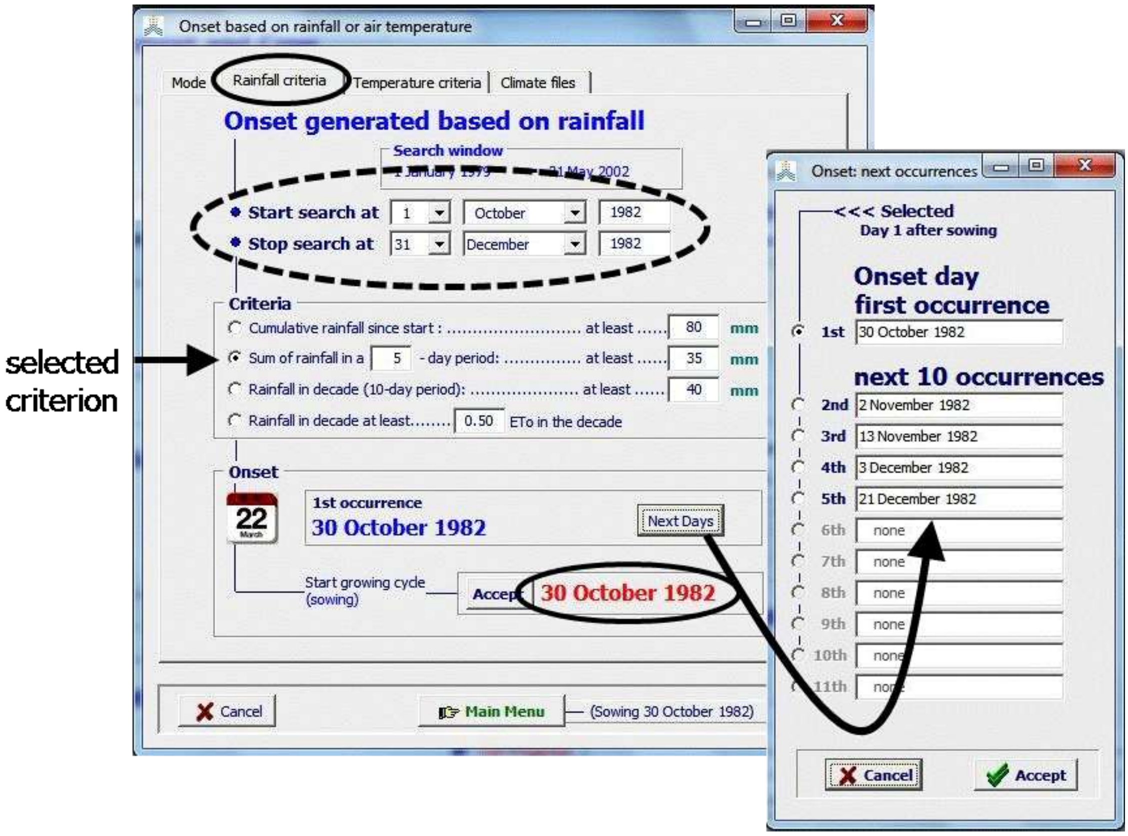


Figure 4.2 – Generating the first occurrence of an onset date within a specified search window (dotted oval), based on rainfall by selecting a criterion. The next occurrences of possible onset days are displayed in the *Onset: next occurrences* menu and can be accepted.

Generation based on rainfall: the option might be well suited for rainfed cropping where sowing or planting is typically determined by rainfall events (example winter wheat in Mediterranean climates).

Generation based on temperature: the option might be well suited to estimate the planting dates for spring crops in cool climates (example tomato's in temperate climate).

Next days: The first occurrence of the onset date is the first date for which the selected criterion holds. Also, one of the next occurrences of the onset day can be selected by clicking on the the **<Next Days>** command (Fig. 4.2). When the start of the rainy season or spring is uncertain at the first occurrence of the selected criterion, selecting one of the next occurrences or specifying a more stringent criterion might avoid early canopy senescence and a complete crop failure after germination.

4.2 Tuning of crop parameters

The data base of AquaCrop contains crop files in which the calibrated and fully validated crop parameters are stored. **Conservative crop** parameters do not need to be tuned, since they do not change much with time, management practices, geographic location or climate and cultivar. When opening the ***Crop characteristics*** menu in its default mode ('Limited set'), only the **Cultivar specific and non-conservative** parameters are displayed (Fig. 4.3). These parameters might require an adjustment when selecting a cultivar different from the one considered for crop calibration, or when the environmental conditions differ from the conditions assumed at calibration. The parameters are listed in a set of tabular sheets:

<u>Description</u>: to adjust the description of the crop file;
<u>Mode</u>: to switch from Calendar days to Growing degree-days at the end of the tuning process (see section 4.2.5);
<u>Development</u>: to adjust cultivar specific parameters and parameters affected by planting, management, and conditions in the soil profile;
<u>Production</u>: to adjust the Harvest Index;
<u>Fertility-stress</u>: to calibrate the crop biomass response to soil fertility and/or soil salinity stress;
<u>Calendar</u>: to get an overview and/or adjust the calendar of the growing cycle.

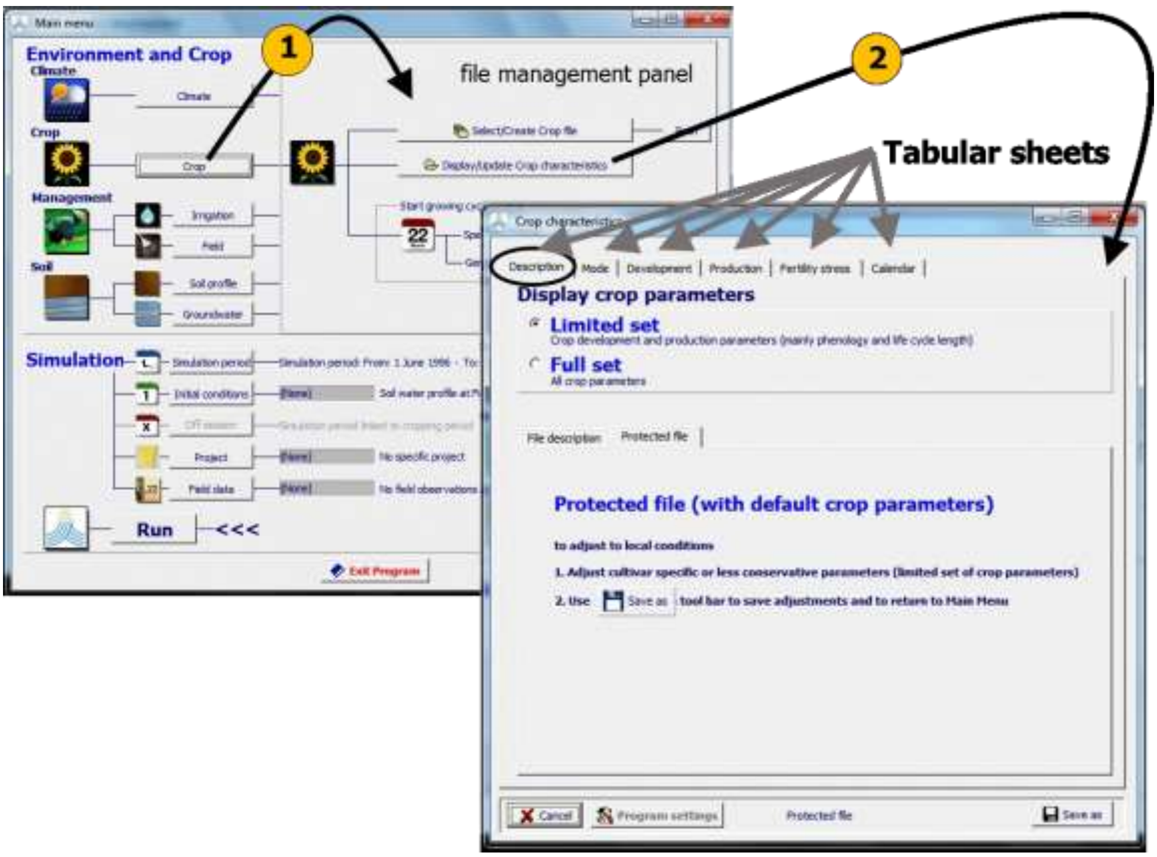


Figure 4.3 – By selecting (1) the <Crop> command and subsequently (2) the <Display/Update Crop characteristics> command in the file management panel of the Main menu, the user gets access to the Crop characteristics menu in which the crop parameters can be fine-tuned to the environment.

4.2.1 Parameters affected by planting and management:

- **Type of planting method** (Fig. 4.4, direct sowing or transplanting): AquaCrop makes a distinction between direct sowing and transplanting. When the crop is sown, the size of the canopy of the germinating seedling is given (it is a conservative parameter). On the other hand, the size of the transplanted seedling depends on the time the plant remained in the nursery, and its size needs to specified by the user;
- **Plant density**, which will determine the initial (CC_o) canopy cover. The plant density is specified directly or by (Fig. 4.4):
    - selecting one of the CC_o classes (ranging from very small to very high cover);
    - specifying directly the percentage of CC_o (which might be useful for transplanted seedlings). The corresponding plant density will be derived from CC_o and the canopy size of the seedling; or
    - selecting the **<estimate>** command to estimate plant density either from sowing rate or plant spacing.
- **Maximum canopy cover (CC_x),** that will be reached at mid-season, is generally around 75 % up to 100 %. CC_x varies with crop type but it is also determined by planting density. CC_x is specified by selecting one of the predefined classes or as direct input (Fig. 4.5);
- **Time to reach 90% seedling emergence** (depends on field preparation and soil temperature) (Fig. 4.5).

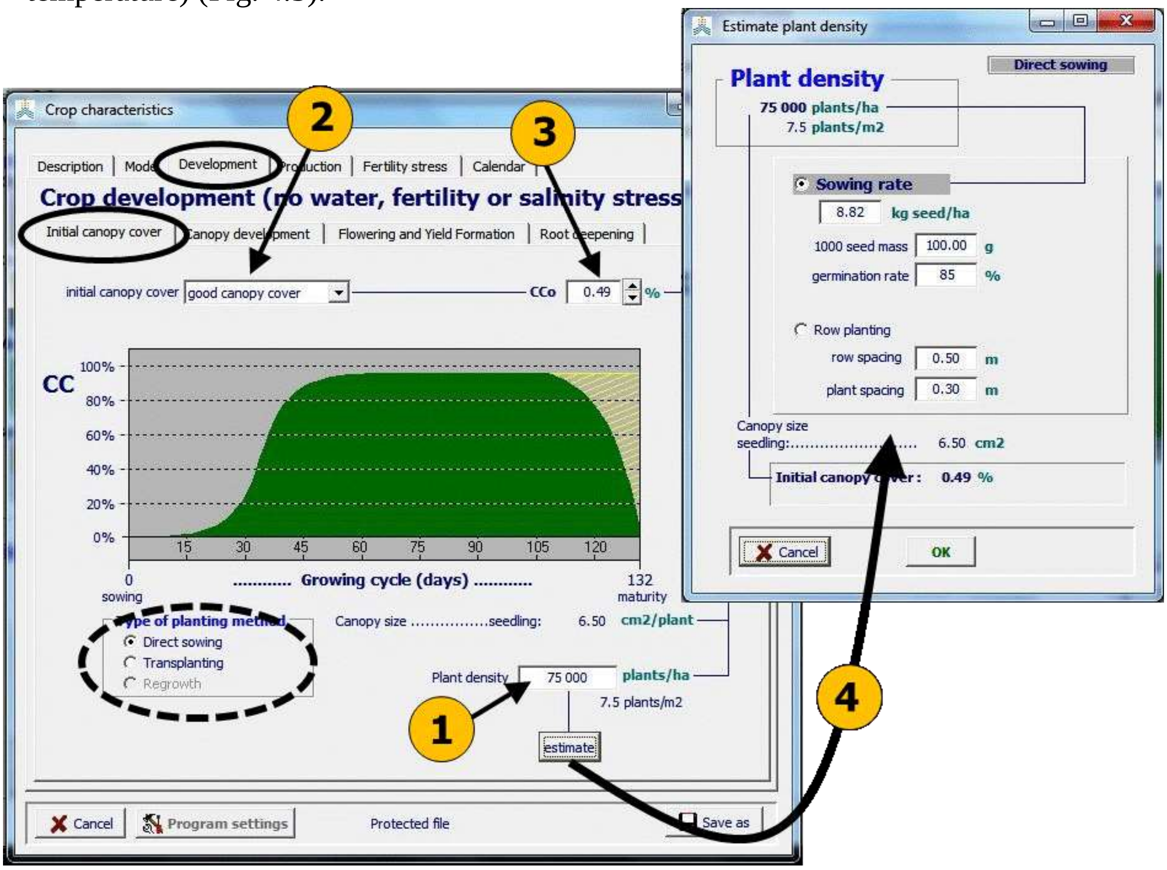


Figure 4.4 – The 'Initial canopy cover' tabular sheet of the 'Development' tabular sheet of the *Crop characteristics* menu in which the type of planting method (dotted oval) and the initial canopy cover (CC_o) is determined (1) by specifying plant density, (2) by selecting a predefined CC_o class, (3) by specifying the percentage or (4) from sowing rate or plant spacing data.

4.2.2 Cultivar specific crop parameters:

☐ Many of the differences between crop cultivars are related to the **timing of developmental stages**. The timing to reach a particular stage, or its duration, are specified in the 'Development' tabular sheet of the ***Crop characteristics*** menu (Fig. 4.5):

- **Time to reach maximum canopy cover (CC_x)**: Altering the time required to reach CC_x, results in an automatic fine tuning of CGC (Canopy Growth Coefficient) to the local conditions;
- **Time to start of canopy senescence**: It is the time when green leaf area start to decline as a result of yellowing of leaves, under optimal conditions with no water stress;
- **Time to physiological maturity** (length of crop cycle): At the time of maturity the simulation of biomass production and yield formation will be halted. Harvest does not necessary coincide with crop maturity;
- **Time to start flowering** (or the start of yield formation);
- **Duration of flowering**.

☐ **Reference Harvest Index (HIo)**: HI_o is conservative to a fair extent but can be cultivar specific through plant breeding and biotechnology. It is the representative HI reported in the literature for the chosen crop species under non-stressed conditions, and is specified in the 'Harvest Index' tabular sheet of the 'Production' tabular sheet of the ***Crop characteristics*** menu.

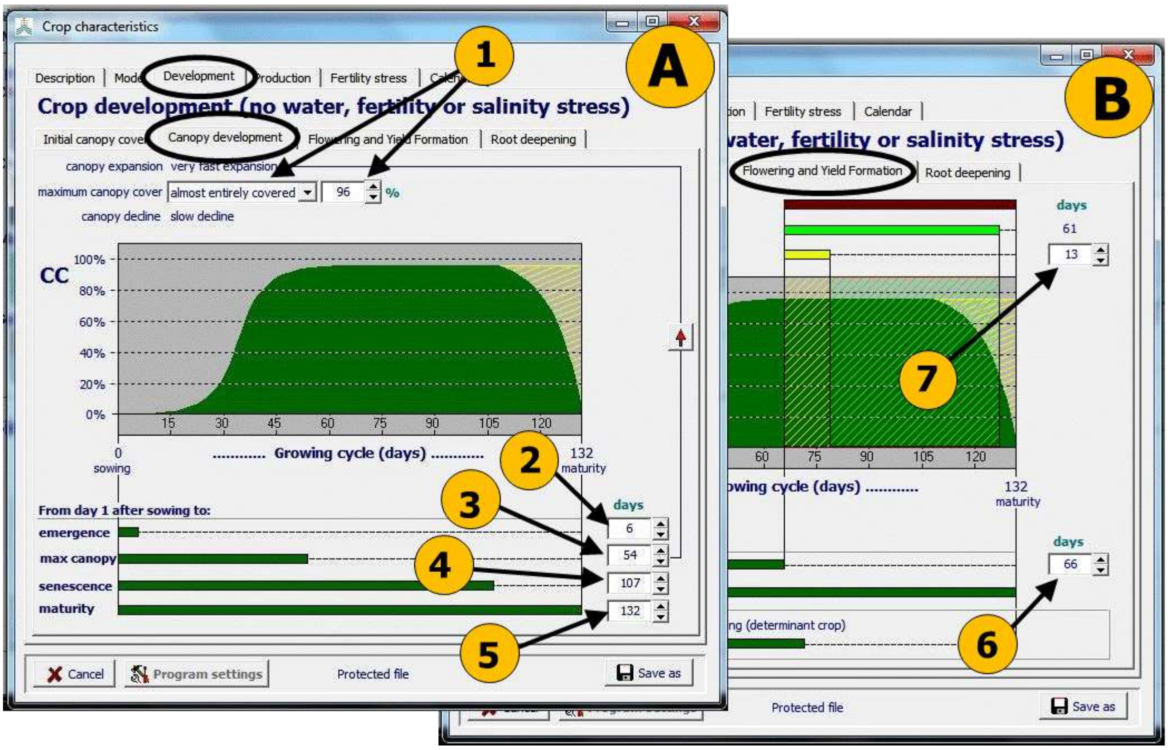


Figure 4.5 – The (A) 'Canopy development' and (B) 'Flowering and yield formation' tabular sheet of the 'Development' tabular sheet of the *Crop characteristics* menu including: (1) the maximum canopy cover (CC_x) by selecting a class or specifying the percentage, and the time to reach (2) 90% seedling emergence, (3) maximum canopy cover, (4) start of canopy senescence, (5) physiological maturity, and the (6) start of flowering or yield formation, and (7) the duration of flowering.

4.2.3 Parameters affected by conditions in the soil profile:

The maximum effective rooting depth (Z_x) and root deepening rate (or the time to reach Z_x) are affected by soil physical (temperature, mechanical impedance, aeration) and soil chemical (pH, salinity, high levels of aluminium or manganese) characteristics. Rooting depth and expansion rate are specified in the 'Root deepening' tab-sheet of the 'Development' tab-sheet of the ***Crop characteristics*** menu (Fig. 4.6):

- **Maximum effective rooting depth (Z_x)**: It can be specified by selecting one of the predefined classes or by entering directly the numeric value in meter;
- **Time to reach Z_x**: By altering the time from sowing to Z_x, the corresponding root zone expansion rate is defined. The average root zone expansion is displayed as a reference, although in AquaCrop the expansion is described by an exponential function. Knowledge of the typical root zone expansion, can be used to estimate the time when Z_x will be reached. Root zone expansion rates are often about 1 cm/day but may be up to 2 cm/day if the environment is optimal for growth (soil not cold, and soil layers not limiting growth).

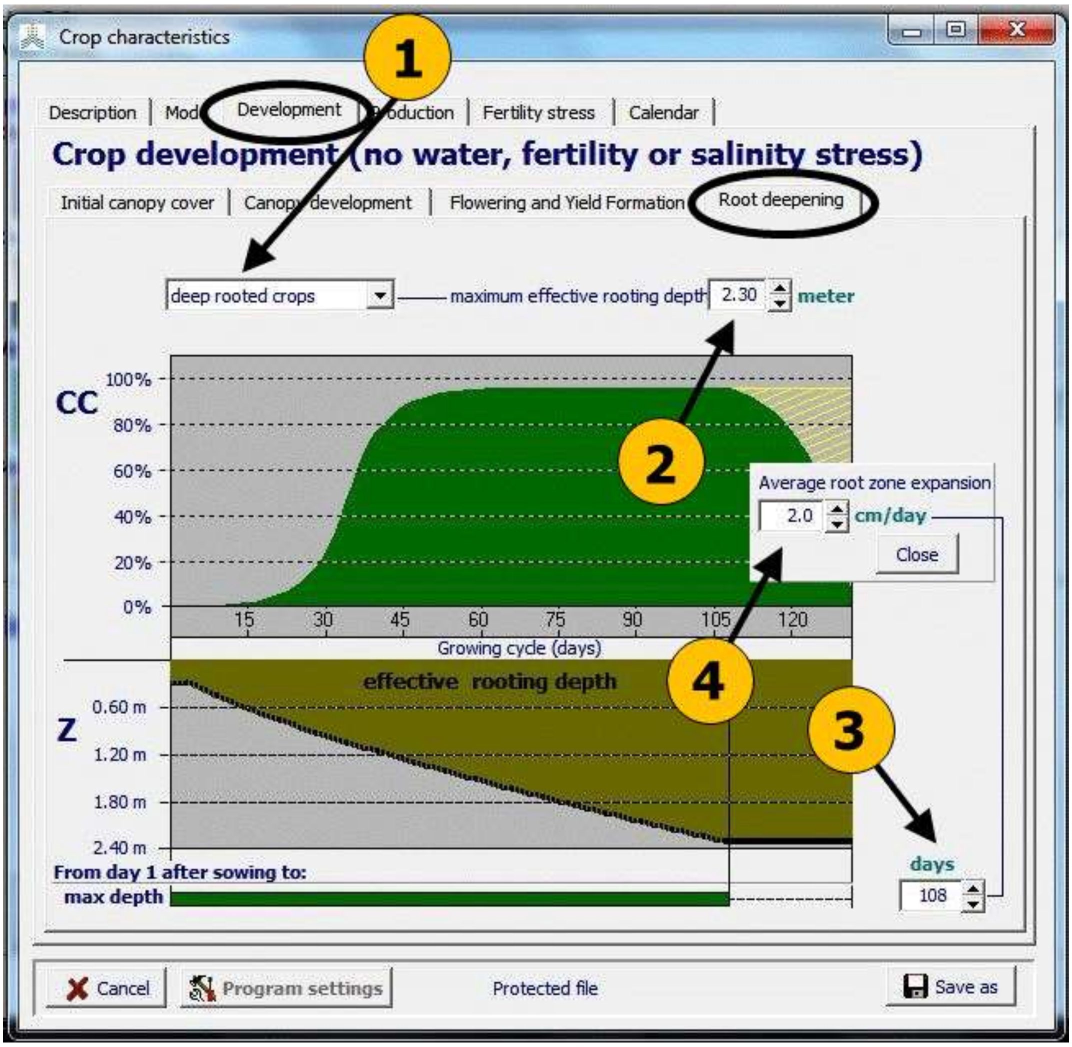


Figure 4.6 – The 'Root deepening' tabular sheet of the 'Development' tabular sheet of the *Crop characteristics* menu including: the maximum effective rooting depth (Zx), specified by (1) selecting a predefined class, or (2) by entering the value in meter, and the time to reach Z_x specified by (3) the time to reach Zx, or (4) the average root zone expansion rate.

4.2.4 Calendar of the growing cycle

An overview of the calendar of the growing cycle is displayed in the 'Calendar' tabular sheet of the ***Crop characteristics*** menu (Fig. 4.7A). The planting date and the length of the different growth stages can be adjusted with the help of the spin buttons. The length of the corresponding FAO56 stages can be displayed as well. These stages were defined in earlier FAO publications (Irrigation and Drainage Papers Nr. 24, 33 and 56) in which indicative values for lengths of crop development stages for various planting period and climate regions for common agriculture crops are presented.

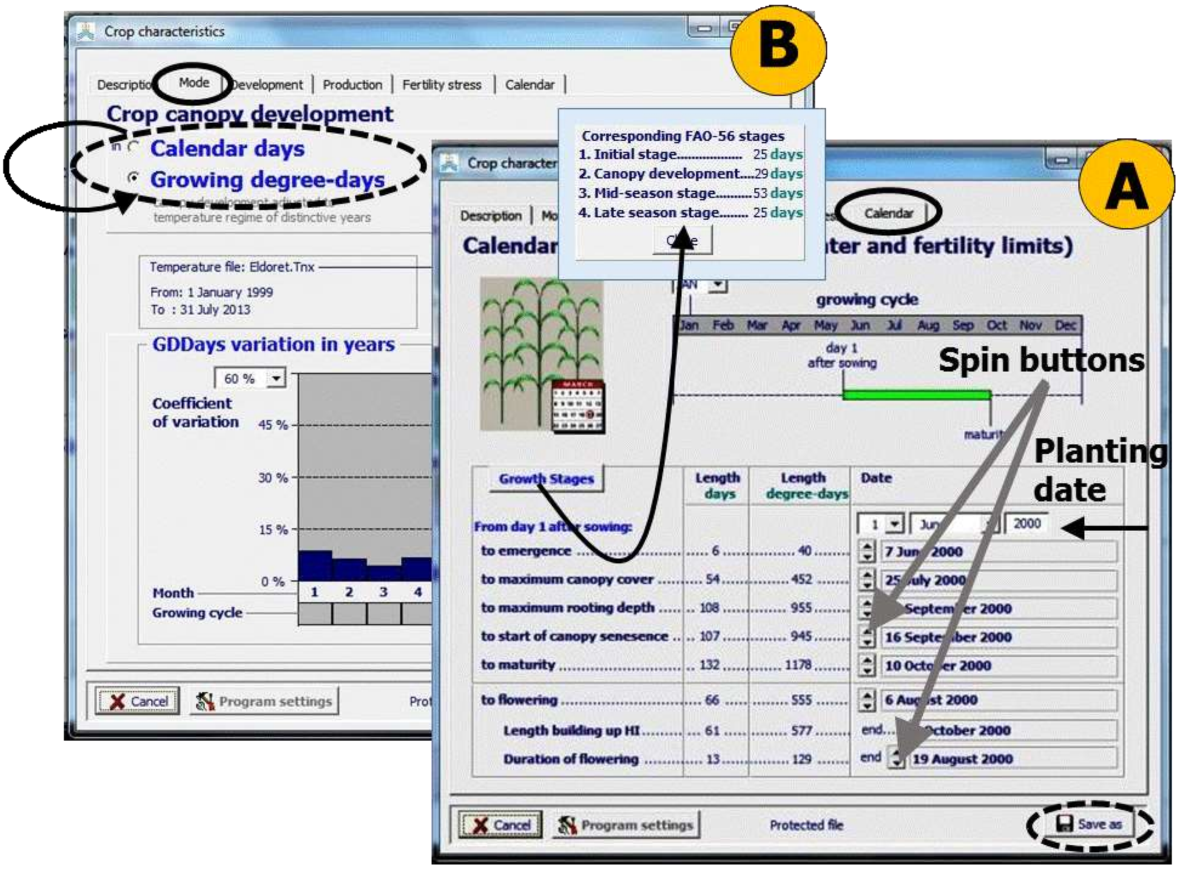


Figure 4.7 – (A) The 'Calendar' tabular sheet, to inspect or adjust the calendar of the growing period, and (B) The 'Mode' tabular sheet of the *Crop characteristics* menu to switch between calendar and thermal time. With the <Save as> command the fine-tuned crop characteristics can be saved in a new crop file.

4.2.5 Converting calendar into thermal time

At the end of the fine-tuning process, it is strongly recommended to convert the calendar time into thermal time. As such the length and duration of the crop development stages will be adjusted to the temperature regimes of the distinctive years in which simulations are run. This is done in the 'Mode' tabular sheet of the ***Crop characteristics*** menu (Fig. 4.7B). Make sure to select a representative climate file and sowing date for the conversion.

4.3 Calibration for soil fertility stress

In a fertility stressed field, aboveground biomass (B) is limited. This is the result of a smaller canopy cover (CC) and a decrease of the biomass water productivity (WP*) in the stressed field. The soil fertility level selected for the simulation, is a field management characteristics (Chapter 5), while the crop response to soil fertility stress is a crop characteristic. Since the effect of soil fertility stress is affected by the type of limiting nutrients, and environmental conditions such as climate and soil type, a calibration of the crop response to soil fertility stress is required and most likely will have to be repeated for each type of environment.

The crop response to soil fertility stress is calibrated in the ***Crop characteristics*** menu (Fig. 4.8). In the 'Field observation' tabular sheet of the ***Calibration soil fertility stress*** menu, the user specifies:

a) total biomass produced in a stressed field, expressed as a relative value, B_{rel} (= 100 x $B_{stress}/B_{reference}$). B_{rel} is the maximum relative dry aboveground biomass (B_{rel}) that can be expected in that field with limited soil fertility as compared to stress-free conditions;
b) maximum canopy cover that can be reached in a stressed field (CCx_{stress}); and
c) degree (small, medium or strong) of the canopy cover decline in the season.

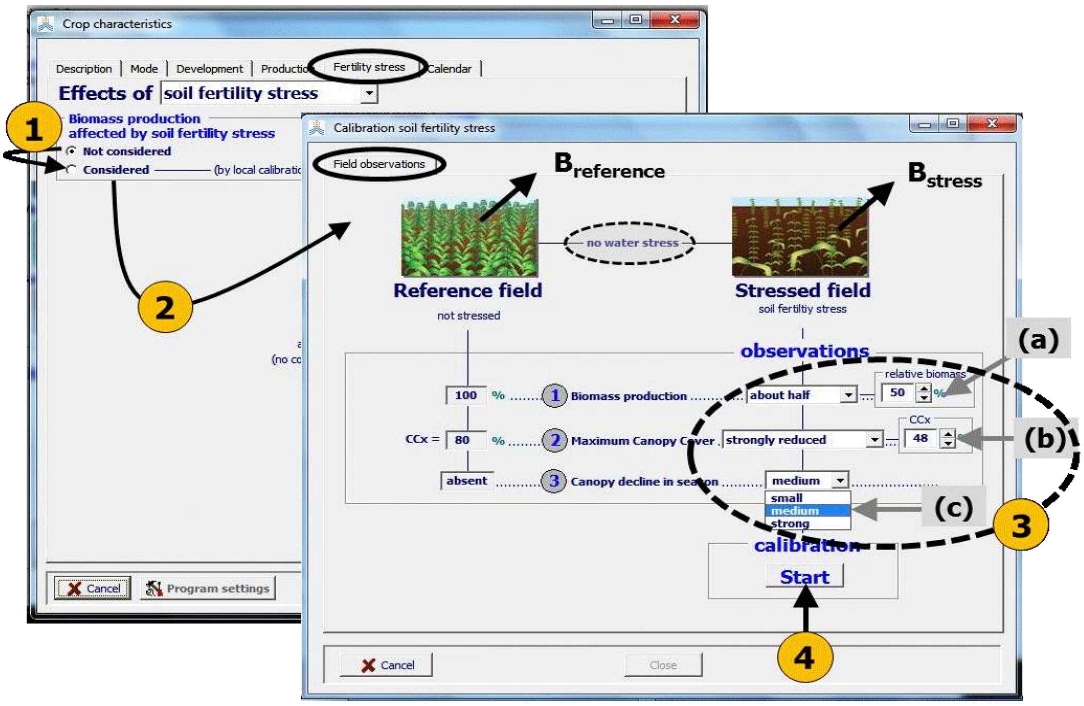


Figure 4.8 – (1) By selecting 'Considered' in the 'Fertility-stress' tabular sheet, (2) the 'Field observations' tabular sheet of the *Calibration soil fertility stress* menu becomes available in which the user (3) specifies the observed or expected (a) relative biomass production, (b) maximum canopy cover and (c) canopy decline in season in a stressed field and (4) launches the calibration for soil fertility stress.

After launching the calibration process, AquaCrop searches for a setting of the 4 stress coefficients, for which the reduced WP* and smaller CC results in a B_{rel} equal to the B_{rel} for which the crop response is being calibrated ('a' in Fig. 4.8).

It considers thereby the CCx and decline in canopy cover specified as input for calibration in the 'Field observations' tabular sheet ('b' and 'c' in Fig. 4.8). The CC and decline of WP* during the season, fulfilling the requirement (i.e. resulting in the specified B_{rel}), are displayed in the ‘Crop response to soil fertility stress’ tabular sheet of the ***Calibration soil fertility stress*** menu (Fig. 4.9).

With the help of spin buttons, the user can alter the development curve of CC by increasing/decreasing one of the effects of soil fertility stress, until the pattern of the CC progression over time is more realistic or corresponds to field data. For each state AquaCrop searches automatically the setting of the four stress coefficients resulting in a relative production equal to the specified B_{rel}.

With the **<Close>** command in the control panel at the bottom of the screen of the ***Calibration soil fertility stress*** menu, the calibration process is finalized (which consist in saving the setting of the 4 stress coefficients), and the command is returned to the ***Crop characteristics*** menu.

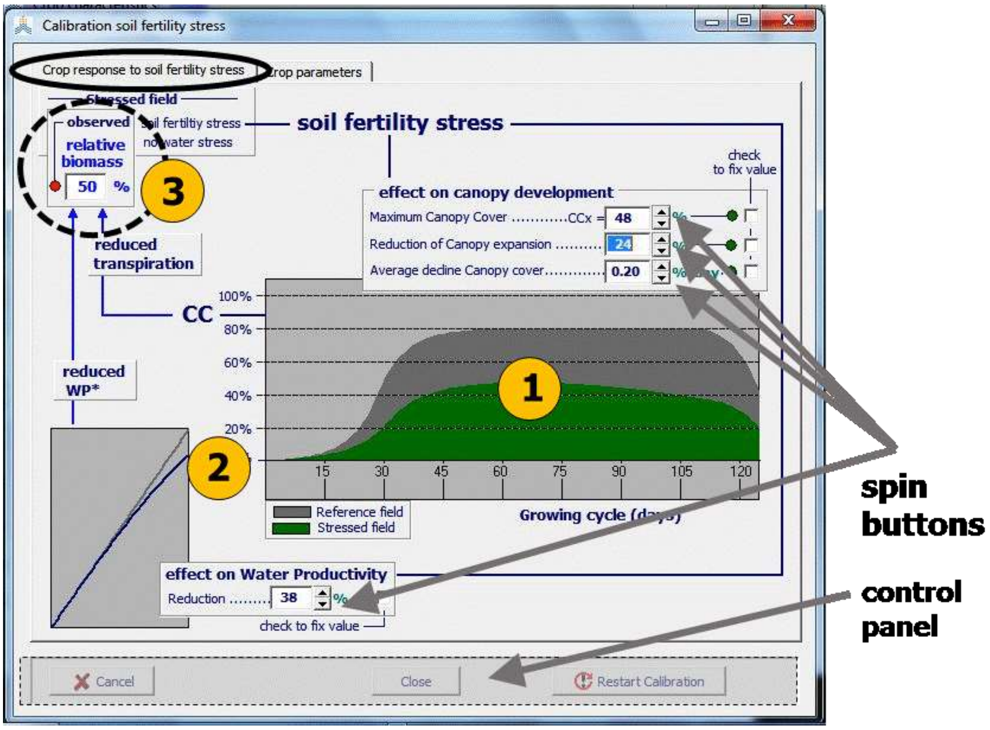


Figure 4.9 – The ‘Crop response to soil fertility stress’ tabular sheet of the *Calibration soil fertility stress* menu in which the effect of soil fertility stress (1) on canopy cover and (2) on the decline of WP* during the season, is plotted and is fine-tuned by means of the four spin buttons and (3) by respecting the specified relative biomass.

4.4 Calibration for soil salinity stress

The average electrical conductivity of the saturation soil-paste extract (ECe) from the root zone is the indicator for soil salinity stress. At a lower threshold of ECe, the stress starts to affect biomass production, and at (and above) an upper threshold, the salinity stress becomes so severe that biomass production is no longer possible. Values for the lower and upper thresholds of ECe for many agriculture crops are given in Annex III of the reference manual of AquaCrop.

The reduction in biomass production is the result of a less dense crop, a poor development of the canopy cover, and a partial closure of the stomata. Since the individual effects of salinity stress on crop density, development of the canopy cover and closure of the stomata are not well documented in literature for simulation in AquaCrop, the user can calibrate the crop response to soil salinity stress in the ‘Crop response’ tabular sheet of the ***Crop characteristics*** menu.

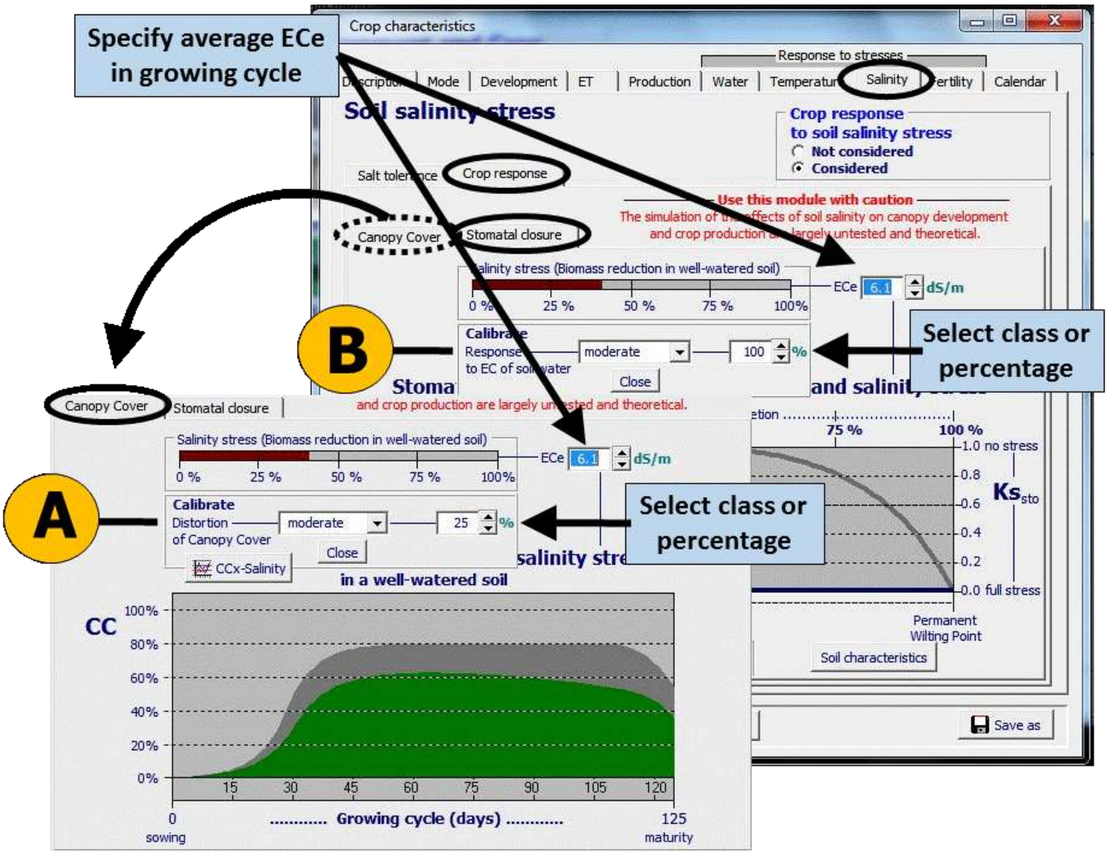


Figure 4.10 – The 'Crop response' in the 'Salinity' tabular sheet of the *Crop characteristics* menu in which the effect of soil salinity stress on (A) Canopy Cover in a well-watered soil and (B) Stomatal closure in a water depleted soil, can be updated

- **Crop response in a well-watered soil:** If the development of the canopy cover is observed in the field, the user can select a class or percentage of canopy cover distortion after specifying the average ECe during the growing cycle (Fig. 4.10A). The distortion is expressed with reference to the canopy development in the absence of any stress;
- **Crop response when root zone depletion increases the salinity stress:** Due to the root zone depletion between wetting events, salts concentrate in the remaining soil water. Although the depletion does not alter ECe (the indicator for soil salinity), the depletion results in an increase of the electrical conductivity of the soil water (ECsw), stronger osmotic forces, a stronger closure of the stomata, and a lower biomass production. The effect of ECsw on stomata closure can be calibrated by selecting a class or percentage for the effect of ECsw on stomatal closure (Fig. 4.10B).

4.5 Save the fine-tuned crop parameters in a new crop file

Crop files which come with the AquaCrop software contain crop parameters that are calibrated and validated by FAO. After fine-tuning the crop parameters and/or calibrating the crop for soil fertility stress in the ***Crop characteristics*** menu, the adjustments cannot be saved in the protected file. Select the **<Save as>** command to save the fine-tuned crop parameters in a new crop file (Fig. 4.7A).

Chapter 5. Management

5.1 Irrigation management

5.1.1 Creating irrigation management files

When creating an irrigation management file, the type of file has to be specified in the ***Select irrigation file*** menu (Fig. 5.1):

a) Net irrigation water requirement: to determine the requirement in a given environment;

b) Irrigation schedule: to assess an existing irrigation schedule;

c) Generation of irrigation schedule: to generate a schedule according to specified criteria.

Subsequently the users specifies the required parameters in the ***Create irrigation file*** menu. The parameters can be displayed and updated in the ***Irrigation management*** menu (Fig. 5.2 to 5.4).

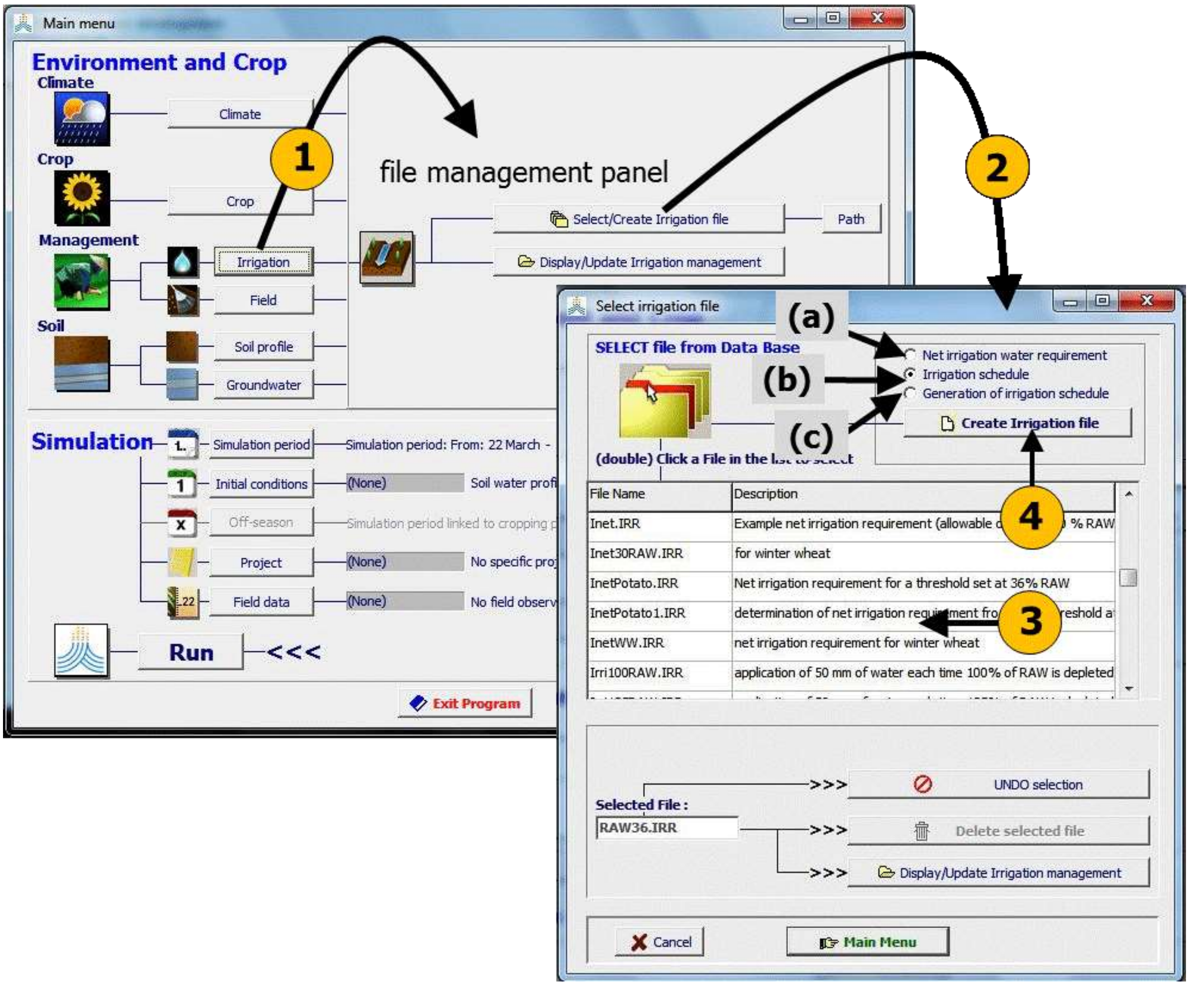


Figure 5.1 – By selecting (1) the <Irrigation> command and subsequently (2) the <Select/Create Irrigation file> command in the file management panel of the Main menu, the user gets access to the Select irrigation file menu, in which (3) one of the available irrigation files or (4) the option to <Create irrigation file> (by specifying its type: ‘a’, ‘b’, or ‘c’) is selected.

5.1.2 Determination of net irrigation water requirement

In the ‘Net Irrigation Requirement’ tabular sheet of the ***Irrigation management*** menu, the allowable root zone depletion can be altered by means of the spin button (Fig. 5.2). This selection determines the minimum amount of water that has to remain in the root zone throughout the growing cycle, and as such the water stress that is allowed in the season. Thresholds, below which the leaf expansion growth is hampered and stomata of the selected crop start to close are given as a reference.

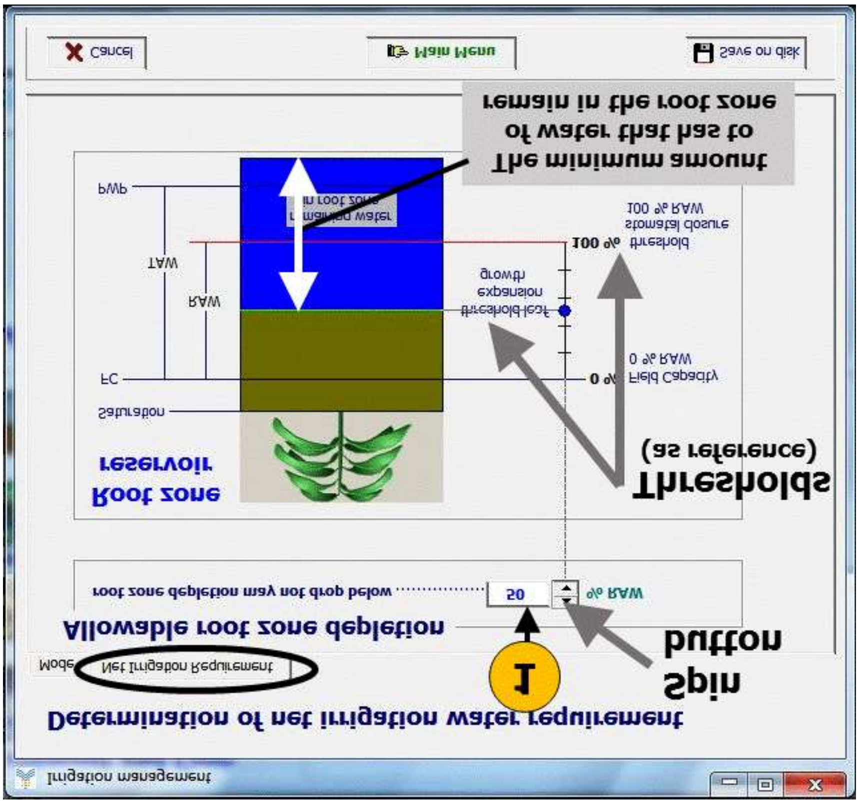


Figure 5.2 –Specified (1) allowable root zone depletion, for the determination of the net irrigation water requirement, in the ‘Net Irrigation Requirement’ tabular sheet of the *Irrigation management* menu.

5.1.3 Assessing an irrigation schedule

To assess an existing irrigation schedule, the irrigation method (which determines the fraction of the soil surface wetted by irrigation) and the irrigation events have to be specified. In the ‘Irrigation events’ tabular sheet of the ***Irrigation management*** menu, the user specifies for each event (Fig. 5.3):

1. **Time of application**: The time is entered as days after sowing (DAS) and is translated by the program to the corresponding calendar day;
2. **Application depth**: The irrigation depth refers to the irrigation amount that has infiltrated in the field. Extra water applied to the field to account for conveyance losses or the uneven distribution of irrigation water on the field should not be added;
3. **Water quality**: If the water quality remains constant over the season, a constant value (whether or not corresponding to an irrigation water quality class) can be assigned.

As a reference, the canopy cover development for the selected crop, and the irrigation events in the season can be plotted.

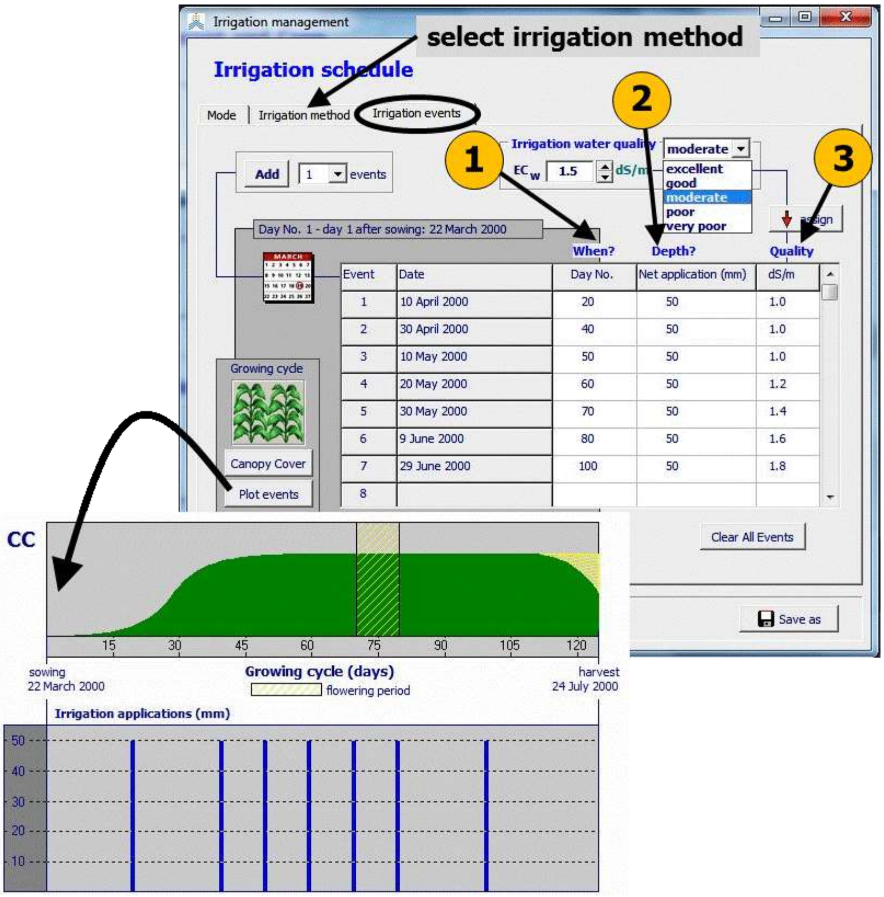


Figure 5.3 – Specified (1) time of application, (2) application depth, and (3) water quality, for the assessment of an irrigation schedule in the 'Irrigation events' tabular sheet of the *Irrigation management* menu. The irrigation method is determined in the 'Irrigation method' tabular sheet.

5.1.4 Generation of an irrigation schedule

To generate an irrigation schedule for evaluating or planning a particular irrigation strategy, the irrigation method (which determines the fraction of the soil surface wetted by irrigation) and the time and depth criteria have to be specified. Time and depth criteria used for the generation of irrigation schedules are listed in Table 5.1. Indicative values for irrigation intervals and application depths for various irrigation methods are given in Table 5.2.

In the 'Time and Depth criteria' tabular sheet of the ***Irrigation management*** menu, the user specifies (Fig. 5.4):

1. **Time (as day number):** from which the specified values for the time and depth criteria are valid. The time is entered as days after sowing (DAS) and is translated by the program to the corresponding calendar day. The values specified will be valid till the date where another value is specified or to the end of the growing period when no values at later dates are specified. As such one can adjust the values to crop development or the time in the season. In the example of Fig. 5.4, a depletion of 500 % RAW is far below permanent wilting point (and hence can never occur) and a fixed application depth of 0 mm will neither generate an irrigation. Hence, irrigations are restricted to the period 1 May and 30 June (e.g. as a deficit irrigation strategy);
2. **Value for the selected time criterion;**

3. **Value for the selected depth criterion;**
4. **Water quality:** If the water quality remains constant over the season, a constant value (whether or not corresponding to a predefined irrigation water quality class) can be assigned.

As a reference, the canopy cover and the various thresholds for water stress for the selected crop, can be plotted.

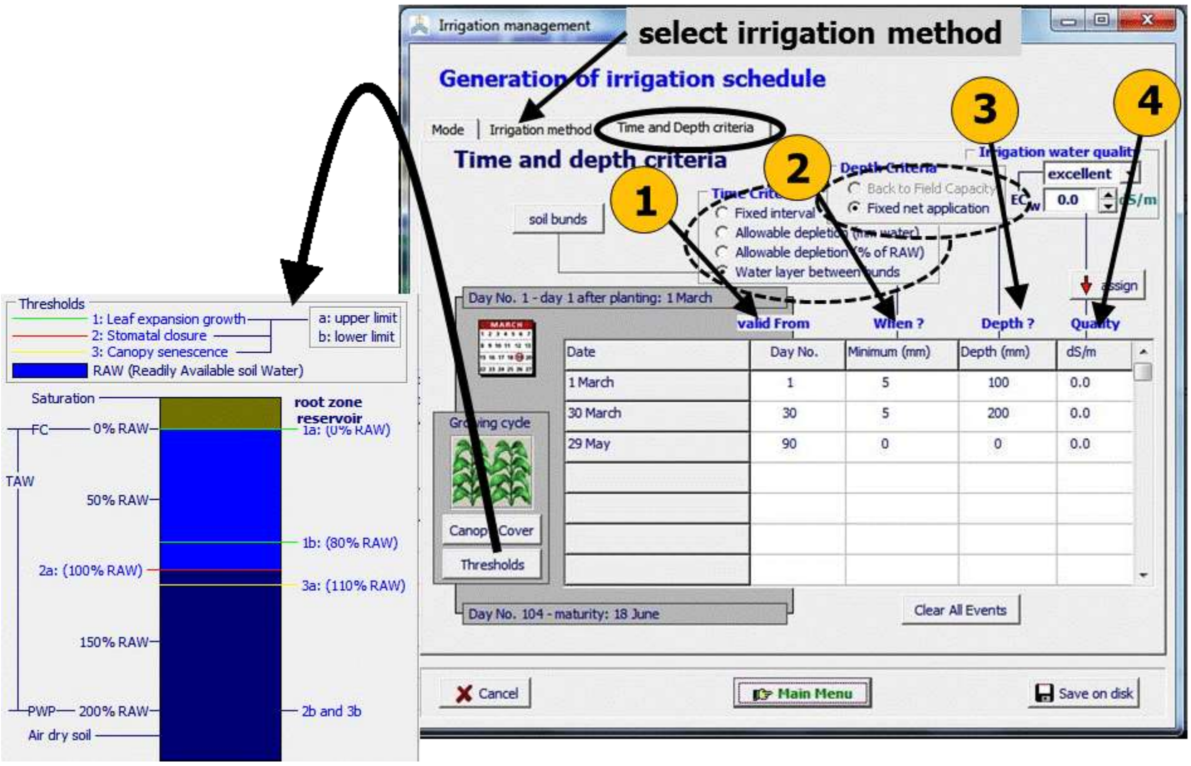


Figure 5.4 – Specified (1) day from which the selected criteria are valid, and values for the (2) time criterion, (3) depth criterion and (4) water quality, for the generation of an irrigation schedule in the 'Time and Depth criteria' tabular sheet of the *Irrigation management* menu. The irrigation method is determined in the 'Irrigation method' tabular sheet.

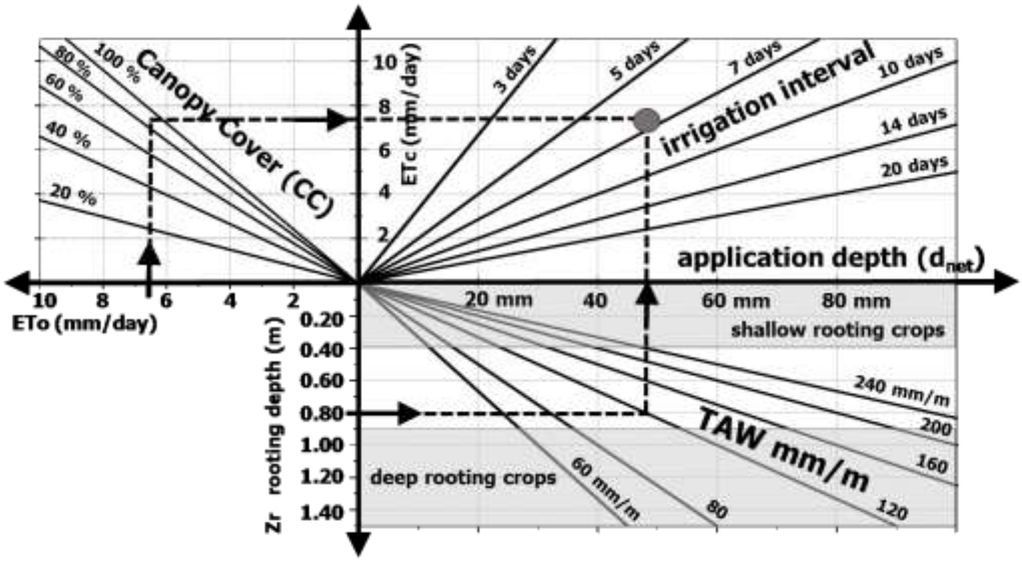
Table 5.1 – Types of time and depth criteria used for generating irrigation schedules

Time Criterion	Parameter
Fixed interval (days)	Interval between irrigations (e.g. 10 days). See Tab. 5.2
Allowable depletion (mm water)	Amount of water that can be depleted from the root zone (the reference is soil water content at field capacity) before an irrigation has to be applied (e.g. 30 mm)
Allowable depletion (% of RAW)	Percentage of RAW that can be depleted before irrigation water has to be applied (for example 100 %)
Water layer between bunds (mm water)	Threshold for the depth of the surface water layer that should be maintained between the soil bunds (for example 5 mm). An irrigation is generated when the level of the water layer reaches the threshold,. This time criterion is only applicable when 'Fixed net application' is the depth criterion

Depth Criterion	Parameter
Back to Field Capacity (+/- extra mm water)	Extra water on top of the amount of irrigation water required to bring the root zone back to Field Capacity. The specified value can be zero, positive or negative: ▪ zero : the applied irrigation will bring the soil water content in the root zone at Field Capacity (reached at the end of the day); ▪ positive: an over irrigation is planned for example for leaching salts out of the root zone (for example + 20 mm); ▪ negative: an under irrigation is planned for example to profit from expected rainfall (for example – 10 mm)
Fixed application depth (mm water)	The irrigation amount that infiltrates in the field. Indicative values are given in Table 5.2

Table 5.2 – Indicative values for irrigation intervals and application depths

Indicative values for the maximum net application depth and irrigation interval in the absence of rain can be obtained from the figure below by considering the weather conditions (ETo), crop canopy cover, rooting depth and soil physical characteristics (TAW). The net application depth and corresponding irrigation interval should be adjusted to the local characteristics of the irrigation method and irrigation practices.



Example: For a crop with an effective rooting depth (Zr) of 0.8 m, cultivated on a sandy loam soil (TAW = 120 mm/m), the maximum net irrigation application depth (d_{net}) is about 48 mm. For a reference evapotranspiration (ETo) of 6.5 mm/day, and a Canopy Cover (CC) of 90%, the crop evapotranspiration (ETc) will be 7.5 mm/day. The corresponding irrigation interval will be about 6.5 days.

Assumptions: d_{net} = (0.5) TAW Zr [meter]. The value of 0.5 is a representative threshold for the root zone depletion at which stomata start to close (50 % TAW);

ETc = (1.2) CC* ETo [mm/day]; CC* is CC adjusted for micro-advective effects. The value of 1.2 is a representative value for $Kc_{Tr,x}$, but increased to consider soil evaporation.

Characteristics of the irrigation method:	
Irrigation method	**Indicative irrigation application depths**
Surface irrigation	Basin : 50 - 150 mm; Border: 40 - 80 mm; Furrow: 30 - 60 mm.
Sprinkler irrigation	Solid set: 30 – 80 mm; Center pivot, linear move and travelling gun: 15 - 35 mm (if infiltration allows: up to 80 mm)
Localized irrigation	5 - 25 mm.

Indicative values for TAW (Total Available soil Water) for soil texture classes					
Soil class	**TAW (mm/m)**		**Soil class**	**TAW (mm/m)**	
	Mean	**Range**		**Mean**	**Range**
Sand	70	55 – 75	Sandy clay loam	120	90 – 135
Loamy sand	80	65 – 85	Clay loam	160	145 – 175
Sandy loam	120	110 – 130	Silty clay loam	210	195 – 215
Loam	160	155 – 185	Sandy clay	120	100 – 125
Silt loam	200	170 – 225	Silty clay	180	175 – 190
Silt	240	225 – 250	Clay	150	135 – 160

5.2 Field management

5.2.1 Creating field management files

In the Create field management file, the user specifies (Fig. 5.5):

a) File **name**;
b) File **Description**;
c) Degree of **Soil fertility**: by selecting a predefined class or specifying directly a value for the potential biomass production;
d) Presence of **mulches** by selecting a predefined class or specifying directly the percentage of surface cover. If mulches are present, also the **type** of mulches has to be specified;
e) **Field surface practices**: **practices preventing runoff**, and/or the presence and height of **soil bunds**, which keep non infiltrated water between the bunds;
f) **Weed management**: by selecting a predefined class of management, or by specifying the relative cover of weeds.

After creating the file, the ***Field management*** menu is displayed, in which the user can further fine-tune or adjust the field management characteristics (Fig. 5.6 to 5.9).

5.2.2 Field management characteristics

The field management characteristics are displayed and can be updated in the various tabular sheets of the ***Field management*** menu (Fig. 5.6 to 5.9):

- **Description**: to adjust the description of the soil profile file;
- **Soil fertility**: to specify the maximum relative dry aboveground biomass that can be expected when soil fertility is limited;
- **Mulches**: to specify the soil cover by mulches and the type of mulches;
- **Field surface practices**: to specify if surface runoff is affected or inhibited by the practices or if soil bunds are available between which water can be stored on top of the field surface;
- **Weed management**: to specify the degree of weed management and the corresponding relative cover of weeds.

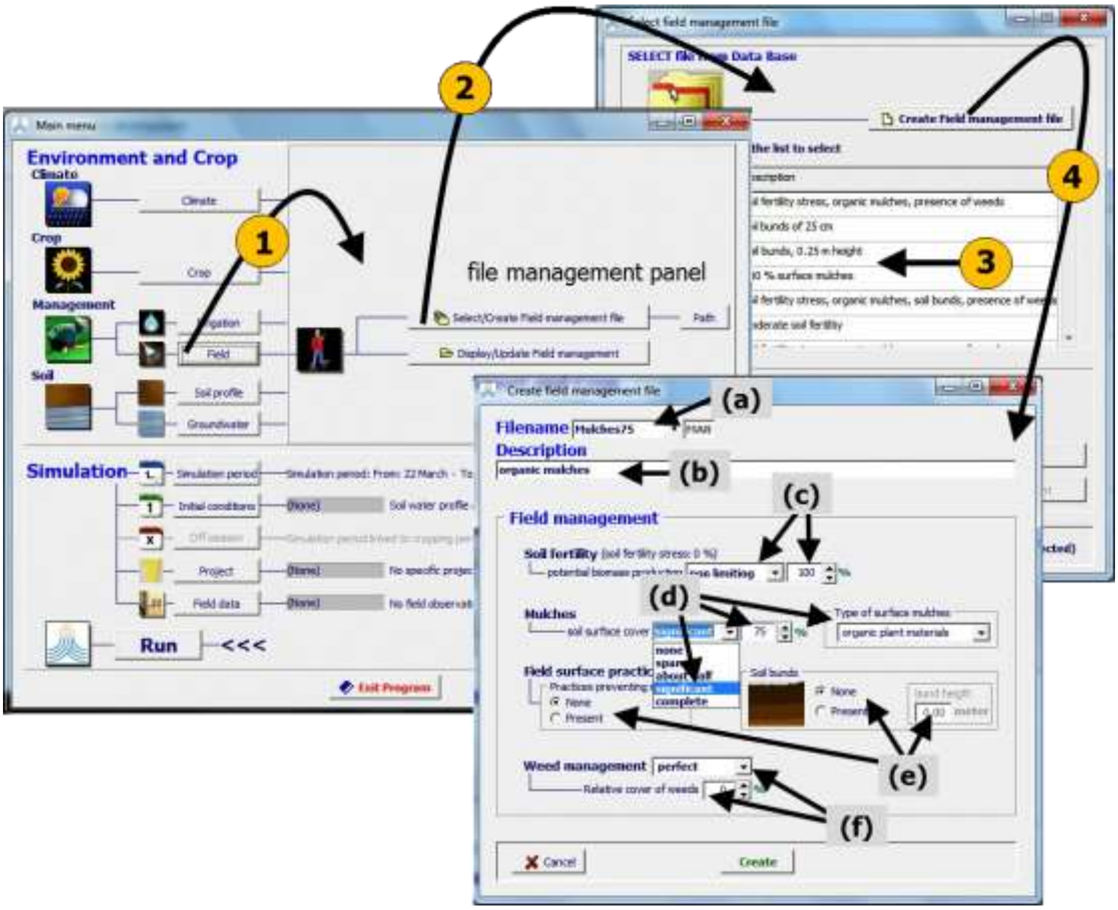


Figure 5.5 – By selecting (1) the <Field> command and subsequently (2) the <Select/Create field management file> command in the file management panel of the *Main menu*, the user gets access to *Select field management file* menu, in which (3) one of the available files or (4) the command to <Create Field management file> is selected.

Figure 5.6 – The *Field management* menu with its tabular sheets: 'Description' (displayed), 'Soil fertility', 'Mulches', 'Field surface practices', and 'Weed management'.

☐ **Soil fertility:**

Only if the crop for soil fertility stress is calibrated (Chapter 4, section 4.3), soil fertility can be specified in the 'Soil fertility' tabular sheet of the ***Field management*** menu (Fig. 5.7). The user has to specify the maximum relative dry aboveground biomass that can be expected in the field in the absence of other stresses than the soil fertility stress. In various tabular sheets the effect on canopy cover, water productivity and biomass production can be displayed.

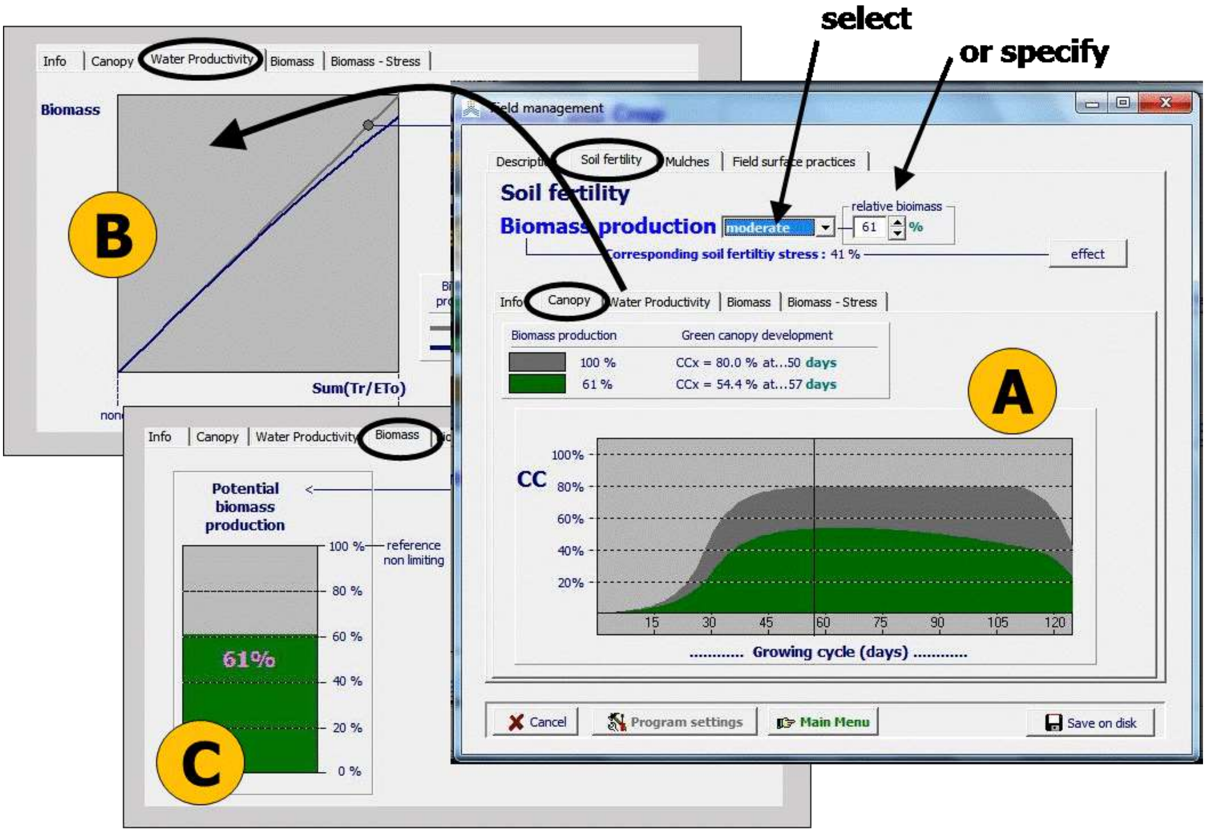


Figure 5.7 – The 'Soil fertility' tabular sheet of the *Field management* menu in which the maximum relative dry aboveground biomass that can be expected in the soil fertility stressed field is specified, and the corresponding effect on (A) canopy cover, (B) water productivity, and (C) potential biomass production is displayed in different tabular sheets.

☐ **Mulches:**

The presence of mulches affecting soil evaporation are specified in the 'Mulches' tabular sheet of the ***Field management*** menu (Fig. 5.8). The user has to specify the fraction of the soil surface covered by the mulches and the type of mulches. The effect of the mulches on soil evaporation throughout the growing cycle is displayed. The potential reduction in canopy cover due to soil fertility stress is thereby considered.

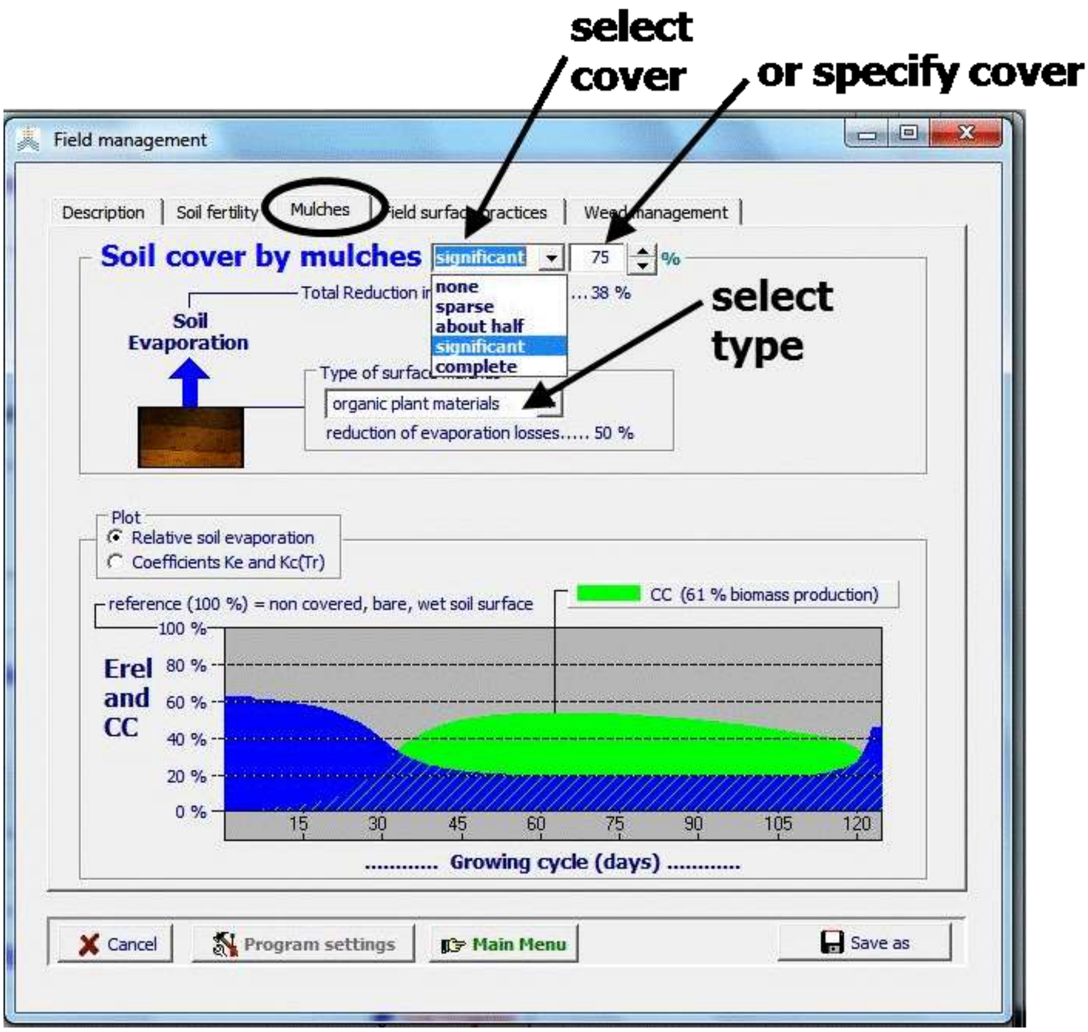


Figure 5.8 – The 'Mulches' tabular sheet of the *Field management* menu in which the soil cover by mulches and the type of mulches are specified, and the corresponding effect on soil evaporation is displayed.

☐ **Field surface practices:**

Practices affecting or inhibiting surface runoff are specified in the 'Field surface practices' tabular sheet of the ***Field management*** menu (Fig. 5.9). The user can specify if such practices:

1. **do NOT affect surface runoff**. Surface runoff is based exclusively on the soil profile characteristic (CN_{soil});
2. **affect surface runoff.** CN_{soil}, which is based on soil profile characteristics, can be adjusted by considering the crop type (if different from 'small grain'), treatment and hydrologic conditions (Fig. 5.8). By selecting the **<guide to adjustments>** command, indicative values for the percent increase/decrease are displayed in the ***CN adjustment*** menu.;
3. **prevent surface runoff.** Practices, such as tied-ridges and closed-end furrows, will prevent surface runoff;
4. **Soil bunds.** Soil bunds not only prevent surface runoff, but store excess water that could not infiltrate during the day between the bunds. The height of the soil bunds has to be specified in meter.

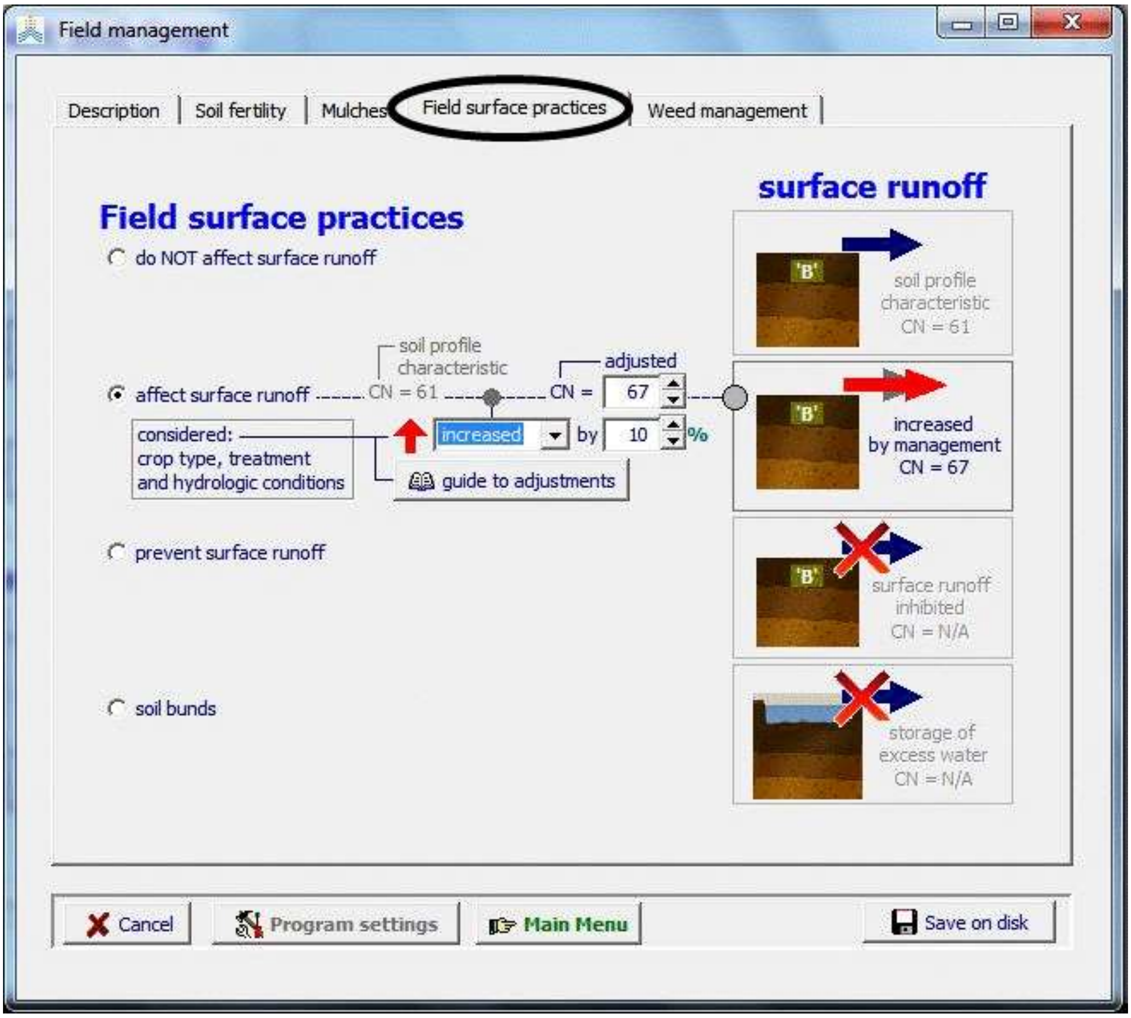


Figure 5.9 – The 'Field surface practices' tabular sheet of the *Field management* menu in which the effect of field surface practice on surface runoff is specified.

☐ **Weed management:**

In AquaCrop weed infestation is expressed by the relative cover of weeds (RC), which is the ratio between the ground area covered by leaves of weeds and the total canopy cover of weeds and crop. RC is easily determined by estimating the fraction of the total canopy cover that is weed. It can be assessed by a visual estimate in the field or by analysing photographs taken vertically from above the crop.

To specify weed infestation in the field, the user specifies in the 'Weed management' tabular sheet of the ***Field management*** menu (Fig. 5.10):

A. the Relative Cover (RC) of weeds in the season, which expresses the weed infestation level as observed in the field. This can be quantified (Fig. 5.10):
   1. by selecting a class for weed management. This results in assigning default values for the relative cover of weeds (RC); or
   2. by specifying the relative cover of weeds (RC) at canopy closure. It is regarded as a crucial measurement of the competitive process of the weeds since it is far too late for any control treatment, and proved to be a good yield loss predictor; and
   3. by specifying the relative cover of weeds (RC) at the end of the season (at the start of senescence). Due to the competitive ability of the crop and weeds to suppress each other

(one overgrowing the other), the RC might not remain constant, but can significantly increase or decrease during the mid-season stage.

B. the expansion of CC due to weed infestation, which expresses how the total canopy cover responds to weed infestation under non limiting soil fertility. Since weeds can occupy space that is not used by the crop in weed-free conditions, the total CC might be larger than the crop canopy cover in weed-free conditions. The expansion can be quantified (Fig. 5.10);
   4. by specifying the expansion directly as a percentage increase of the crop canopy cover in weed-free conditions; or
   5. by specifying the total CC of crop and weeds in the mid-season stage; or
   6. by selecting a class for the canopy expansion.

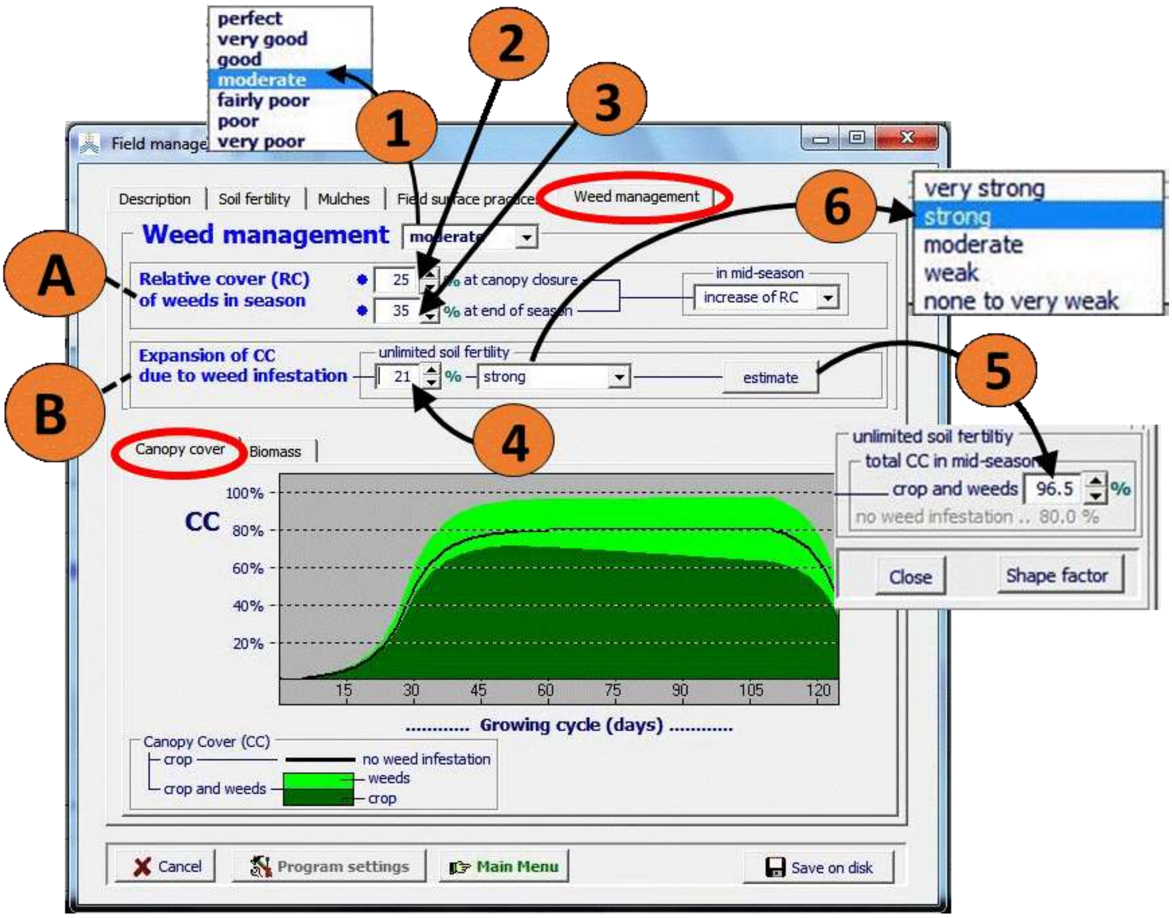


Figure 5.10 – The 'Weed management' tabular sheet of the *Field management* menu in which (A) the relative cover of weeds and (B) the expansion of the Canopy Cover (CC) due to weed infestation is specified.

In the 'Canopy cover' tabular sheet of Weed management (Fig. 5.10), the corresponding total canopy cover of crop (dark green) and weeds (light green) in the weed infested field is displayed. The canopy cover for weed-free conditions (black line) is given as a reference.

In the 'Biomass' tabular sheet of Weed management, an estimate of the maximum biomass production that can be obtained in the weed infested field is displayed.

Chapter 6. Running simulations

6.1 Start of the simulation period

The dates specified in the ***Simulation period*** menu, delimits the simulation period (Fig. 6.1).

- The simulation period may or may not coincide with the growing cycle but can be shorter or longer as long as the period does not exceed the range of climatic data;
- At the starting date of the simulation period, the initial conditions needs to be known. The initial conditions can be measured at the field. If field data are not available, the simulation can start at a day at which conditions can be well estimated, such as early spring when the soil water content is likely to be at field capacity after long winter rains. Another appropriate starting time of the simulation might be at the end of a long dry period when the soil water content is likely to be close to permanent wilting point.

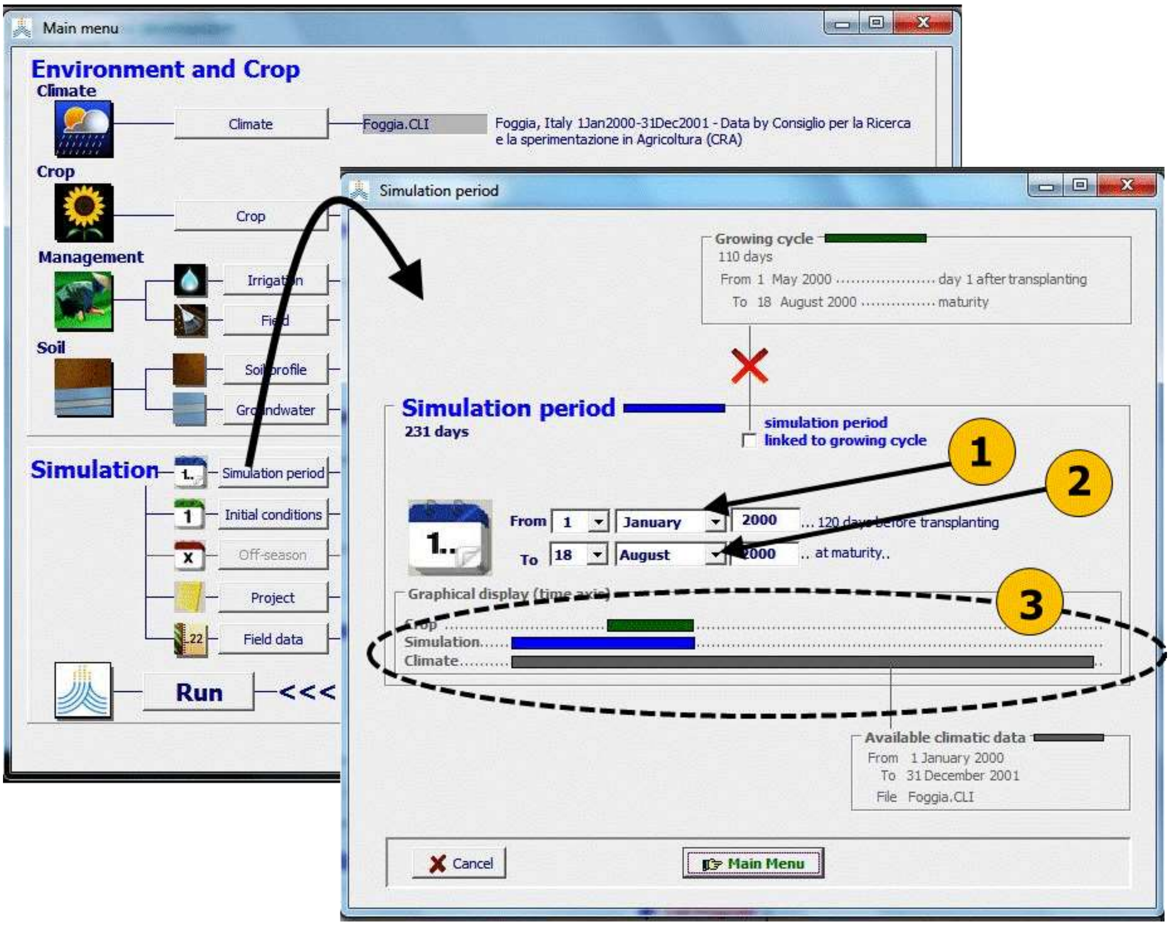


Figure 6.1 – By selecting the <Simulation period> command in the *Main menu*, the user gets access to the *Simulation period* menu, in which (1) the start and (2) end date of the simulation period are specified and (3) the growing period (green), simulation period (blue) and time range of available climatic data (grey) are plotted.

6.2 Initial conditions at start of the simulation period

The initial conditions refer to the status of the soil water and salt content in the soil profile, and the crop development and production, at the start of the first day of the simulation period.

6.2.1 Creating files with initial conditions

A file containing the initial conditions at the start of the simulation period, can be created by selecting the **<Create file initial conditions>** command in the ***Select file with initial conditions*** menu (Fig. 6.2).

The initial conditions are displayed and can be updated in the various tabular sheets of the ***Initial conditions*** menu (Fig. 6.3 and 6.4):

- **Description**: to adjust the description of the file containing the initial conditions;
- **Initial soil water and salinity content**; to adjust the soil water and salinity contents;
- **Initial crop development and production**; to adjust the degree of crop development and production, when the simulation period starts after germination.

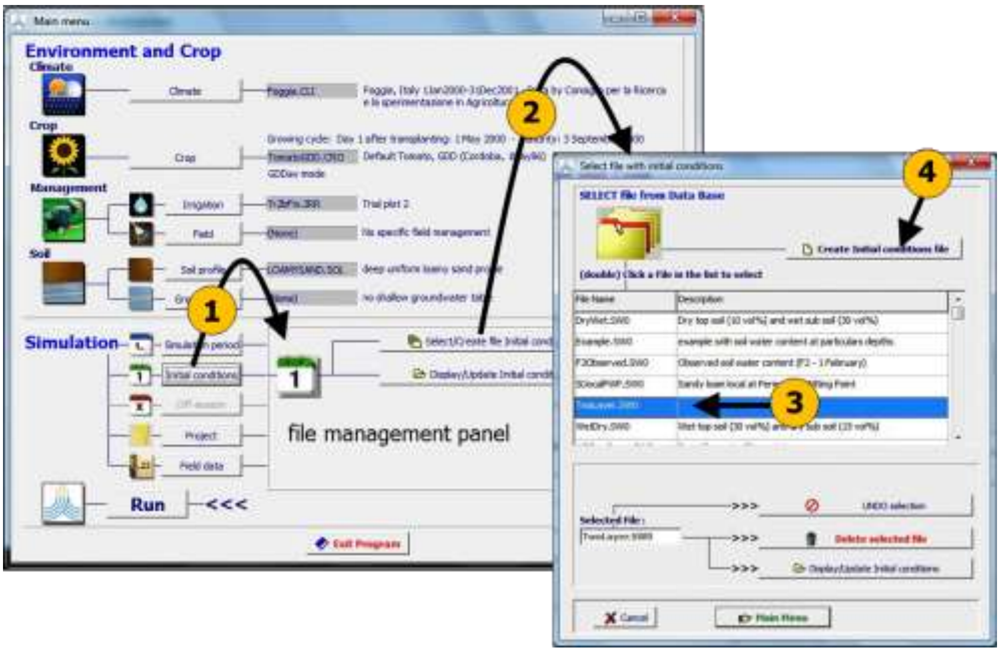


Figure 6.2 – By selecting (1) the <Initial conditions> command and subsequently (2) the <Select/Create file Initial conditions> command in the file management panel of the *Main menu*, the user gets access to the *Select file with initial conditions* menu, in which (3) one of the available files with initial conditions or (4) the command to <Create file initial conditions> can be selected.

6.2.2 Initial soil water and salinity content

In the 'Initial soil water and salinity content' tabular sheet of the ***Initial conditions*** menu, the soil water content and salinity content at various points in the soil profile at the start of the simulation period can be specified (Fig. 6.3):

1. Indicate if the contents are specified at particular depths or for specific soil layers. This is not the same as the number of horizons, specified in the soil profile file;

2. Select the number of different depths (layers) that were sampled or for which the water and salinity contents can be estimated (from 1 representative up to 12 distinctive depths/layers);
3. Specify (a) the depth (or thickness of the layer), and (b) the soil water and (c) salinity content at each depth (or for each layer). Soil water contents are specified in volume percentage and soil salinity in the Electrical Conductivity of the saturation soil-paste extract (ECe).

With the help of predefined commands, the whole soil profile can be put at a specific soil water content (at saturation, field capacity, permanent wilting point, or at a specific percentage of TAW) and salinity content (specific ECe). To use the predefined commands, the correct soil profile file should have been selected.

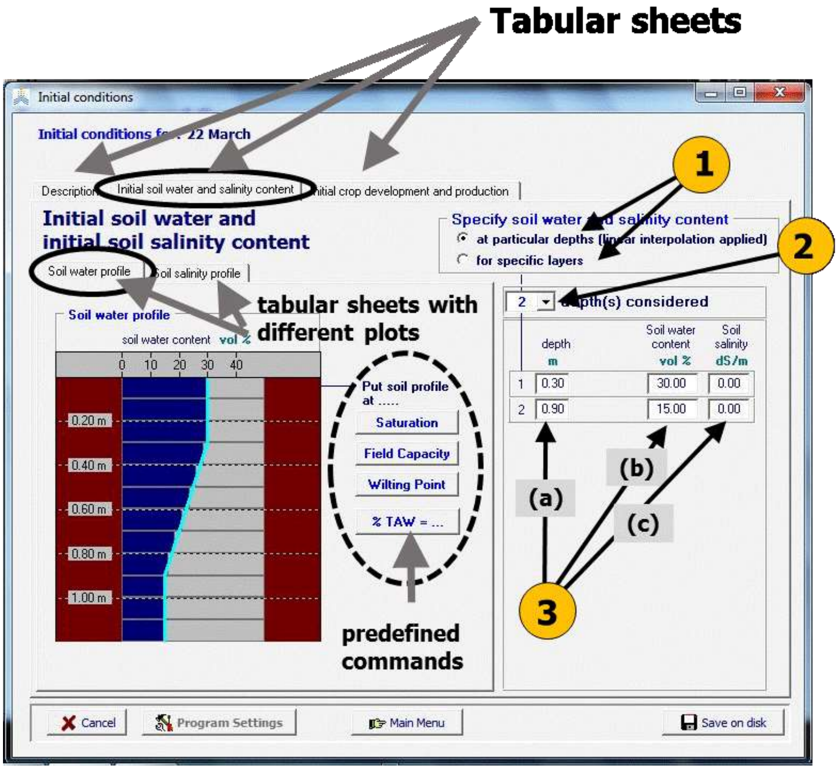


Figure 6.3 – The *Initial conditions* menu with its tabular sheets: 'Description', 'Initial soil water and salinity content' (displayed), and 'Initial crop development and production'.

6.2.3 Initial crop development and production

The simulation period might need to start after the germination of the crop, if reliable estimates of the initial conditions are not available at or before planting, or due to the absence of climatic data. If stresses have affected crop development before the simulation period, the user has to adjust the status of canopy cover (CC), rooting depth (Z), and the above-ground biomass (B) already produced, at the start of the simulation period. The initial conditions of CC, B and Z can be measured at the field or estimated with the help of remote sensing.

In the 'Initial crop development and production' tabular sheet of the *Initial conditions* menu the user specifies (Fig. 6.4):

1. Initial canopy cover (CC) in percentage, if different from the maximum canopy cover that could have been reached without water stress (which is the default), at the start of the simulation period;

Dry mass of above-ground biomass (B) already produced at the start of the simulation period in ton per hectare, if different from zero (which is the default);

2. Initial rooting depth (Z) in meter, if different from the maximum rooting depth that could have been reached without water stress (which is the default), at the start of the simulation period.

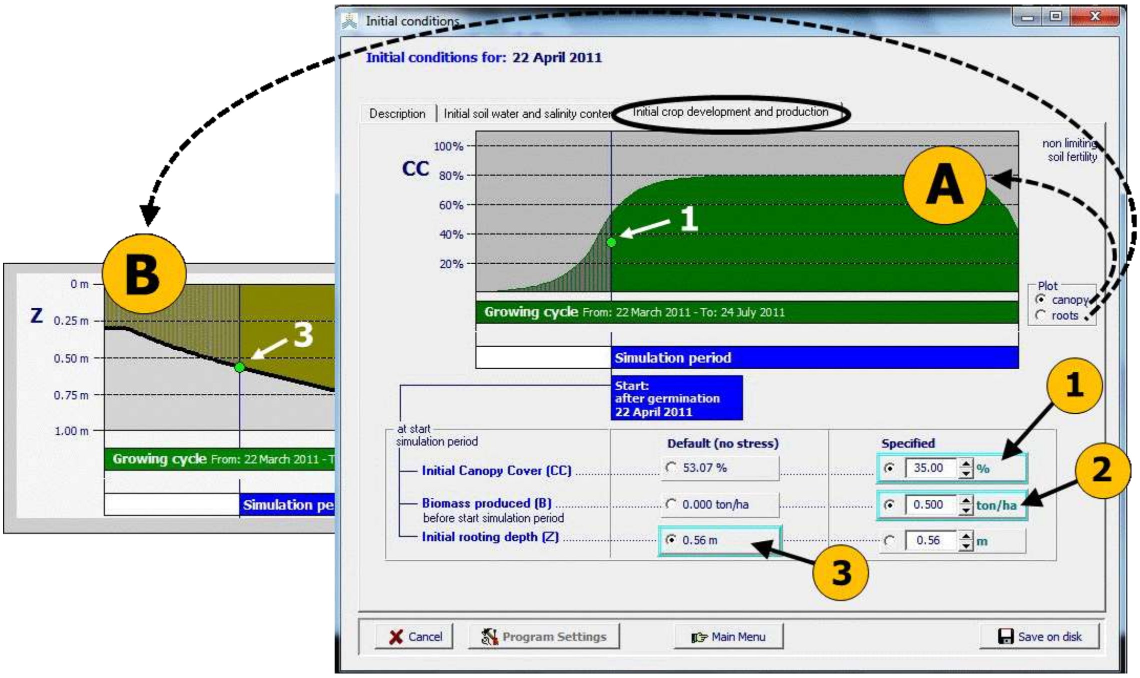


Figure 6.4 – Specified (1) canopy cover, (2) biomass produced, and (3) rooting depth at the start of the simulation period, in the 'Initial crop development and production' tabular sheet of the *Initial conditions* menu, with indication of the specified canopy cover and rooting depth in the corresponding plots (A and B).

6.3 Successive simulations: Keep/Reset initial conditions

By default the specified conditions in the ***Initial conditions*** menu are reconsidered at the start of each simulation run (RESET to specified Initial conditions). AquaCrop offers also the option to consider the simulated soil water and salinity content at the end of the simulation run, as the initial conditions for the next run (KEEP values from previous simulation run). Since this is not the default option, it requires a change in the settings of one of the program parameters, which has to be done in the ***Program settings: Simulation run parameters*** menu (Fig. 6.5). The **<KEEP values from previous simulation run>** setting applies as long as the soil file remains the same, and the option is not reset to its default (**<RESET to specified initial conditions>**).

Running with the "KEEP" option is for example useful for simulating the building up of salts over successive years. By repeating the simulations and by taking whole years as the simulation periods, the effect of winter rains leaching salts out of the root zone can be studied. In the example presented in Figure 6.6, successive simulations were run for tomato's planted on 1 May in the region of Tunis (Tunisia) on a uniform sandy clay loam soil. The crop was irrigated by furrows and a pre-irrigation at planting was provided. The irrigation water was of poor quality (4 dS/m). Simulations were run from 1 January to 31 December, and repeated for a number of years, until the salt content in the root zone and the corresponding salinity stress and drop in crop production reached a more or less constant level.

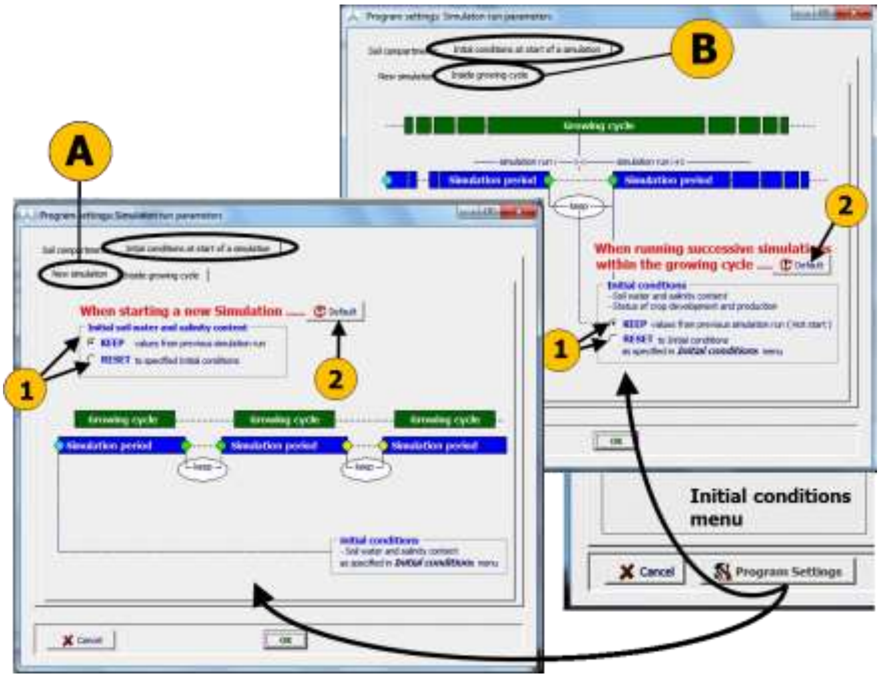


Figure 6.5 – By selecting the <Program Settings> command in the *Initial conditions* menu, the user gets access to the *Program settings: Simulation parameters* menu, in which the (1) KEEP or RESET option, or (2) Default setting for simulation program parameters can be selected, for (A) successive simulations enveloping the growing cycle and (B) successive simulations within the growing cycle (hot starts).

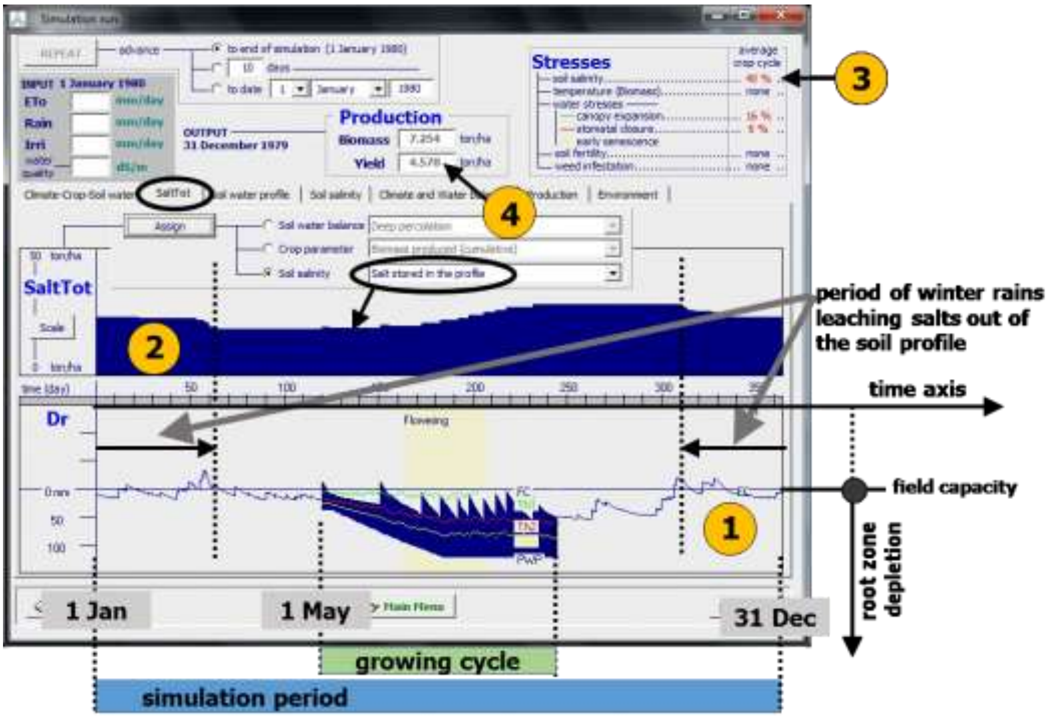


Figure 6.6 – Display, in the *Simulation run* menu, of (1) root zone depletion, (2) salt stored in the soil profile, (3) soil salinity stress and (4) crop yield, as a result of irrigating with water of poor quality and the leaching effect of winter rains in the off-season. Runs were repeated for a number of years, with the KEEP option for the initial conditions.

6.4 Projects

6.4.1 Project file

Before running a simulation, the user has to select in the ***Main menu***: the fine-tuned crop file, the files describing the environment in which the crop is cultivated (climate, management, soil), and the initial conditions, and to specify the start of the growing cycle and the simulation period. Simulations will run according to the settings of the program parameters (default settings are used unless explicitly changed). Instead of doing the required selections and specifications in the ***Main menu***, the user can also load a project file which contains all the above information required for the simulation.

Distinction is made between projects containing the required information for a **single simulation run** ('.PRO' files) or projects consisting of a set of successive runs, the so called **multiple run projects** ('.PRM' files). With a multiple run project the user can run a particular simulation for a number of successive years. A multiple run project can also be used to simulate a crop rotation (successive crops).

6.4.2 Structure of project files

A project file is a text file which contains (a) information about the project, (b) the simulation and cropping period, (c) settings for program parameters, and (d) the names of files (crop, environment, initial conditions) which are required for the simulation run (Tab. 6.1).

Table 6.1 – Structure of a project file

Line Number	**Description**
a. – Information	
1	Description of the project
2	AquaCrop version number
b. – Simulation and cropping period (the growing cycle) for the first run	
3	Day number(1) for the first day of the simulation period
4	Day number(1) for the last day of the simulation period
5	Day number(1) for the first day of the growing cycle
6	Day number(1) for the last day of the growing cycle
c. – Program parameters	
7 up to 27	Values for 21 program parameters
d. – The names(2) and directories(3) for the 12 files containing the characteristics of the fine-tuned crop, environment (climate, management and soil), and initial conditions	

28 up to 37	- Climate file and the enveloped:
	  - air temperature file,
	  - ETo file,
	  - rainfall file, and
	  - CO2 file;
	- Crop file;
	- Irrigation management file;
	- Field management file;
	- Soil profile file;
	- Groundwater table file;
	- Initial conditions file;
	- Off-season conditions file.

In case of **multiple projects**, section ‘b’ and section ‘c’ are specified for each of the successive runs (in the next 40 lines). Program parameters cannot be re-specified, since the settings specified for the 1st run (section c) are valid for all runs.
(1) Day number: The day number refers to the days elapsed since 0th January 1901 at 0 am (see reference manual for the calculation procedure); (2) File name: in the absence of a file (None), the default conditions (see Tab. 1.1) are considered; (3) Directory (path): in the absence of a file, (None) is specified as directory.

6.4.3 Creating project files

Creating a project is easy, when before launching the creation, the files containing the characteristics of the fine-tuned crop, environment (climate, management, and soils), and initial conditions for the specific run are selected in the ***Main menu***.

The project is created by selecting the <**Create project file**> command in the ***Select project file*** menu, after specifying its type (Fig. 6.7):

a) Single simulation run;
b) Successive years (multiple runs);
c) Crop rotations (multiple runs);

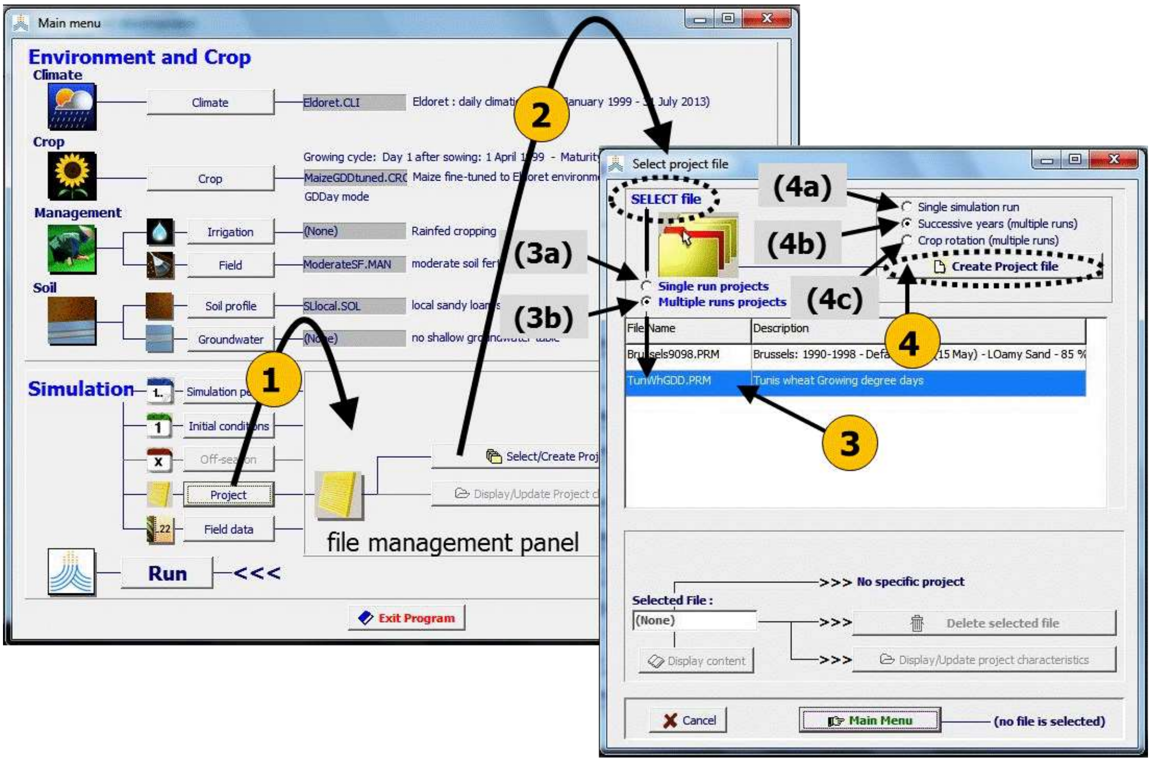


Figure 6.7 – By selecting (1) the <Project> command and subsequently (2) the <Select/Create Project file> command in the file management panel of the *Main menu*, the user gets access to the *Select project file* menu, in which (3) one of the available project files (by specifying its type: ‘3a’, or ‘3b’) or (4) the option to <Create project file> (by specifying its type: ‘4a’, ‘4b’, or ‘4c’) is selected.

After selecting the **<Create project file>** command, the ***Create project file*** menu is displayed (Fig. 6.8 and 6.9). In the case of a multiple run project, which consists in repeating a simulation over a number of successive years, the number of years (according to the data available in the selected Climate file) are displayed at the top of the menu. By means of a spin button, the number of years (series of simulation runs) can be altered.

By selecting one of the key commands at the left side of the ***Create project file*** menu, a corresponding information sheet is displayed with indication of the selected file (and the option to select another file) and other required information. If no file is selected, default conditions are considered (see Table 1.1). The data specified in the information sheets consist of:

- **Climate**: Selected files containing the rainfall, ETo, air temperature and CO_2 data and the name of the enveloping climate file;
- **Crop**: Selected crop file, and the way the sowing/planting date is specified (Fig. 6.8):
  - o specific date;
  - o generated date, based on rainfall data: The search window, selected criterion and the number of occurrence the criterion has to be met before the onset is generated, are specified in the 'Rain criteria' tabular sheet (see section 4.1.2);
  - o generated date, based on air temperature data: The search window, selected criterion and number of occurrence the criterion has to be met before the onset is generated, are specified in the 'Temperature criteria' tabular sheet (see section 4.1.2);

  In the case of a multiple run project with successive years, the year is only specified for the 1st of the series of simulation runs;
- **Irrigation**: Selected irrigation management file;
- **Field**: Selected field management file;

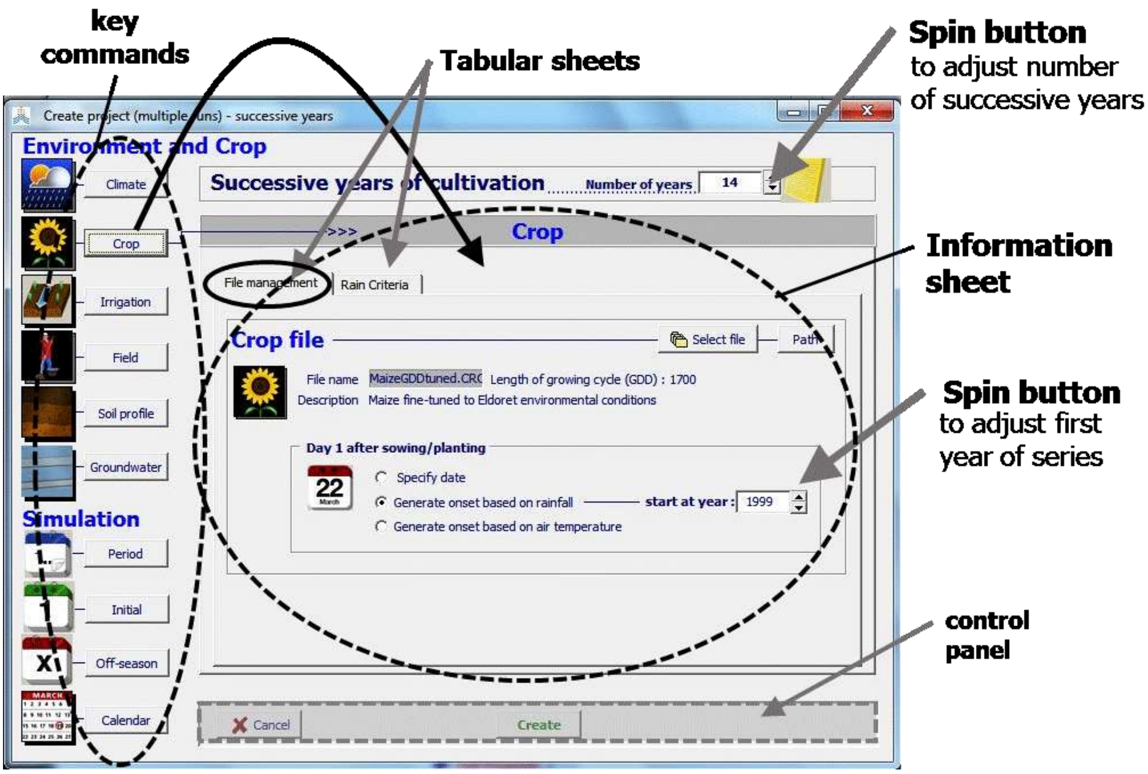


Figure 6.8 – The key commands in the *Create project* menu, with which information sheets can be displayed for file management and other data.

- **Soil profile**: Selected soil profile file;
- **Groundwater**: Selected groundwater table file;

- **Period**: The simulation period, which can be:
    - linked to the growing cycle;
    - start at a specific date.

  In the case of a multiple run project with successive years, also the start of the simulation period for the next runs (successive years) is specified:
    - linked to the growing cycle;
    - start at a specific date for each year;
    - linked to the simulation run of the previous year (the 'KEEP' option for the initial conditions applies for this case. See section 6.3);
- **Initial**: Selected file with the initial conditions;
- **Off-season**: Selected file with the off-season conditions;
- **Calendar**: Graphical and numerical display with the start and end day of the growing cycle and simulation period in the various tabular sheets (Fig. 6.9).

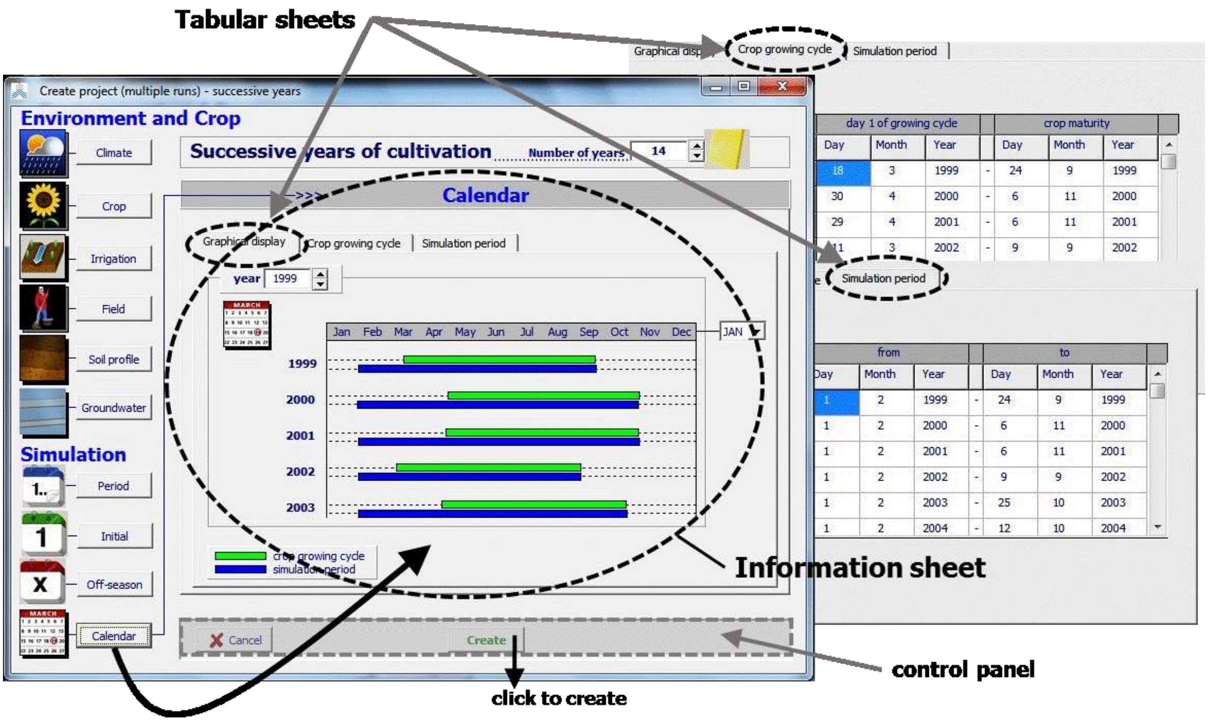


Figure 6.9 – The selected 'Calendar information sheet' in the *Create project* menu, with the graphical and numerical display of the start of the growing cycle and simulation period in the various tabular sheets. In the example, planting is based on meeting a rainfall criterion (2nd occurrence) in the time window 1 March – 30 April, while simulation starts each year on 1 February at which a dry soil profile can be assumed.

By selecting the <**Create**> command in the control panel at the bottom of the ***Create project file*** menu (Fig. 6.9), the project is created (which consists in saving a text file with the structure and information presented in Table 6.1).

6.4.4 Running AquaCrop in project mode

Once a project is loaded (Fig. 6.7 – 3) or created (Fig. 6.9) the layout of the ***Main menu*** is adjusted (Fig. 6.10). This is required to prevent the selection of files different from the one enclosed by the project. As such, the key commands for selecting other files are no longer available in the ***Main menu*** (Fig. 6.10). However, by clicking on the icons, the corresponding characteristics of the input can still be displayed (see also section 1.3). In case of multiple runs project, the content of other runs (which can contain different set of files) can be displayed with the spin button at the top of the menu.

By selecting the <**UNDO project selection**> command in the ***Main menu***, one return to the default settings considered at the start of AquaCrop (see Tab. 1.1).

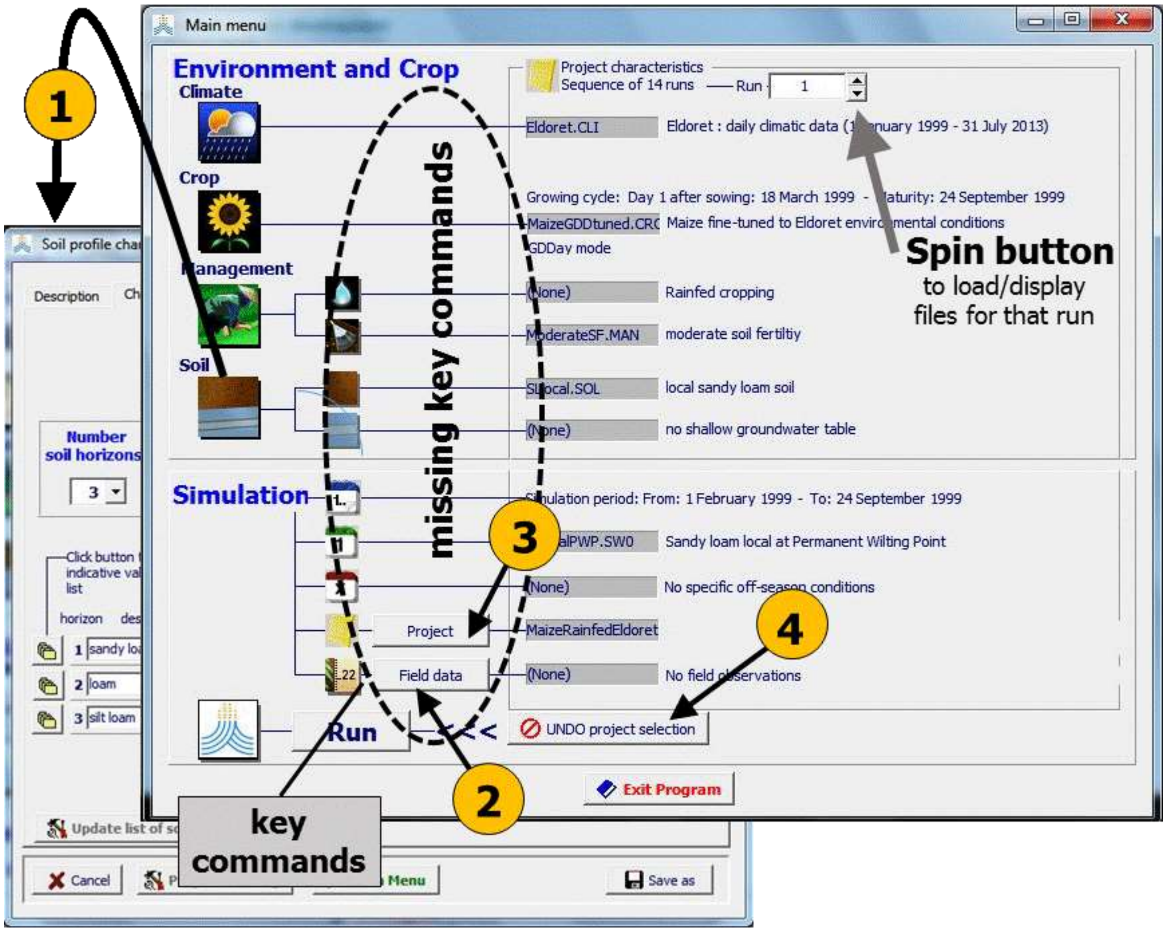


Figure 6.10 – The *Main menu* in project mode (with missing key commands), in which (1) characteristics of the input can be displayed, (2) field data can be added, (3) characteristics of projects can be updated and/or other projects can be created or selected, and (4) the project selection can be undone (return to the default mode).

6.4.5 Updating project characteristics

The selected files, planting date, simulation period and program parameters for running a project, are displayed and can be updated in the various tabular sheets of the ***Project characteristics*** menu, (Fig. 6.11):

- **Description**: to adjust the description of the project file;
- **Environment and simulation files**: In case of multiple run projects, select the run number, since the planting date, simulation period and set of files might differ between the runs:
  - to display the characteristics of the input;
  - to select other crop file(s), irrigation file(s), field management file(s), another soil profile file, groundwater file(s), file(s) with initial conditions, and file(s) with off-season conditions in the corresponding file management panels.

    With the exception of the climate file, the soil profile file and the crop file (if successive years are considered), the files need not to be common between the simulation runs of a multiple runs project. Use the corresponding check buttons if the selected files apply to all runs of a multiple runs project;
  - to alter the start of the growing cycle;
  - to alter the start and the end of the simulation period;
- **Calendar**: to display the period of the growing cycle and simulation period**;**
- **Program settings**: to alter the settings of program parameters.

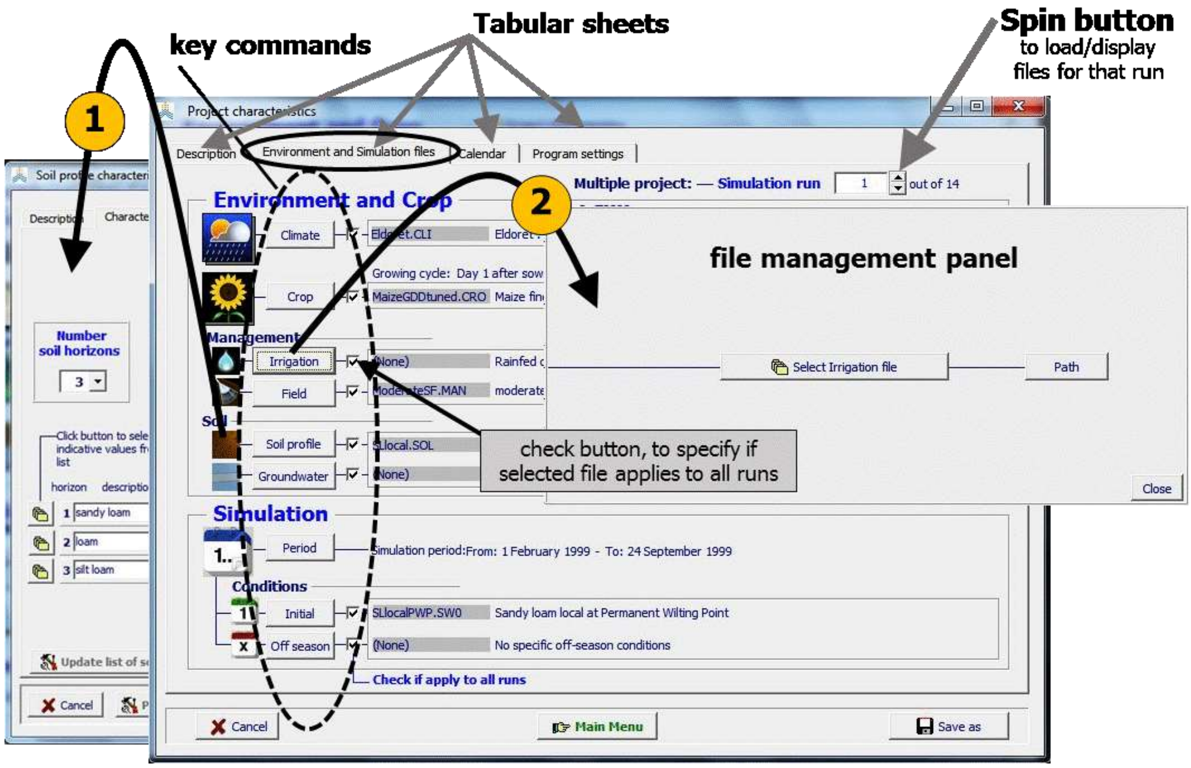


Figure 6.11 – The *Project characteristics* menu with its tabular sheets: 'Description', 'Environment and Simulation files' (displayed), 'Calendar', and 'Program settings'. In the 'Environment and Simulation files' tabular sheets (1) characteristics of the selected input can be displayed, and (2) other input files can be selected in the appropriate file management panels.

Projects can also be updated by making the changes directly in the project file (Box 6.1). This is an advanced way, that gives the user more flexibility than via the software interface.

Box 6.1 – Advanced way of updating project files with more flexibilities

By respecting the structure of the project file (Table 6.1), the user can alter its content by making the required changes directly in the text file. This is useful for making a quick adjustment in multiple runs projects, or to build other types of multiple runs projects than the two available through the interface (successive years and crop rotation). By doing so, one is no longer restricted by current limitations of the interface. For example, by copying/pasting one can design very fast multiple runs projects, with runs that only differ in soil type or field management, while all other input (included climate) remains identically.

6.5 Field data

6.5.1 Creating field data files

A file containing observed field data can be created by selecting the <**Create Field data file**> command in the ***Select field data file*** menu (Fig. 6.12).

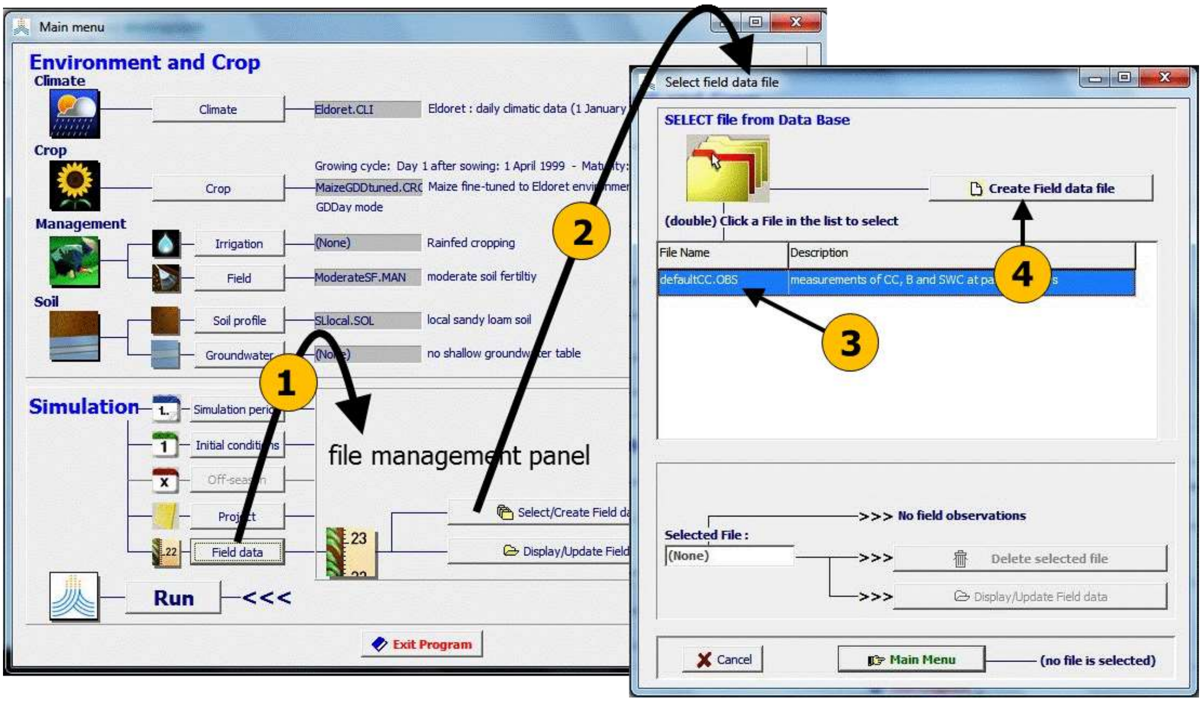


Figure 6.12 – By selecting (1) the <Field data> command and subsequently (2) the <Select/Create Field data file> command in the file management panel of the *Main menu*, the user gets access to the *Select field data file* menu, in which (3) one of the available field data files or (4) the command to <Create Field data file> can be selected.

6.5.2 Field data characteristics

The field data are displayed and can be updated in the various tabular sheets of the ***Field data menu*** (Fig. 6.13):

- **<u>Description</u>**: to adjust the description of the file containing the field data;
- **<u>Field data</u>**: to adjust the observed green Canopy cover (CC), dry above-ground Biomass (B) and soil water content (SWC) at particular days:
  - the time of the observations are expressed as day numbers with reference to a specified first day whether or not linked to a specific year;
  - field data can cover several years;
  - a mean value together with its standard deviation can be specified, if several observations were made during the sampling at a specific day;
  - green Canopy cover (CC) is expressed as a percentage;
  - dry above-ground Biomass (B) is expressed in ton/ha;
  - soil water contents (SWC) are expressed as totals (mm of water) for a well specified depth (e.g. maximum root zone): see inset within Fig. 6.13.

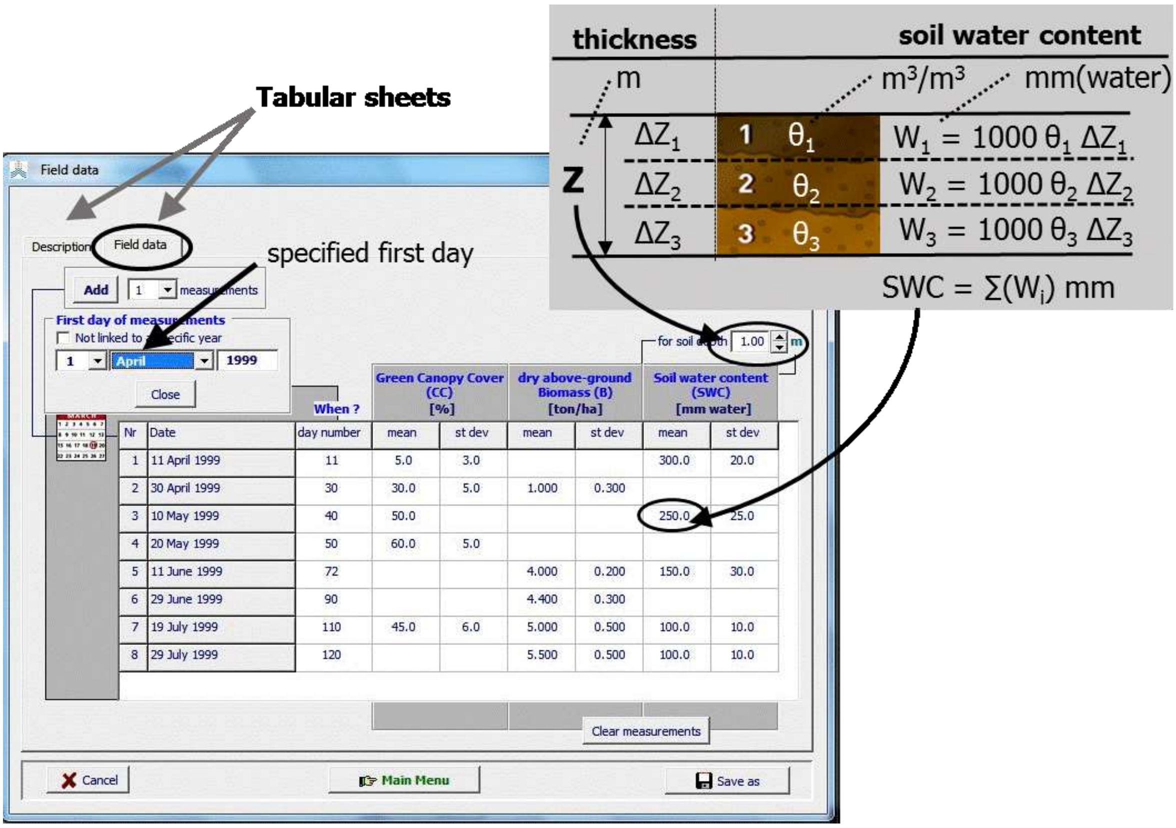


Figure 6.13 – The *Field data* menu with its tabular sheets 'Description' and 'Field data' (displayed) in which the first day of observations and field data (green canopy cover, dry above-ground biomass and/or soil water contents) at particular days are specified.

6.6 Simulation run

6.6.1 Launching the simulation

By selecting the <**Run**> command in the ***Main menu***, the user gets access to the ***Simulation run*** menu, in which the simulation can be launched (Fig. 6.14). By selecting one of the options, the simulation will advance:

a) to the end of the simulation period. In case of multiple runs projects, the simulation advances to the end of the simulation period of the specified run number;
b) by the specified number of days; or
c) to a specified date.

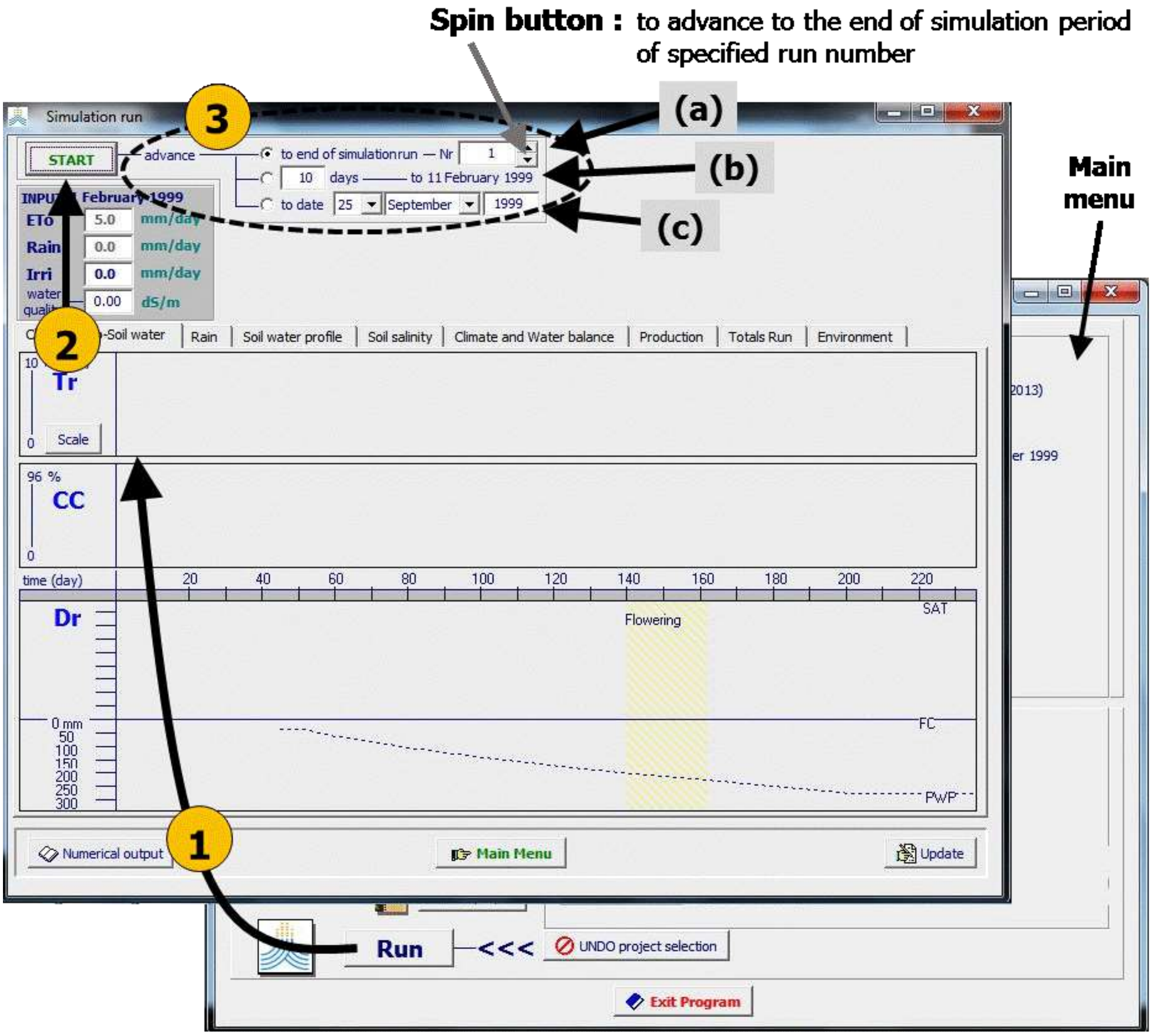


Figure 6.14 – By selecting (1) the <Run> command in the *Main menu*, the user gets access to the *Simulation run* menu, in which (2) the simulation can be started. Depending on (3) the selected advance option the simulation will (a) run to the end of the simulation period, (b) advance by a specified number of days, or (c) run to a specified date.

6.6.2 Display of simulation results

Simulation results, which are updated at the end of each daily time step, are available in the ***Simulation run*** menu (Fig. 6.15). The results are valid for the displayed output date (day to which the simulation is advanced). It consists of the total biomass and crop yield produced at that day, stress levels occurring on that day, and averages of stresses over the growing cycle till that day. Additionally a lot of data and graphs are available in a series of tabular sheets, through which the user can follow the effects of water, temperature, fertility, salinity and weed stress on crop development and production during the simulation run.

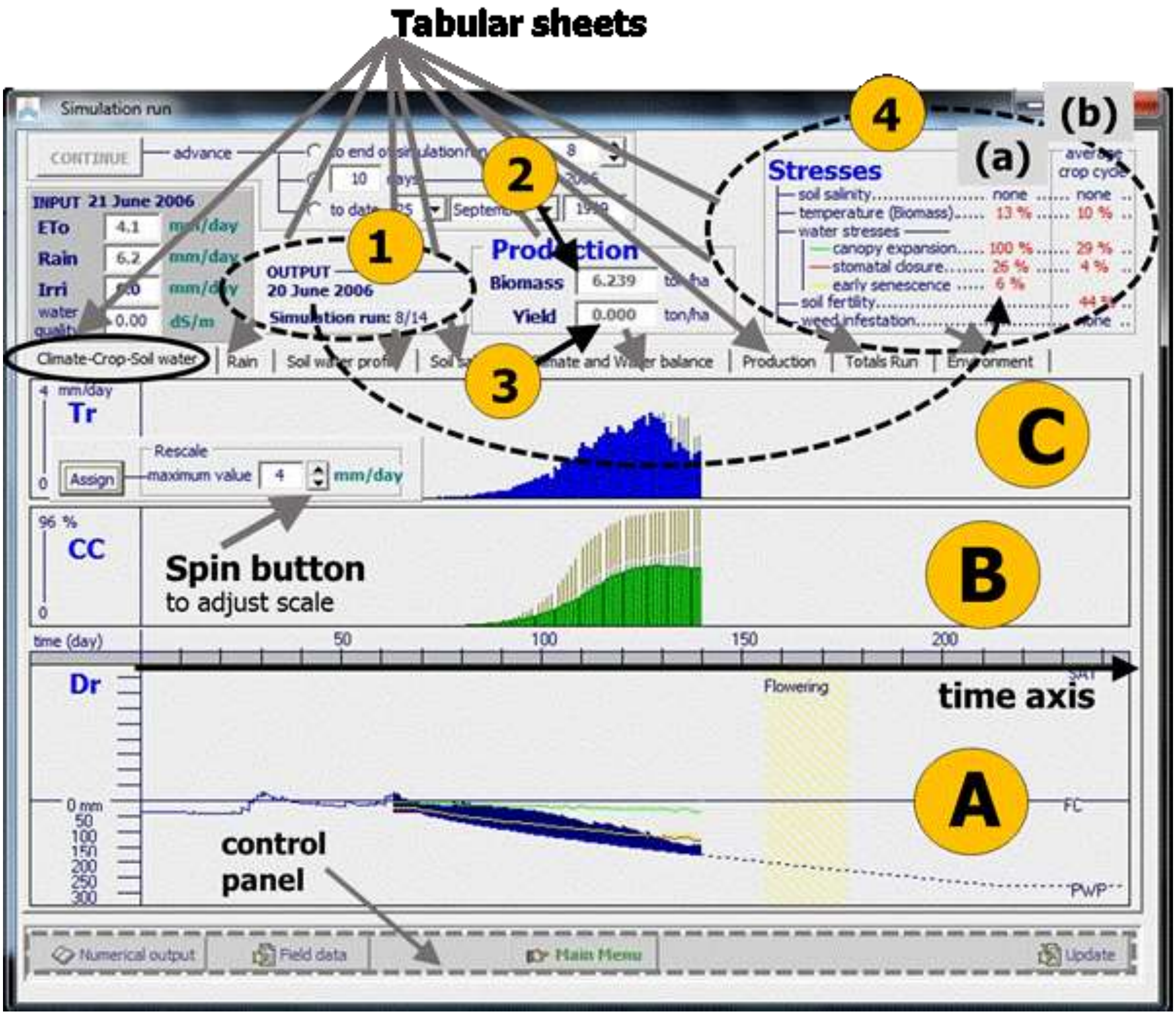


Figure 6.15 – Display of simulation results in the *Simulation run* menu (1) for the day to which the simulation has advanced. Total (2) biomass and (3) crop yield produced so far at the end of that day, (4) stress levels occurring (a) on that day and (b) averages of stresses over the growing cycle till that day, are displayed. In the tabular sheet of 'Climate-Crop-Soil water' the (A) root zone depletion, (B) green canopy development, and (C) crop transpiration is plotted in different panels.

☐ **Tabular sheet: 'Climate-Crop-Soil water' (Fig. 6.15)**

The 'Climate-Crop-Soil water' tabular sheet contains graphs with plots of (A) the soil water depletion of the root zone (Dr), (B) the corresponding development of the green canopy cover (CC), and (C) the transpiration (Tr), plotted as functions of time (Fig. 6.17). If the water content in the root zone drops below the threshold (green line) canopy expansion is affected. This will result in a slower canopy development than expected. In the canopy cover graph (CC) the canopy cover without water stress is plotted in light gray in the back portion of the figure as a reference. More severe water stress will result in stomata closure (red line), resulting in reduced crop transpiration. In the transpiration graph (Tr), the maximum crop transpiration that can be reached when the crop is well watered is plotted in light gray in the back as a reference. Severe water stress might even trigger early canopy senescence when the root zone depletion exceeds the threshold for senescence (yellow line).

☐ **Tabular sheet with selected parameter**

In the second sheet of the ***Simulation run*** menu, the user can select a particular parameter for further analysis (default is 'Rain'). Several crop parameters and parameters of the soil water and soil salinity balance, as well as simulated stresses can be selected and the scale for the plot can be adjusted.

☐ **Tabular sheet: Soil water profile**

In the 'Soil water profile' tabular sheet, the simulated water content in the various compartments of the soil profile is adjusted for every day of the simulation period.

☐ **Tabular sheet: Soil salinity**

In the 'Soil salinity' tabular sheet, the simulated soil salinity profile and the parameters of the salt balance in the soil profile and root zone are adjusted for every day of the simulation period.

☐ **Tabular sheet: Climate and Water balance**

In the 'Climate and Water balance' tabular sheet, values are given for soil evaporation, crop transpiration, surface runoff, infiltrated water, drainage, and capillary rise. By selecting the <**Irrigation events**> command, the events are displayed in the ***Irrigation Events*** menu.

☐ **Tabular sheet: Production**

In the 'Production' tabular sheet, information is given on the ante and post-anthesis impact of water stress on the adjustment of HI. The simulated amount of biomass produced and the biomass that could have been produced in the absence of water, soil fertility, salinity and weed stress are displayed as well. The ET water productivity (yield per unit of evapotranspired water) is also presented in this sheet.

☐ **Tabular sheet: Totals Run** (only for a multiple runs project)

In the 'Totals Run' tabular sheet, information is given on totals for two selected parameters at the end of each simulation run.

☐ **Tabular sheet: Environment**

In the 'Environment' tabular sheet, the selected input files for the simulation run are displayed and the settings for program parameters can be checked. By selecting one of the icons, the corresponding characteristics for that input are displayed.

6.6.3 Options available in the Control panel

From the control panel at the bottom of the Simulation run menu, the user gets access to a series of other menus (Fig. 6.16):

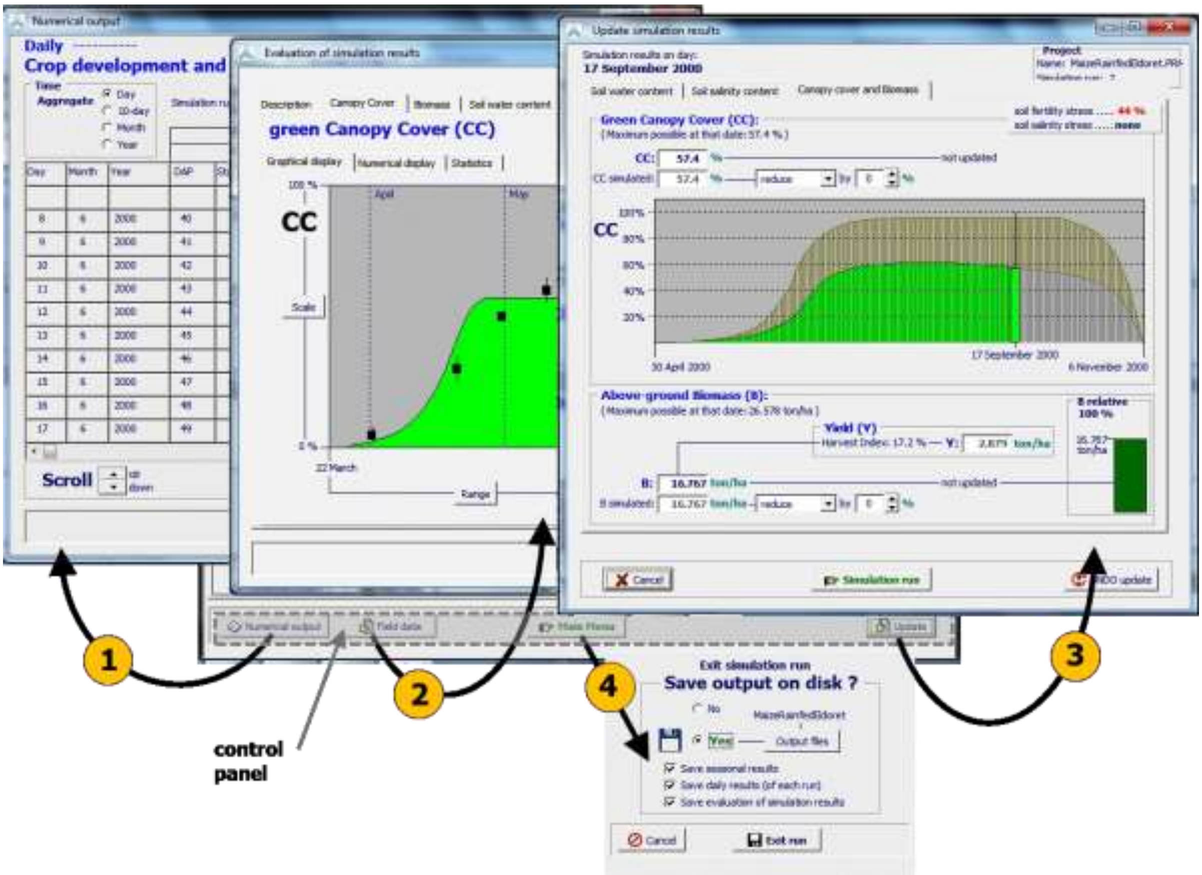


Figure 6.16 – By selecting the (1) <Numerical output>, (2) <Field data>, (3) <Update> or (4) <Main menu> command in the control panel at the bottom of the *Simulation run* menu, the user gets access to respectively the *Numerical output* menu, *Evaluation of simulation results* menu, *Update simulation results* menu and the Exit panel.

☐ **Numerical output:**
Simulation results are recorded in output files and the data of one of the selected files can be displayed in the ***Numerical output*** menu by selecting the <**Numerical output**> command. The data can be aggregated to 10-day, monthly or yearly data.

☐ **Evaluation of the simulation results:**
When running a simulation, users can evaluate the simulation results with the help of the field data stored in an field data file (see Section 6.5). The user gets access to the ***Evaluation of simulation results*** menu by selecting the **<Field data>** command. For each of the 3 sets of field data (Canopy Cover, Biomass and Soil water content) the user can display:

- graphical display where the simulated and observed (with their standard deviations) values are plotted;
- numerical display where the simulated and observed values (with their standard deviations) are displayed; and
- statistical indicators evaluating the simulation results.

☐ **Update state variables while running a simulation**

When running a simulation, users can update some state variables in the ***Update simulation results*** menu by selecting the **<Update>** command. This might be required because AquaCrop does not simulate:

- pests, diseases, frost, hail, … destroying part of the green canopy cover (CC) and the above-ground biomass (B) during the season;
- subsurface horizontal water flow, moving water in or out of the soil profile (seepage).

As a consequence CC, B and/or the soil water profile (θ-z) after such an event might be different from what is observed. Therefore AquaCrop offers the option to update CC, B and θ-z at the end of the event day, based on observations or estimates made on that day. After the update, AquaCrop resumes the simulation with the adjusted CC, B and/or θ-z.

☐ **Save simulation results in output files**

On exit of the ***Simulation run*** menu (select <**Main menu**> command), it is possible to save the output. Distinction is made between files containing daily simulation results, seasonal results and evaluation of simulation results. The files are stored by default in the OUTP directory of AquaCrop. By using different filenames (and even directories), the user can prevent that the simulation results are overwritten at each run.

Part B - Exercises

The main purpose of the exercises is to make the user familiar with the different steps involved in running various kind of simulations. The content and learning objectives of the exercises are listed in Annex I, with reference to different sections of the handbook.

The exercises are grouped in 3 chapters:

- Chapter 7. Wheat production in Tunis
- Chapter 8. Cereal production in Hyderabad
- Chapter 9. Potato production in Brussels

The exercises do not need to be made in order of appearance. For each exercise a table lists all required data and AquaCrop files which are required to run the exercises. A lot of those files come with installation of the software and are available in the DATA subdirectory of AquaCrop. For some exercises, the user will have to make extra input files. These files are available in the 'Handbook_II_RunningAquaCrop' folder of the memory stick. If AquaCrop (Version 6.0) is properly installed in its default path (C:\FAO\AquaCrop), the project files on the memory stick can be loaded as well. The stick contains also EXCELL sheets with the solutions of the exercise.

Chapter 7. Wheat production in Tunis

Introduction

This set of exercises will assess the average winter wheat production that can be expected in Tunis (Tunisia) under different environmental conditions and agronomic practices (local crop varieties, soils, management). Both rainfed and irrigated cropping systems will be evaluated.

The capital Tunis is located in north Tunisia (36°48’N, 10°10’E) and has a semi-arid climate (Fig. 7.1). Rainfed crops can be cultivated between October and March, when most rainfall events take place and ET_0 is relatively low. In addition, irrigated crops can be cultivated at other times in the year, even in the summer months when no rainfall occurs.

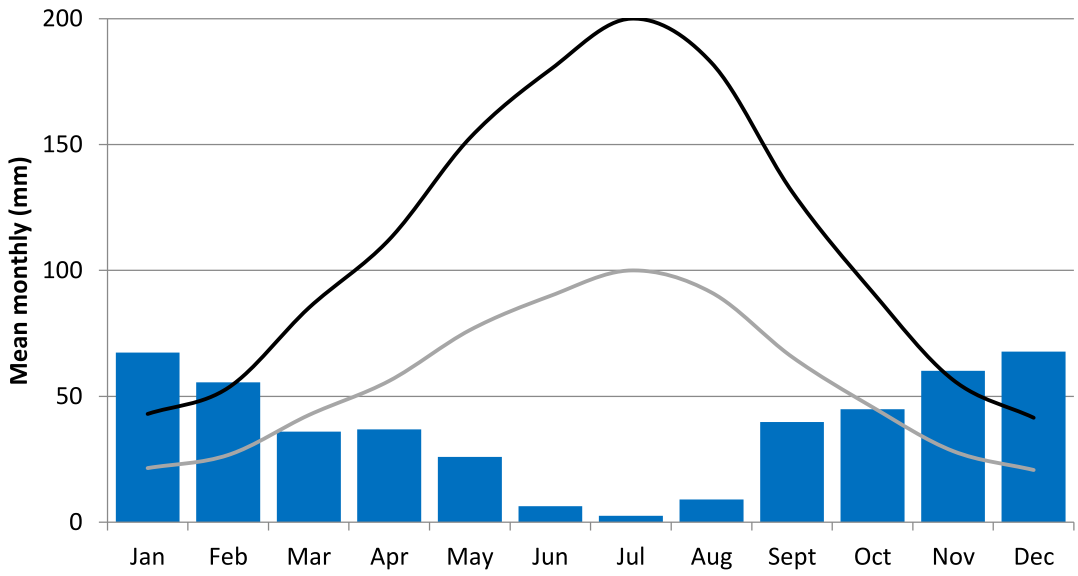


Figure 7.1: Mean monthly rainfall (bars), reference evapotranspiration ET_0 (black line), and $0.5*ET_0$ (grey line) for Tunis in Tunisia for period 1979-2002.

Exercise 7.1: Assessing crop yield for local soils

7.1.1 Assignment

Determine the average winter wheat yield that can be expected in the region of Tunis when soil fertility is non-limiting. Run therefore a series of 23 years of historical weather data (1979-2002). According to local practices, farmers sow wheat at the beginning of the rainy season, assume on 15 October. Assess the yield on a sandy loam soil and on a local soil, for which observed characteristics are presented in Tab 7.1. Assume that on the day of sowing the soil is wetted at the top, but still dry in deeper soil layers.

Table 7.1 – Characteristics of local clay loam soil in Tunis

Soil texture	Thickness (m)	Soil water content (vol%)			Ksat (mm/ day)
		PWP	FC	SAT	
Clay loam	0.3	24	40	50	155
Silt loam	1.7	11	33	46	500

7.1.2 Steps

- Create a new soil file corresponding to the local soil characteristics (*TunisLocal.SOL*)
- Create a project for 23 successive years (*Tun_WW_LocalSoil.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Tunis.CLI*
    - Crop: *WheatGDD.CRO*
    - Sowing date: 15 October
    - Irrigation/field management: rainfed – non limiting soil fertility (=default)
    - Soil file: *TunisLocal.SOL*
    - Start simulation: 15 October (linked to growing cycle)
    - Initial conditions: *WetDry.SW0*
- Run the project and assess yield for every season
- Select the default Sandy Loam soil file in the project (*SandyLoam.SOL*)
- Assure that the correct initial conditions are selected (*WetDry.SW0*)
- Save and run the new project (*Tun_WW_SLSoil.PRM)*

7.1.3 Files

Type	Required files	Created files
Climate	Tunis.CLI	
Crop	WheatGDD.CRO	
Irrigation Management		
Field Management		
Soil profile	SandyLoam.SOL	TunisLocal.SOL
Initial conditions	WetDry.SW0	
Project		Tun_WW_LocalSoil.PRM Tun_WW_SLSoil.PRM

7.1.4 Solution sheet

	Yield (ton/ha)	
Growing season	**Local soil**	**Sandy loam**
1979/1980		
1980/1981		
1981/1982		
1982/1983		
1983/1984		
1984/1985		
1985/1986		
1986/1987		
1987/1988		
1988/1989		
1989/1990		
1990/1991		
1991/1992		
1992/1993		
1993/1994		
1994/1995		
1995/1996		
1996/1997		
1997/1998		
1998/1999		
1999/2000		
2000/2001		
2001/2002		
Average		
St. deviation		

Exercise 7.2: Assessing crop yield for local crop varieties

7.2.1 Assignment

Determine the average winter wheat yield that can be expected in the region of Tunis for a local wheat variety with a long crop cycle when soil fertility is non-limiting. Run therefore a series of 23 years of historical weather data (1979-2002). The long cycle wheat variety emerges 15 days after sowing (DAS), reaches CC_x at 170 DAS, starts senescence at 210 DAS and reaches maturity at 240 DAS. Flowering starts 170 DAS and lasts for 20 days. The wheat is sown at a density of 350 plants/m² and reaches therefore only a CC_x of 90%. According to local practices, farmers sow wheat at the beginning of the rainy season, assume on 15 October. Assess the yield on a sandy loam soil assuming initially a wet topsoil and dry deeper layers at the start of the simulation period.

7.2.2 Steps

- Select the climate of Tunis (*Tunis.CLI*)
- Adjust the default wheat file (*Wheat.CRO*) to match the characteristics of the local wheat variety
- Convert to growing degree days and save as a new crop file (*WheatLongGDD.CRO*)
- Create a project for 23 successive years (*Tun_WW_LongVar.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Tunis.CLI*
    - Crop: *WheatLongGDD.CRO*
    - Sowing date: 15 October
    - Irrigation/field management: rainfed – non limiting soil fertility (=default)
    - Soil file: *SandyLoam.SOL*
    - Start simulation: 15 October (linked to growing cycle)
    - Initial conditions: *WetDry.SW0*
- Run the project and assess yield for every season
- Create a new project (*Tun_WW_NormVar.PRM)* for the other crop file (*WheatGDD.CRO*)

7.2.3 Files

Type	Required files	Created files
Climate	Tunis.CLI	
Crop	Wheat.CRO WheatGDD.CRO	WheatLongGDD.CRO
Irrigation Management		
Field Management		
Soil profile	SandyLoam.SOL	
Initial conditions	WetDry.SW0	
Project		Tun_WW_LongVar.PRM Tun_WW_NormVar.PRM

7.2.4 Solution sheet

	Yield (ton/ha)	
Growing season	**Local variety (long cycle)**	**Default wheat crop**
1979/1980		
1980/1981		
1981/1982		
1982/1983		
1983/1984		
1984/1985		
1985/1986		
1986/1987		
1987/1988		
1988/1989		
1989/1990		
1990/1991		
1991/1992		
1992/1993		
1993/1994		
1994/1995		
1995/1996		
1996/1997		
1997/1998		
1998/1999		
1999/2000		
2000/2001		
2001/2002		
Average		
St. deviation		

Exercise 7.3: Importance of initial conditions

7.3.1 Assignment

Assess the importance of specifying the correct initial conditions for soil water content when simulating rainfed wheat production in 1988/1989 on a sandy loam soil in Tunis. According to local practices, farmers sow wheat on 15 October. Start the simulation at 15 October and assess yield and biomass for 4 different initial conditions at the beginning of the season: (1) Wet topsoil (*WetDry.SW0*); (2) Field capacity; (3) 30% TAW, and (4) 75% TAW.

7.3.2 Steps

- Select the correct soil file (*SandyLoam.SOL*)
- Create 3 initial soil water content files corresponding to the above mentioned options (2-4)
- Save the files as *SL_FC.SW0*, *SL_30%TAW.SW0*, *SL_75%TAW.SW0*
- Select the input files for the local environment and the correct simulation settings
    - Climate: *Tunis.CLI*
    - Crop: *WheatGDD.CRO*
    - Sowing date: 15 October 1988
    - Irrigation/field management: rainfed – non limiting soil fertility (=default)
    - Soil file: *SandyLoam.SOL*
    - Start simulation: 15 October (linked to growing cycle)
    - Initial conditions: one of the four options
- Run the simulation and assess final biomass and yield
- Repeat for each of the initial conditions

7.3.3 Files

Type	Required files	Created files
Climate	Tunis.CLI	
Crop	WheatGDD.CRO	
Irrigation Management		
Field Management		
Soil profile	SandyLoam.SOL	
Initial conditions	WetDry.SW0	SL_FC.SW0 SL_30%TAW.SW0 SL_75%TAW.SW0

7.3.4 Solution sheet

Initial soil water content	Crop production in 1988/1989	
	Biomass (ton/ha)	Yield (ton/ha)
Wet topsoil/Dry subsoil		
Field capacity		
30% TAW		
75% TAW		

Exercise 7.4: Generating planting dates

7.4.1 Assignment

Generate planting dates for winter wheat cultivated in the region of Tunis on a sandy loam soil. Assume that the entire soil profile is at permanent wilting point at the end of the dry season (15 August). Farmers will sow when a total of at least 35 mm of rain falls in 5 successive days, but never before 1 October and never after 31 December. Compare planting dates in which the farmer sows the first time the criterion is fulfilled, with planting dates in which the farmer will wait till the second occurrence. Run a series of 22 years of historical weather data (1979-2002) and determine for each year the planting date (onset) and the corresponding yield, when soil fertility is non-limiting.

7.4.2 Steps

- Select the correct soil file (*SandyLoam.SOL*)
- Create a file describing the initial soil water content (*SL_PWP.SW0*)
- Create a project for 22 successive years (*Tun_WW_Sowdate1.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Tunis.CLI*
    - Crop: *WheatGDD.CRO*
    - Sowing date: generation based on a rainfall criterion using following settings
        - Search window: 1 October -31 December
        - Criterion: 35 mm in 5 days
        - Accept occurrence: first
    - Irrigation/field management: rainfed – non limiting soil fertility (=default)
    - Soil file: *SandyLoam.SOL*
    - Start simulation: 15 August (NOT linked to growing cycle) for each run
    - Initial conditions: *SL_PWP.SW0* for each run
- Assess the sowing dates in the project calendar
- Run the project and assess yield for every season
- Create a new project for the other sowing scenario (2nd occurrence of rainfall criteria) (*Tun_WW_Sowdate2.PRM*)
- Assess the sowing dates in the project calendar and run the new project to assess yield

7.4.3 Files

Type	Required files	Created files
Climate	Tunis.CLI	
Crop	WheatGDD.CRO	
Irrigation Management		
Field Management		
Soil profile	SandyLoam.SOL	
Initial conditions		SL_PWP.SW0
Project		Tun_WW_Sowdate1.PRM Tun_WW_Sowdate2.PRM

7.4.4 Solution sheet

	1st occurrence		2nd occurrence	
Growing season	**Sowing date**	**Yield (ton/ha)**	**Sowing date**	**Yield (ton/ha)**
1979/1980				
1980/1981				
1981/1982				
1982/1983				
1983/1984				
1984/1985				
1985/1986				
1986/1987				
1987/1988				
1988/1989				
1989/1990				
1990/1991				
1991/1992				
1992/1993				
1993/1994				
1994/1995				
1995/1996				
1996/1997				
1997/1998				
1998/1999				
1999/2000				
2000/2001				
Average				
St. deviation				
# Failure years				

Exercise 7.5: Assessing impact of soil fertility management on crop yield

7.5.1 Assignment

Determine the average wheat productivity in the region of Tunis under non limiting soil fertility and on a soil with moderate soil fertility. The crop is sown on a sandy loam soil on 15 October. Assume that on the day of sowing the soil is wetted at the top, but still dry in deeper soil layers. Run a time series of 23 years of historical data (1979-2002) for both soil fertility management scenarios, and determine for each year the expected crop yield and ET water productivity (WP_{ET}).

7.5.2 Steps

- Select the climate of Tunis (*Tunis.CLI*) and correct sowing date and calibrate the crop response (*WheatGDD.CRO*) to soil fertility stress using the default settings
- Save the new crop file as *WheatGDDFert.CRO*
- Create 2 field management files for moderate and non-limiting soil fertility (=default)
- Save the files as *ModFert.MAN* and *NonLimFert.MAN*
- Create a project for 22 successive years (*Tun_WW_NonLimFert.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Tunis.CLI*
    - Crop: *WheatGDDFert.CRO*
    - Sowing date: 15 October
    - Irrigation management: rainfed (=default)
    - Field management: *NonLimFert.MAN*
    - Soil file: *SandyLoam.SOL*
    - Start simulation: 15 October (linked to growing cycle)
    - Initial conditions: *WetDry.SW0* for each run
- Run the project and assess yield and WP_{ET} for every season
- Select a different field management file in the project (*ModFert.MAN*)
- Save and run the new project (*Tun_WW_ModFert.PRM)*

7.5.3 Files

Type	Required files	Created files
Climate	Tunis.CLI	
Crop	WheatGDD.CRO	WheatGDDFert.CRO
Irrigation Management		
Field Management		ModFert.MAN NonLimFert.MAN
Soil profile	SandyLoam.SOL	
Initial conditions	WetDry.SW0	
Project		Tun_WW_NonLimFert.PRM Tun_WW_ModFert.PRM

7.5.4 Solution sheet

	Non limiting soil fertility		Moderate soil fertility	
Growing season	**Yield (ton/ha)**	**WP_{ET} (kg/m³)**	**Yield (ton/ha)**	**WP_{ET} (kg/m³)**
1979/1980				
1980/1981				
1981/1982				
1982/1983				
1983/1984				
1984/1985				
1985/1986				
1986/1987				
1987/1988				
1988/1989				
1989/1990				
1990/1991				
1991/1992				
1992/1993				
1993/1994				
1994/1995				
1995/1996				
1996/1997				
1997/1998				
1998/1999				
1999/2000				
2000/2001				
2001/2002				
Average				
St. deviation				

Exercise 7.6: Net irrigation requirement and potential yield

7.6.1 Assignment

Determine the net irrigation requirement for winter wheat cultivated in the region of Tunis, when soil fertility is non-limiting. According to local practices, farmers sow irrigated wheat at the start of the winter period (1 December) on a sandy loam soil. Assume that the entire soil profile is at permanent wilting point at the end of the dry season (15 August). Run a time series of 22 years of historical data (1979-2002) and determine for each growing season the total net irrigation requirement that ensures a stress free crop development. Assess also the corresponding potential yield levels.

7.6.2 Steps

- Select the correct crop file (*WheatGDD.CRO)*
- Create a net irrigation requirement file that ensure that crop canopy development is never affected by water stress (threshold = 30% RAW)
- Save the net irrigation requirement file as *WheatNetReq.IRR*
- Create a project for 22 successive years (*Tun_WW_NetIrr.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Tunis.CLI*
    - Crop: *WheatGDD.CRO*
    - Sowing date: 1 December
    - Irrigation management: *WheatNetReq.IRR*
    - Field management: Non limiting soil fertility (=default)
    - Soil file: *SandyLoam.SOL*
    - Start simulation: 15 August (NOT linked to growing cycle) for each run
    - Initial conditions: *SL_PWP.SW0* for each run
- Run the project and assess yield and net irrigation requirements for every season

7.6.3 Files

Type	**Required files**	**Created files**
Climate	Tunis.CLI	
Crop	WheatGDD.CRO	
Irrigation Management		WheatNetReq.IRR
Field Management		
Soil profile	SandyLoam.SOL	
Initial conditions	SL_PWP.SW0 (1)	
Project		Tun_WW_NetIrr.PRM

(1) created in a previous exercise (available on the memory stick)

7.6.4 Solution sheet

Growing season	Yield (ton/ha)	Seasonal net irrigation requirement (mm)
1979/1980		
1980/1981		
1981/1982		
1982/1983		
1983/1984		
1984/1985		
1985/1986		
1986/1987		
1987/1988		
1988/1989		
1989/1990		
1990/1991		
1991/1992		
1992/1993		
1993/1994		
1994/1995		
1995/1996		
1996/1997		
1997/1998		
1998/1999		
1999/2000		
2000/2001		
2001/2002		
Average		
St. deviation		

Exercise 7.7: Assess (deficit) irrigation schedules

7.7.1 Assignment

Design a deficit irrigation strategy for wheat production in the region of Tunis. According to local practices, farmers sow irrigated wheat at the start of the winter period (1 December) on a sandy loam soil. Assume that the entire soil profile is at permanent wilting point at the end of the dry season (15 August). Since irrigation water is limited, water is only available i) for a 30 mm at sowing to assure good germination and ii) for 2 irrigations of 40 mm each, later in the season. Sprinkler irrigation systems are common in the region. Run a time series of 22 years of historical data (1979-2002), and assume non-limiting soil fertility. Determine the optimal period to apply irrigation by assessing both yield and ET water productivity (WP_{ET}).

7.7.2 Steps

- Select the correct crop file *(WheatGDD.CRO)*
- Create an irrigation management file (*WheatDeficit.IRR*) to assess an irrigation schedule with following characteristics
    - Irrigation method: Sprinkler
    - Net application depth: 30 mm (fixed at sowing), and 2 applications of 40 mm
    - Try different application dates for the 2 applications of 40 mm
    - Quality of water: Excellent with EC_W = 0dS/m (=default)
- Create a project for 22 successive years (*Tun_WW_Deficit.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Tunis.CLI*
    - Crop: *WheatGDD.CRO*
    - Sowing date: 1 December
    - Irrigation management: *WheatDeficit.IRR*
    - Field management: Non limiting soil fertility (=default)
    - Soil file: *SandyLoam.SOL*
    - Start simulation: 15 August (NOT linked to growing cycle) for each run
    - Initial conditions: *SL_PWP.SW0* for each run
- Run the project and assess crop yield, WP_{ET}, crop development and water stress
- Try different schedules to optimize crop (water) productivity

7.7.3 Files

Type	Required files	Created files
Climate	Tunis.CLI	
Crop	WheatGDD.CRO	
Irrigation Management		WheatDeficit.IRR
Field Management		
Soil profile	SandyLoam.SOL	
Initial conditions	SL_PWP.SW0 (1)	
Project		Tun_WW_Deficit.PRM

(1) created in a previous exercise (available on the memory stick)

7.7.4 Solution sheet

Strategy	Date(s) & Net application depth	Average Yield (ton/ha) & WP_{ET} (kg/m³)	Comments:
1			
2			
3			
4			
5			

Best strategy = ……..

Exercise 7.8: Evaluating simulation results

7.8.1 Assignment

A field experiment was performed in Tunis to evaluate AquaCrop's performance to simulate crop yield of a new wheat variety. Wheat was sown on a sandy loam soil on 17 November 1990. The crop was grown under non limiting soil fertility. Sprinkler irrigation with a net application depth of 30 mm was applied on 1 May, 10 May and 20 May 1991 to prevent water stress affecting crop development or inducing stomatal closure. Assume that the soil was at permanent wilting point at the end of the dry season (15 August). The observed biomass and yield at maturity were 18.9 ton/ha and 9.15 ton/ha respectively. During the growing season, also other field observations were made:

Crop canopy cover (%)			**Dry crop biomass (ton/ha)**			**Soil water content in root zone (0-1.5 m) (mm)**		
Date	**Mean**	**SD**	**Date**	**Mean**	**SD**	**Date**	**Mean**	**SD**
26-11-1990	5	1	15-1-1991	2.7	0.6	26-11-1990	232	4
1-1-1991	40	2	4-2-1991	4.75	0.45	1-1-1991	328	5
4-2-1991	77	2.5	24-2-1991	7.9	0.5	26-1-1991	367	4
5-4-1991	84	3	16-3-1991	10.8	0.75	16-3-1991	295	5
15-5-1991	62	2	5-4-1991	13.05	0.4	5-4-1991	265	6
28-5-1991	33	2	25-4-1991	15.56	0.65	15-5-1991	224	4
			15-5-1991	17.9	0.8			
			4-6-1991	18.9	0.9			

Assess AquaCrop's performance for the growing season of 1990/1991. Is performance satisfactory? If not, what could be the cause? Improve the simulation results. Which additional field observations would be helpful to further improve simulations?

7.8.2 Steps

- Select the correct crop file (*WheatGDD.CRO*)
- Create an irrigation management file (*ObservedSchedule.IRR*) that matches the observed irrigation schedule
- Create a field data file containing above listed observations *(Tunis9091.OBS)*
- Select the input files for the local environment and correct simulation settings
    - Climate: *Tunis.CLI*
    - Crop: *WheatGDD.CRO*
    - Sowing date: 17 November 1990
    - Irrigation management: *ObservedSchedule.IRR*
    - Field management: non limiting soil fertility (=default)
    - Soil file: *SandyLoam.SOL*
    - Start simulation: 15 August (not linked to growing cycle)
    - Initial conditions: *SL_PWP.SW0*
- Run the simulation and evaluate the simulation results by looking at the graphs and goodness-of fit statistics
- Proper tune the crop parameters (CC_0, CC_x, length of crop cycle) to improve simulations and save the tuned file as *WheatGDDTuned.CRO*
- Assess the final simulation results by looking at the graphs and goodness-of fit statistics

7.8.3 Files

Type	Required files	Created files
Climate	Tunis.CLI	
Crop	WheatGDD.CRO	WheatGDDTuned.CRO
Irrigation Management		ObservedSchedule.IRR
Field Management		
Soil profile	SandyLoam.SOL	
Initial conditions	SL_PWP.SW0 (1)	
Field data		Tunis9091.OBS

(1) created in a previous exercise (available on the memory stick)

7.8.4 Solution sheet

☐ **Evaluation of first simulation**

	Wr	**CC**	**B season**
r (-)			
CV(RMSE) (%)			
EF (-)			
d (-)			
Comments:			

Observed final biomass:……ton/ha versus simulated final biomass:…… ton/ha
Observed final yield:……ton/ha versus simulated final yield:…… ton/ha

☐ **Evaluation of final simulation ("best result")**

	Wr	**CC**	**B season**
r (-)			
CV(RMSE) (%)			
EF (-)			
d (-)			
Comments:			

Observed final biomass:……ton/ha versus simulated final biomass:…… ton/ha
Observed final yield:……ton/ha versus simulated final yield:…… ton/ha

Chapter 8. Cereal production in Hyderabad

Introduction

This set of exercises will assess the average cereal production that can be expected in the region of Hyderabad (India) under different environmental conditions and agronomic practices (local crop varieties, soils, management). Both rainfed rice and irrigated wheat production will be evaluated.

Hyderabad is located in central India (17°27'N, 78°27'E, 545 m.a.s.l.) and has a dry subhumid climate (Fig. 8.1). Rainfed crops are cultivated in the Kharif season, between June and September. Irrigated crops, are cultivated during the Rabi season, from October to spring.

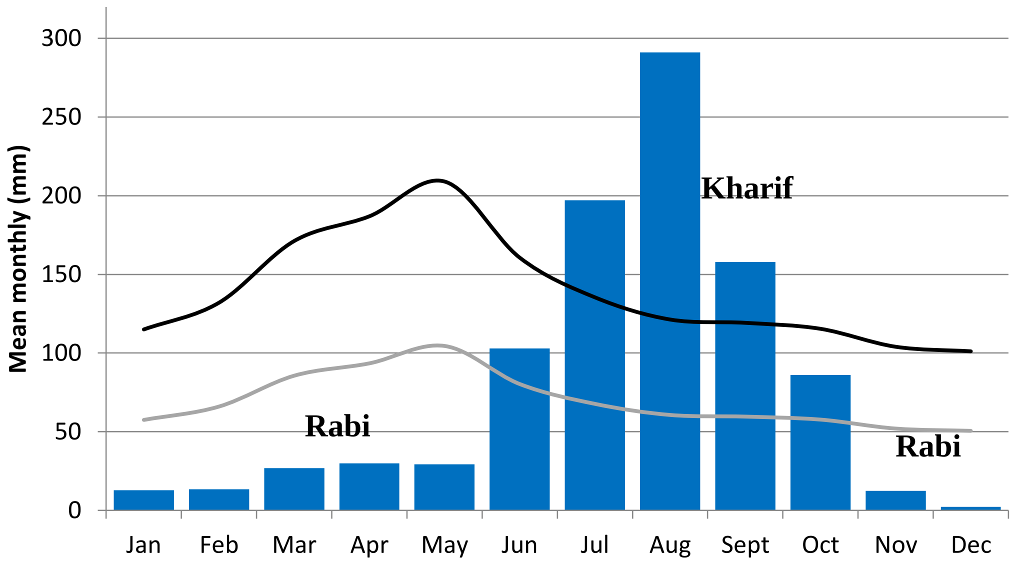


Figure 8.1 – Mean monthly rainfall (bars), reference evapotranspiration ET_0 (black line), and $0.5*ET_0$ (grey line) in Hyderabad in India for period 2000-2010.

Exercise 8.1: Importing local daily climatic data

8.1.1 Assignment

Create an AquaCrop climate file describing the local climate for the area of Hyderabad. Use the climatic data measured at the weather station of Hyderabad Airport (17°27´ N, 78°27´ E, 545 m.a.s.l.). Daily observations are available from 1 January 2000 to 31 December 2010 and include rainfall (mm), minimum and maximum air temperature (°C), sunshine hours (h) and wind speed measured 2 m above the soil surface (m/s).

8.1.2 Steps

- Create a textfile (*Hyderabad.txt*) that contains daily climatic data organized in 5 columns:
  - Rainfall (mm)
  - Minimum air temperature (°C)
  - Maximum air temperature (°C)
  - Sunshine hours (h)
  - Windspeed (m/s)
- Import the data of *Hyderabad.txt* into an AquaCrop ET_0, rainfall and temperature file
- Save these files as *Hyderabad.ETo, Hyderabad.PLU, Hyderabad.Tnx*
- Create an overall climate file containing the new ET0, rainfall and temperature files together with the default CO_2 file (*MaunaLoa.CO2*).
- Save this climate file as *Hyderabad.CLI*

8.1.3 Files

Available on memory stick:

Type	Required files	Created files
Climate	Climatic_data_Hyderabad(2000-2010).xls (1) MaunaLoa.CO2	Hyderabad.txt Hyderabad.ETo, Hyderabad.PLU, Hyderabad.Tnx Hyderabad.CLI

(1) available on the memory stick

Exercise 8.2: Evaluating planting dates for local rice variety

8.2.1 Assignment

Determine the average rice yield that can be expected in the region of Hyderabad during the Kharif season, when soil fertility is non-limiting. According to local practices, farmers transplant the rice on a paddy soil with bunds of 20 cm in the mid-monsoon season, assume on 1 August. Some farmers also practice early transplanting, assume on 15 July. The local rice variety is characterized by a crop cycle of 105 days. Under optimal conditions, plants recover 6 days after transplanting (DAP), reach maximum canopy cover at 60 DAP and start senescence at 90 DAP. Compare the rice yield that can expected for both transplanting strategies (1 August versus 15 July) for the period 2000-2010.

8.2.2 Steps

- Select the climate of Hyderabad (*Hyderabad.CLI*) and the correct sowing date
- Adjust the default rice file (*PaddyRice.CRO*) to match the characteristics of the local rice variety
- Convert to growing degree days and save as a new crop file (*LocalPaddyRiceGDD.CRO*)
- Create a field management file for bunds of 0.2 m (*Bunds20.MAN*)
- Create a project for 10 successive years (*Hyd_Rice_1Aug.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Hyderabad.CLI*
    - Crop: *LocalPaddyRiceGDD.CRO*
    - Sowing date: 1 August
    - Irrigation management: rainfed (=default)
    - Field management: *Bunds20.MAN*
    - Soil file: *Paddy.SOL*
    - Start simulation: 1 August (linked to growing cycle)
    - Initial conditions: field capacity (=default)
- Run the project and assess yield for every season
- Create a new project for 10 successive years with the other transplanting date (15 July) (*Hyd_Rice_15Jul.PRM)*
- Run the project and assess yield for every season

8.2.3 Files

Type	**Required files**	**Created files**
Climate	Hyderabad.CLI [(1)]	
Crop	PaddyRice.CRO	LocalPaddyRiceGDD.CRO
Irrigation Management		
Field Management		Bunds20.MAN
Soil profile	Paddy.SOL	
Initial conditions		
Project		Hyd_Rice_1Aug.PRM Hyd_Rice_15Jul.PRM

[(1)] created in a previous exercise (available on the memory stick)

8.2.4 Solution sheet

	Crop yield (ton/ha)	
Growing season	**Mid-monsoon transplanting**	**Early transplanting**
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		
2009		
2010		
Average		
St. Deviation		

Exercise 8.3: Importance of initial conditions

8.3.1 Assignment

Assess the importance of specifying the correct initial conditions for soil water content when simulating rainfed rice production in 2002 in Hyderabad, when soil fertility is non-limiting. According to local practices, farmers transplant the local rice variety in the mid-monsoon season, assume on 1 August. Rice is grown on a paddy soil with bunds of 20 cm surrounding the field. Start the simulation on 1 August and assess yield and biomass for 4 initial conditions at the beginning of the season: (1) Field capacity (=default); (2) 30%TAW; (3) 75%TAW; and (4) Field capacity for topsoil (0-0.5m), and 30 vol% for deeper soil layers (0.5-2 m).

8.3.2 Steps

- Select the correct soil file (*Paddy.SOL*)
- Create 3 initial soil water content files corresponding to the above mentioned options (2-4)
- Save the files as *Paddy_30%TAW.SW0*, *Paddy_75%TAW.SW0, Paddy_WetTop.SW0*
- Select the input files for the local environment and correct simulation settings
    - Climate: *Hyderabad.CLI*
    - Crop: *LocalPaddyRiceGDD.CRO*
    - Sowing date: 1 August 2002
    - Irrigation management: rainfed (=default)
    - Field management: *Bunds20.MAN*
    - Soil file: *Paddy.SOL*
    - Start simulation: 1 August
    - Initial conditions: one of the four options
- Run the simulation and assess final biomass and yield
- Repeat for the other potential initial conditions

8.3.3 Files

Type	Required files	Created files
Climate	Hyderabad.CLI (1)	
Crop	LocalPaddyRiceGDD.CRO (1)	
Field Management	Bunds20.MAN (1)	
Soil profile	Paddy.SOL	
Initial conditions		Paddy_30%TAW.SW0, Paddy_75%TAW.SW0, Paddy_WetTop.SW0

(1) created in a previous exercise (available on the memory stick)

8.3.4 Solution sheet

Initial soil water content	Crop production in 2002	
	Biomass (ton/ha)	**Yield (ton/ha)**
Field capacity		
30% TAW		
75% TAW		
Wet topsoil		

Exercise 8.4: Crop response to soil fertility stress

8.4.1 Assignment

Determine the rice productivity in the region of Hyderabad in the year 2002 for five different levels of soil fertility ranging from non-limiting to very poor. According to local practices, farmers transplant the local rice on a paddy soil with bunds of 20 cm in the mid-monsoon season, assume on 1 August. In a field experiment it was observed that in a fertility stressed, irrigated field where only 75% of the potential biomass could be produced, the maximum canopy cover was slightly reduced to 70%. Moreover, there was a medium canopy decline in the season due to soil fertility stress. Compare the expected rice yield and biomass for non-limiting, near optimal, moderate, poor, and very poor soil fertility.

8.4.2 Steps

- Select the climate of Hyderabad (*Hyderabad.CLI*) and the correct sowing date
- Calibrate the crop response (*LocalPaddyRiceGDD.CRO*) to soil fertility stress using following settings:
    - Relative biomass: 75%
    - CC_x: slightly reduced, 70%
    - Canopy decline in season: medium
- Save the new crop file as *LocalPaddyRiceGDDFert.CRO*
- Create 5 field management files that all have soil bunds of 0.2 m, and correspond to the five soil fertility scenarios mentioned above.
- Save the files as *Bunds20_NonLimFert.MAN*, *Bunds20_NearOptFert.MAN*, *Bunds20_ModFert.MAN*, *Bunds20_PoorFert.MAN*, *Bunds20_VeryPoorFert.MAN*
- Select the input files for the local environment and correct simulation settings
    - Climate: *Hyderabad.CLI*
    - Crop: *LocalPaddyRiceGDDFert.CRO*
    - Sowing date: 1 August 2002
    - Irrigation management: rainfed (=default)
    - Field management: one of the five options
    - Soil file: *Paddy.SOL*
    - Start simulation: 1 August (linked to growing cycle)
    - Initial conditions: field capacity (=default)
- Run the simulation and assess final biomass and yield
- Repeat for the other soil fertility levels

8.4.3 Files

Type	Required files	Created files
Climate	Hyderabad.CLI (1)	
Crop	LocalPaddyRiceGDD.CRO (1)	LocalPaddyRiceGDDFert.CRO
Field Management		Bunds20_NonLimFert.MAN, Bunds20_NearOptFert.MAN, Bunds20_ModFert.MAN, Bunds20_PoorFert.MAN, Bunds20_VeryPoorFert.MAN
Soil profile	Paddy.SOL	

(1) created in a previous exercise (available on the memory stick)

8.4.4 Solution sheet

Soil fertility level		Crop production in 2002	
Class	**Relative biomass (%)**	**Biomass (ton/ha)**	**Yield (ton/ha)**
Non-limiting	100		
Near optimal	80		
Moderate	60		
Poor	40		
Very poor	25		

Exercise 8.5: Assessing impact of soil fertility management on crop yield

8.5.1 Assignment

Determine the average rice productivity in the region of Hyderabad under non limiting soil fertility and on a soil with moderate soil fertility. The local rice variety is cultivated on a paddy soil with bunds of 0.2 m, and responds to soil fertility stress as defined in exercise 8.4. Farmers transplant rice between 10 July and 20 August, under the condition that at least 35 mm of cumulated rainfall was received over 5 successive days (2^{nd} occurrence). At the end of the Rabi season (1 May) the soil is at permanent wilting point. Run a time series of 11 years of historical data (2000-2010) for both soil fertility management scenarios, and determine for each year the expected crop yield and ET water productivity (WP_{ET}).

8.5.2 Steps

- Select the correct soil file (*Paddy.SOL*)
- Create an initial soil water content file for the paddy soil at permanent wilting point (*Paddy_PWP.SW0*)
- Create a project for 11 successive years (*Hyd_Rice_NonLimFert.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Hyderabad.CLI*
    - Crop: *LocalPaddyRiceGDDFert.CRO*
    - Sowing date: generation based on a rainfall criteria using following settings
        - Search window: 10 July - 20 August
        - Criteria: 35 mm in 5 days
        - Accept occurrence: second
    - Irrigation management: rainfed (=default)
    - Field management: *Bunds20_NonLimFert.MAN*
    - Soil file: *Paddy.SOL*
    - Start simulation: 1 May (NOT linked to growing cycle) for each run
    - Initial conditions: *Paddy_PWP.SW0* for each run
- Run the project and assess yield and WP_{ET} for every season
- Select a different field management file in the project *Bunds20_ModFert.MAN*
- Save and run the new project (*Hyd_Rice_ModFert.PRM)*

8.5.3 Files

Type	Required files	Created files
Climate	Hyderabad.CLI [1]	
Crop	LocalRiceGDDFert.CRO [1]	
Field Management	Bunds20_NonLimFert.MAN [1] Bunds20_ModFert.MAN [1]	
Soil profile	Paddy.SOL	
Initial conditions		Paddy_PWP.SW0
Project		Hyd_Rice_ModFert.PRM Hyd_Rice_NonLimFert.PRM

[1] created in a previous exercise (available on the memory stick)

8.5.4 Solution sheet

	Non limiting soil fertility		Moderate soil fertility	
Growing season	**Yield (ton/ha)**	**WP_{ET} (kg/m³)**	**Yield (ton/ha)**	**WP_{ET} (kg/m³)**
2000				
2001				
2002				
2003				
2004				
2005				
2006				
2007				
2008				
2009				
2010				
Average				
St. deviation				

Exercise 8.6: Net irrigation requirement and potential yield for local wheat variety

8.6.1 Assignment

Determine the net irrigation requirement for wheat grown during the Rabi season in the region of Hyderabad. According to local practices, farmers sow irrigated wheat on a clay loam soil on 1 November. The local wheat variety emerges 10 days after sowing (DAS) and reaches maximum canopy cover 50 DAS. Flowering is observed 90 DAS. The variety is characterised by natural senescence starting around 115 DAS while maturity is reached 130 DAS. The reference harvest index is 45% and the maximum rooting depth 1 m. Assume that in the late monsoon season (1 September) the total soil is at field capacity, and that soil fertility is non-limiting. Run a time series of 10 years of historical data (2000-2010) and determine for each year the total net irrigation requirement that ensures a stress free crop development. Assess also the corresponding potential yield levels.

8.6.2 Steps

- Select the climate of Hyderabad (*Hyderabad.CLI*) and the correct sowing date
- Adjust the default wheat file (*Wheat.CRO*) to match the characteristics of the local rice variety
- Convert to growing degree days and save as a new crop file (*Hyderabad_WheatGDD.CRO*)
- Select the correct crop file (*Hyderabad_WheatGDD.CRO)*
- Create a net irrigation requirement file that ensure that crop canopy development is never affected by water stress (threshold = 30% RAW)
- Save the net irrigation requirement file as *WheatNetReq.IRR*
- Create a project for 10 successive years (*Hyd_W_NetIrr.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Hyderabad.CLI*
    - Crop: *Hyderabad_WheatGDD.CRO*
    - Sowing date: 1 November
    - Irrigation management: *WheatNetReq.IRR*
    - Field management: Non limiting soil fertility (=default)
    - Soil file: *ClayLoam.SOL*
    - Start simulation: 1 September (NOT linked to growing cycle) for each run
    - Initial conditions: field capacity (=default) for each run
- Run the project and assess yield and net irrigation requirements for every season

8.6.3 Files

Type	Required files	Created files
Climate	Hyderabad.CLI (1)	
Crop	Wheat.CRO	Hyderabad_WheatGDD.CRO
Irrigation Management		WheatNetReq.IRR
Field Management		
Soil profile	ClayLoam.SOL	
Initial conditions		
Project		Hyd_W_NetIrr.PRM

(1) created in a previous exercise (available on the memory stick)

8.6.4 Solution sheet

Growing season	Yield (ton/ha)	Seasonal Net Irrigation requirement (mm)
2000/2001		
2001/2002		
2002/203		
2003/2004		
2004/2005		
2005/2006		
2006/2007		
2007/2008		
2008/2009		
2009/2010		
Average		
St. Deviation		

Exercise 8.7: Irrigation requirement in the presence of a shallow groundwater table

8.7.1 Assignment

Assess the effect of a shallow groundwater table on the irrigation requirement in the region of Hyderabad during the Rabi season. A local wheat variety is sown on 1 November on a clay loam soil. Assume that in the late monsoon season (1 September) the total soil is at field capacity and soil fertility is non-limiting. Farmers prefer to irrigate wheat so that no water stress occurs, but there is limited access to irrigation water. Fortunately, the area has a shallow groundwater table. In field A the groundwater table is at 2 m depth, while in field B the groundwater table is at 1 m depth. Run a time series of 10 years of historical data (2000-2010) for both groundwater table depths, and determine for each year the expected crop yield and net irrigation requirement. How much irrigation water can the farmers save due to the supply of the groundwater? Which farmer benefits most? Compare with the net irrigation requirements of exercise 8.6.

8.7.2 Steps

- Create two groundwater table files with a constant depth at 1 m and 2 m below the soil surface
- Save the files as *Groundwater_1m.GWT* and *Groundwater_2m.GWT*
- Create a project for 10 successive years (*Hyd_W_NetIrr_GW2m.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Hyderabad.CLI*
    - Crop: *Hyderabad_WheatGDD.CRO*
    - Sowing date: 1 November
    - Irrigation management: *WheatNetReq.IRR*
    - Field management: Non limiting soil fertility (=default)
    - Soil file: *ClayLoam.SOL*
    - Groundwater: *Groundwater_2m.GWT*
    - Start simulation: 1 September (NOT linked to growing cycle) for each run
    - Initial conditions: field capacity (=default) for each run
- Run the project and assess yield and net irrigation requirements for every season
- Select a different field management file in the project (*Groundwater_1m.GWT)*
- Save and run the new project (*Hyd_W_NetIrr_GW1m.PRM)*

8.7.3 Files

Type	Required files	Created files
Climate	Hyderabad.CLI [(1)]	
Crop	Hyderabad_WheatGDD.CRO [(1)]	
Irrigation Management	WheatNetReq.IRR [(1)]	
Soil profile	ClayLoam.SOL	
Groundwater table		Groundwater_1m.GWT Groundwater_2m.GWT
Initial conditions		
Project		Hyd_W_NetIrr_GW1m.PRM Hyd_W_NetIrr_GW2m.PRM

[(1)] created in a previous exercise (available on the memory stick)

8.7.4 Solution sheet

	Field A (groundwater at 2 m)		Field B (groundwater at 1 m)	
Growing season	**Seasonal capillary rise (mm)**	**Seasonal net irrigation requirements (mm)**	**Seasonal capillary rise (mm)**	**Seasonal net irrigation requirements (mm)**
2000/2001				
2001/2002				
2002/203				
2003/2004				
2004/2005				
2005/2006				
2006/2007				
2007/2008				
2008/2009				
2009/2010				
Average				
St. deviation				

Chapter 9. Potato production in Brussels

Introduction

This set of exercises will assess the crop production that can be expected in the region of Brussels (Belgium) under different environmental conditions and agronomic practices (local crop varieties, soils, management). Both rainfed and irrigated crop production will be evaluated, for historical as well as future climatic conditions.

Brussels is located in central Belgium (50°N, 4°E, 180 m.a.s.l.) and has a humid climate (Fig. 9.1). Crop production is mostly determined by the temperatures which are warm in summer, but can drop below zero in winter. Crop production is mostly rainfed, since rainfall occurs throughout the year. However, in summer some farmers irrigate their fields to assure maximal yield levels. By 2050, [CO_2] levels and temperatures are expected to rise in Belgium. Moreover, summers will be slightly drier, while more precipitation is expected during winter.

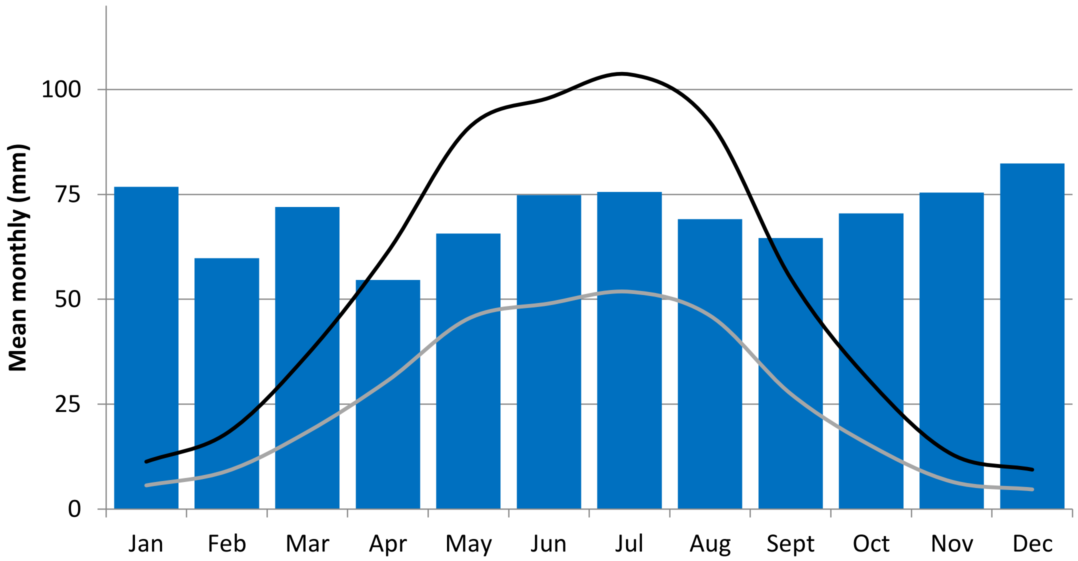


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Figure 9.1 – Mean monthly rainfall (bars), reference evapotranspiration ET_0 (black line), and 0.5*ET_0 (grey line) in Brussels in Belgium for period 1976-2005.

Exercise 9.1: Assessing crop yield for local crop varieties

9.1.1 Assignment

Determine the average potato yield (dry matter) that can be expected in the region of Brussels for a local potato variety, when soil fertility is non-limiting. Run therefore a series of 21 years of historical weather data (1985-2005). The local potato variety is characterized by the following growing stages: emergence = 15 Days after transplanting (DAT), maximum canopy cover = 75 DAT, senescence = 105 DAT, maturity = 125 DAT. The maximal rooting depth of 0.60 m is reached after 50 DAT and the harvest index of the crop is 85%. According to local practices, farmers transplant potato after the winter, assume on 25 April. Assess the yield on a loam soil, as well as the temperature stress experienced by the crop.

9.1.2 Steps

- Select the climate of Brussels (*Bru76-05.CLI*)
- Adjust the default potato file (*Potato.CRO*) to match the characteristics of the local potato variety. Select the right sowing date (25 april 1985).
- Convert to growing degree days and save as a new crop file (*PotatoBrusselsGDD.CRO*)
- Create a project for 21 successive years (*Bru_Pot.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Bru76-05.CLI*
    - Crop: *PotatoBrusselsGDD.CRO*
    - Sowing date: 25 April, start at year: 1985
    - Irrigation/field management: rainfed – non limiting soil fertility (=default)
    - Soil file: *Loam.SOL*
    - Start simulation: 25 April (linked to growing cycle)
    - Initial conditions: Field capacity (=default)
- Run the project and assess yield for every season

9.1.3 Files

Type	Required files	Created files
Climate	Bru76-05.CLI	
Crop	Potato.CRO	PotatoBrusselsGDD.CRO
Irrigation Management		
Field Management		
Soil profile	Loam.SOL	
Initial conditions		
Project		Bru_Pot.PRM

9.1.4 Solution sheet

Growing season	Yield (ton/ha)
1985	
1986	
1987	
1988	
1989	
1990	
1991	
1992	
1993	
1994	
1995	
1996	
1997	
1998	
1999	
2000	
2001	
2002	
2003	
2004	
2005	
Average	
St. deviation	

Exercise 9.2: Generating planting dates

9.2.1 Assignment

Determine the appropriate date for transplanting a local potato cultivar in the region of Brussels on a loam soil. Assume that the entire soil profile is at field capacity at the end of the winter (1 March), and that soil fertility is non-limiting. Farmers never plant before 1 April and wait until the daily average temperature in a 7-day period is at least 8°C. Accept the first occurrence. Run a series of 21 years of historical weather data (1985-2005) and determine for each year an appropriate planting date and the corresponding yield.

9.2.2 Steps

- Create a project for 21 successive years (*Bru_Pot_Sowingdate.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Bru76-05.CLI*
    - Crop: *PotatoBrusselsGDD.CRO*
    - Sowing date: generation based on a temperature criteria using following settings
        - Start at year 1985
        - Search window: 1 April - 1 August
        - Criterion: daily average temperature in 7-day period at least 8°C
        - Accept occurrence: first
    - Irrigation/field management: rainfed – non limiting soil fertility (=default)
    - Soil file: *Loam.SOL*
    - Start simulation: 1 March (NOT linked to growing cycle) for each run
    - Initial conditions: field capacity (=default) for each run
- Assess the sowing dates in the project calendar
- Run the project and assess yield for every season

9.2.3 Files

Type	**Required files**	**Created files**
Climate	Bru76-05.CLI	
Crop	PotatoBrusselsGDD.CRO [1]	
Irrigation Management		
Field Management		
Soil profile	Loam.SOL	
Initial conditions		
Project		Bru_Pot_Sowingdate.PRM

[1] created in a previous exercise (available on the memory stick)

9.2.4 Solution sheet

Growing season	Planting date	Yield (ton/ha)
1985		
1986		
1987		
1988		
1989		
1990		
1991		
1992		
1993		
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
Average		
St. deviation		
# failure years		

Exercise 9.3: Crop response to soil fertility stress

9.3.1 Assignment

Determine the average productivity of potato cultivated in the region of Brussels on a loam soil with non-limiting soil fertility as compared to a situation with near optimal soil fertility. Assume that the entire soil profile is at field capacity at the end of the winter (1 March). According to local practices, farmers never plant before 1 April and wait until the daily average temperature in a 7-day period is at least 8°C. Furthermore, it is observed that on a fertility stressed field where only 75% of the potential biomass can be produced, the maximum canopy cover is reduced to 70% and there is a medium decline of canopy in the season. Run a time series of 21 years of historical data (1985-2005) for both soil fertility management scenarios, and determine for each year the expected crop yield and ET water productivity (WP_{ET}).

9.3.2 Steps

- Calibrate the crop response (*PotatoBrusselsGDD.CRO*) to soil fertility stress using following settings: 75 % Relative biomass; CC_x = 70%; medium canopy decline in season
- Save the new crop file as *PotatoBrusselsGDDFert.CRO*
- Create 2 field management files that correspond to the two soil fertility scenarios
- Save the files as *NonLimFert.MAN*, *NearOptFert.MAN*,
- Create a project for 21 successive years (*Bru_Pot_NonLimFert.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Bru76-05.CLI*
    - Crop: *PotatoBrusselsGDDFert.CRO*
    - Sowing date: generation based on a temperature criteria using following settings
        - Start at year 1985
        - Search window: 1 April - 1 August
        - Criteria: daily average temperature in 7-day period at least 8°C
        - Accept occurrence: first
    - Irrigation management: rainfed (=default)
    - Field management: *NonLimFert.MAN*
    - Soil file: *Loam.SOL*
    - Start simulation: 1 March (NOT linked to growing cycle) for each run
    - Initial conditions: field capacity (=default) for each run
- Run the project and assess yield and WP_{ET} for every season
- Select a different field management file in the project *Bru_Pot_NonLimFert.MAN*
- Save and run the new project (*Bru_Pot_NearOptFert.PRM)*

9.3.3 Files

Type	Required files	Created files
Climate	Bru76-05.CLI	
Crop	PotatoBrusselsGDD.CRO [(1)]	PotatoBrusselsGDDFert.CRO
Field Management		NonLimFert.MAN NearOptFert.MAN
Soil profile	Loam.SOL	
Project		Bru_Pot_NearOptFert.PRM Bru_Pot_NonLimFert.PRM

[(1)] created in a previous exercise (available on the memory stick)

9.3.4 Solution sheet

	Non limiting soil fertility		Near optimal soil fertility	
Growing season	Yield (ton/ha)	WP_{ET} (kg/m³)	Yield (ton/ha)	WP_{ET} (kg/m³)
1985				
1986				
1987				
1988				
1989				
1990				
1991				
1992				
1993				
1994				
1995				
1996				
1997				
1998				
1999				
1998				
1999				
2000				
2001				
2002				
2003				
2004				
2005				
Average				
St. deviation				

Exercise 9.4: Net irrigation requirement and potential yield

9.4.1 Assignment

Determine the net irrigation requirement for potato in the region of Brussels on a loam soil. According to local practices, farmers transplant the local potato variety on 25 April after the winter period. Assume that the entire soil profile is at field capacity at the end of the winter (1 March), and that soil fertility is non-limiting. Run a time series of 21 years of historical data (1985-2005) and determine for each year the seasonal net irrigation requirement that ensures a stress free crop development. Assess also the corresponding potential yield levels.

9.4.2 Steps

- Select the correct crop file (*PotatoBrusselsGDD.CRO*)
- Create a net irrigation requirement file that ensure that crop canopy development is never affected by water stress (threshold = 35% RAW)
- Save the net irrigation requirement file as *PotatoNetReq.IRR*
- Create a project for 21 successive years (*Bru_Pot_NetIrr.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Bru76-05.CLI*
    - Crop: *PotatoBrusselsGDD.CRO*
    - Sowing date: 25 April
    - Start on year 1985
    - Irrigation management: *PotatoNetReq.IRR*
    - Field management: non limiting soil fertility (=default)
    - Soil file: *Loam.SOL*
    - Start simulation: 1 March (NOT linked to growing cycle) for each run
    - Initial conditions: Field capacity (=default) for each run
- Run the project and assess yield and net irrigation requirements for every season

9.4.3 Files

Type	Required files	Created files
Climate	Bru76-05.CLI	
Crop	PotatoBrusselsGDD.CRO (1)	
Irrigation Management		PotatoNetReq.IRR
Field Management		
Soil profile	Loam.SOL	
Initial conditions		
Project		Bru_Pot_NetIrr.PRM

(1) created in a previous exercise (available on the memory stick)

9.4.4 Solution sheet

Growing season	Yield (ton/ha)	Seasonal net irrigation requirement (mm)
1985		
1986		
1987		
1988		
1989		
1990		
1991		
1992		
1993		
1994		
1995		
1996		
1997		
1998		
1999		
2000		
2001		
2002		
2003		
2004		
2005		
Average		
St. deviation		

Exercise 9.5: Generating irrigation schedules

9.5.1 Assignment

Evaluate different irrigation strategies for potato in the region of Brussels cultivated on a light loamy sand soil. The crop is irrigated with a travel gun (sprinkler) applying a net depth of 15 mm. Irrigations are applied when (i) 36 % of RAW is depleted (to avoid any water stress), (ii) 100% of RAW is depleted (to avoid stomatal closure), and (iii) 150 % of RAW is depleted (to reduce labour cost of irrigation). According to local practices, farmers transplant the local potato variety on 25 April after the winter period. Assume that the entire soil profile is at field capacity at the end of the winter (1 March), and that soil fertility is non-limiting. Run a time series of 21 years of historical data (1985-2005) and determine for each year the total number of irrigation applications, the potato yield, and the ET water productivity (WP_{ET}).

9.5.2 Steps

- Select the correct crop file (*PotatoBrusselsGDD.CRO*)
- Create an irrigation schedule file, with 'sprinkler' as irrigation method, with 'fixed application depth' of 15 mm as depth criterion, and
    - 36% of RAW as 'allowable depletion' for time criterion (*Pot36RAW.IRR*)
    - 100% of RAW as 'allowable depletion' for time criterion (*Pot100RAW.IRR*)
    - 150% of RAW as 'allowable depletion' for time criterion (*Pot150RAW.IRR*)
- Create a project for 21 successive years specifying the local environment and the correct simulation settings:
    - Climate: *Bru76-05.CLI*
    - Crop: *PotatoBrusselsGDD.CRO*
    - Sowing date: 25 April
    - Start on year 1985
    - Irrigation management: *Pot36RAW.IRR*
    - Field management: non limiting soil fertility (=default)
    - Soil file: *LoamySand.SOL*
    - Start simulation: 1 March (NOT linked to growing cycle) for each run
    - Initial conditions: Field capacity (=default) for each run
- Save (*Bru_Pot_Irr36RAW.PRM*) and run the project
- Select a different irrigation management file (*Pot100RAW.IRR)* applicable to all runs, save the project as *Bru_Pot_Irr100RAW.PRM*, and run the project
- Select a different irrigation management file (*Pot150RAW.IRR)* applicable to all runs, save the project as *Bru_Pot_Irr150RAW.PRM* and run the project
- Asses for each of the three different irrigation strategies (projects) and for every season, the number of irrigation applications, potato yield and WP_{ET}

9.5.3 Files

Type	Required files	Created files
Climate	Bru76-05.CLI	
Crop	PotatoBrusselsGDD.CRO (1)	
Irrigation Management		Pot36RAW.IRR; Pot100RAW.IRR; Pot150RAW.IRR
Soil profile	LoamySand.SOL	
Project		Bru_Pot_Irr36RAW.PRM Bru_Pot_Irr100RAW.PRM Bru_Pot_Irr150RAW.PRM

(1) created in a previous exercise (available on the memory stick)

9.5.4 Solution sheet

Growing season	36% RAW			100% RAW			150% RAW		
	# Irr	Yield	WP_{ET}	# Irr	Yield	WP_{ET}	# Irr	Yield	WP_{ET}
	(-)	ton/ha	kg/m^3	(-)	ton/ha	kg/m^3	(-)	ton/ha	kg/m^3
1985									
1986									
1987									
1988									
1989									
1990									
1991									
1992									
1993									
1994									
1995									
1996									
1997									
1998									
1999									
2000									
2001									
2002									
2003									
2004									
2005									
Average									
St. Dev									

Exercise 9.6: Assessing the impact of climate change

9.6.1 Assignment

Assess the impact of climate change on potato production in the region of Brussels. Assume that in 2050 farmers will still apply the same local practices, and transplant the local potato variety on 25 April after the winter period on a loam soil. Assume that the entire soil profile is at field capacity at the end of the winter (1 March), and that soil fertility is non-limiting. Run a climate series of 30 year that represents the climate that is expected for 2050. Compare average seasonal rainfall, ET_0 and crop yield for 2050, with the average value obtained from a historical time series of 30 years (1976-2005). Which cropping or management practices would help farmers optimize crop production in the future?

9.6.2 Steps

- Create a project for 30 successive years (*Bru_Pot_Historical.PRM*) specifying the local environment and the correct simulation settings:
    - Climate: *Bru76-05.CLI*
    - Crop: *PotatoBrusselsGDD.CRO*
    - Sowing date: 25 April
    - Irrigation/field management: rainfed – non limiting soil fertility (=default)
    - Soil file: *Loam.SOL*
    - Start simulation: 1 March (NOT linked to growing cycle) for each run
    - Initial conditions: Field capacity (=default) for each run
- Run the project and assess rainfall, ET_0 and yield for every season
- Create a new project of 30 successive year (*Bru_Pot_Future.PRM*) for the future climate *Brussels2050.CLI*
- Run the new project and assess rainfall, ET_0 and yield for every season for each run representing the year 2050

9.6.3 Files

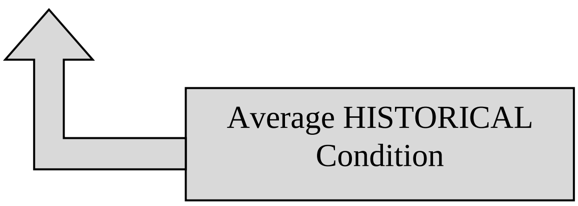
Type	Required files	Created files
Climate	Bru76-05.CLI (2) Brussels2050.CLI (2)	
Crop	PotatoBrusselsGDD.CRO (1)	
Irrigation Management		
Field Management		
Soil profile	Loam.SOL	
Initial conditions		
Project		Bru_Pot_Historical.PRM Bru_Pot_Future.PRM

(1) created in a previous exercise (available on the memory stick)

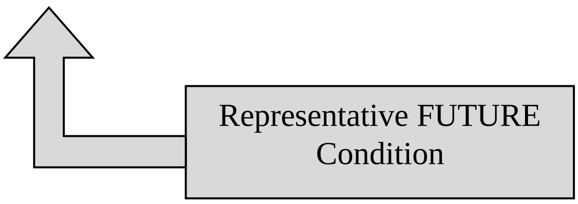
(2) Available on memory stick

9.6.4 Solution sheet

Growing season	Seasonal rainfall	Seasonal ET_0	Yield (ton/ha)
1976			
1977			
1978			
1979			
1980			
1981			
1982			
1983			
1984			
1985			
1986			
1987			
1988			
1989			
1990			
1991			
1992			
1993			
1994			
1995			
1996			
1997			
1998			
1999			
2000			
2001			
2002			
2003			
2004			
2005			
Average			
St. deviation			

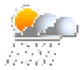
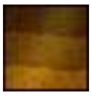
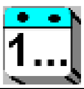


Growing season (Run#)	**Seasonal rainfall**	**Seasonal ET_0**	**Yield (ton/ha)**
2050 (#1)			
2050 (#2)			
2050 (#3)			
2050 (#4)			
2050 (#5)			
2050 (#6)			
2050 (#7)			
2050 (#8)			
2050 (#9)			
2050 (#10)			
2050 (#11)			
2050 (#12)			
2050 (#13)			
2050 (#14)			
2050 (#15)			
2050 (#16)			
2050 (#17)			
2050 (#18)			
2050 (#19)			
2050 (#20)			
2050 (#21)			
2050 (#22)			
2050 (#23)			
2050 (#24)			
2050 (#25)			
2050 (#26)			
2050 (#27)			
2050 (#28)			
2050 (#29)			
2050 (#30)			
Average			
St. deviation			



Annexes

Annex I. Content and learning objectives of the exercises

Topic		Learning objective: Know how …	Part A Explanation sections	Part B Exercises sections
	**Climate**	- to import climatic data - to create a climate file	2.2 and 2.4	8.1
	**Soil profile**	- to specify soil physical characteristics - to create a soil profile file	3.1 and 3.2	7.1
	**Groundwater table**	- to specify characteristics of the groundwater table - to create a groundwater file	3.3 and 3.4	8.7
	**Crop**	- to generate planting dates	4.1	7.4, 8.5, 9.2
		- to tune non-conservative crop parameters by considering characteristics of the environment and cultivar	4.2	7.2, 8.6, 9.1, 8.2
		- to calibrate a crop file to response to soil fertility stresses	4.3	9.3, 8.4
	**Irrigation management**	- to determine the net irrigation requirement	5.1	7.6, 8.6, 9.4
		- to specify an irrigation schedule	5.1	7.7
		- to generate an irrigation schedule	5.1	7.9, 9.5
	**Field management**	- to specify field management characteristics (soil fertility, mulches, field surface practices, weed management)	5.2	7.5, 8.5
	**Simulation period**	- to specify the start of the simulation period	6.1	7.4, 8.3, 9.2
	**Initial conditions**	- to specify the initial conditions of the simulation period	6.2	7.3, 7.4, 8.3, 9.2
		- to run successive simulations keeping the initial conditions	6.3	
	**Projects**	- to create a project file	6.4	Nearly all exercises

	**Field data**	- to evaluate the simulation results with field data	6.5	7.8
	**Simulation run**	Know how to run simulations:	6.6	
		- to explore the effect of soil profile characteristics on crop yield		7.1
		- to explore the effect of crop cultivars on crop yield		7.2, 9.1
		- to explore the importance of initial conditions in model simulations		7.3, 8.3
		- to explore the effect of the planting date		7.4, 8.2, 9.2
		- to assess the impact of soil fertility on crop yield		7.5, 8.4, 8.5, 9.3
		- to determine net irrigation requirement		7.6, 8.6, 9.4
		- to assess the effect of capillary rise from a shallow groundwater table on the net irrigation requirement		8.7
		- to design (deficit) irrigation schedules		7.7
		- to evaluate different irrigation strategies		9.5
		- to evaluate simulation results		7.8
		- to assess the impact of climate change		9.6

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