Food and Agriculture Organization of the United Nations

# AquaCrop training handbooks


# Book II.
# Running AquaCrop

**July 2026**

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**AquaCrop training handbooks**
**Book II. – Running AquaCrop**
**July 2026**

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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 7.3).

The first chapter introduces the user to the file management. The next chapters cover respectively the climate, soil, crop, 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'. Full reference is given in Chapter 2 (Users guide) of the Reference Manual of AquaCrop available on the AquaCrop web site.

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# Chapter 1. File management

## 1.1 Main menu

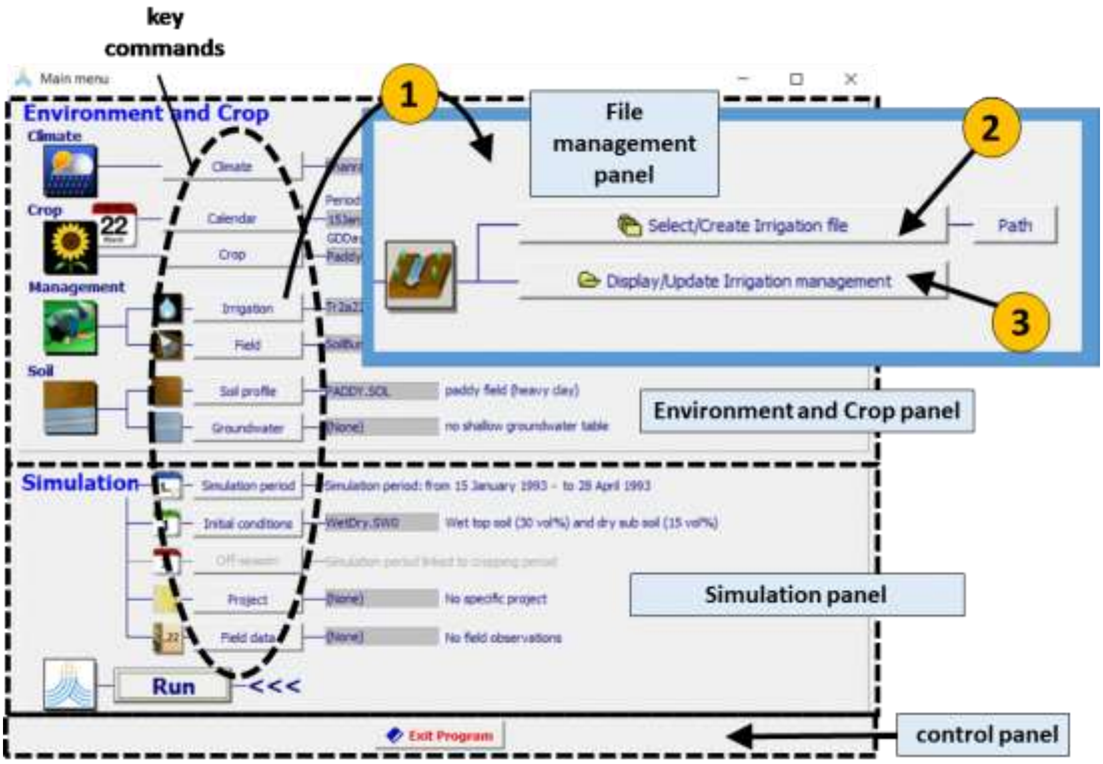



**Figure 1.1 – *Main menu* of AquaCrop. By selecting (1) one of the key commands, the user gets access to the file management panel from which (2) files can be selected or created and (3) the input characteristics can be displayed and updated.**

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**, **Calendar**, **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.

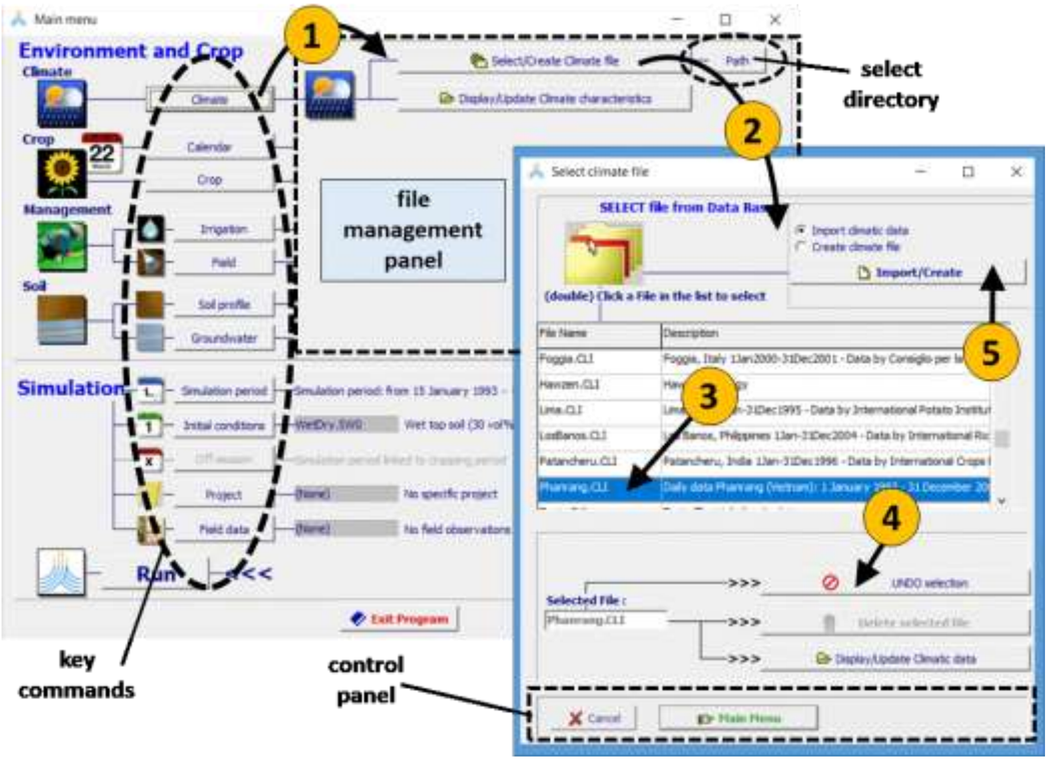



**Figure 1.2 – By selecting (1) one of the key commands and subsequently (2) the corresponding <Select/Create> command in the file management panel in the *Main menu*, the user gets access to the *Select file* menus in which (3) one of the available files can be selected, (4) the selection can be undone, 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 |
| Calendar | (None) | The onset of the growing period is specified by the user |
| 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 in the soil profile |
| Off-season | (None) | Optimal field management conditions are assumed |
| Project | (None) | |
| Field data | (None) | |

## 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).

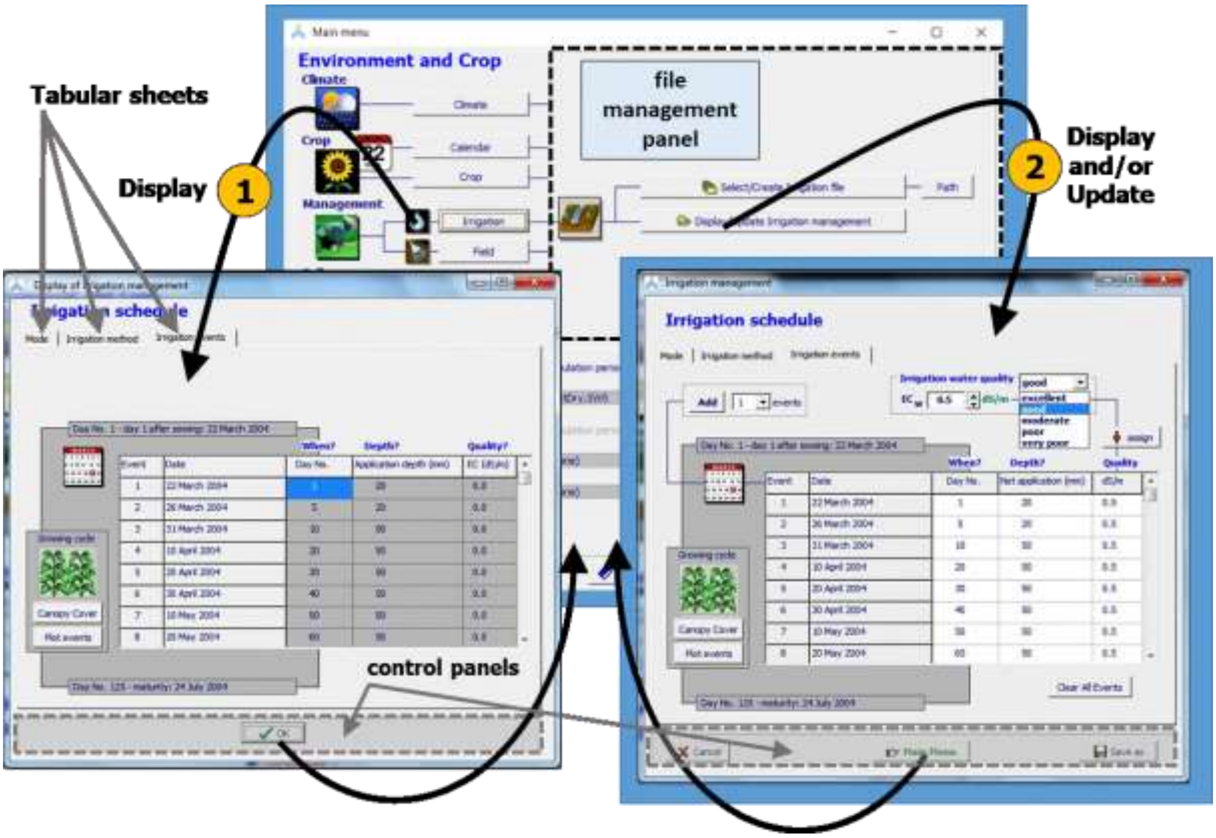



**Figure 1.3 – From the *Main menu*, the user has the option (1) to only display the characteristics or (2) to display and update the characteristics of a file**

## 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 (Option 1, in Fig. 1.4). In the files, characteristics of the climate, calendar, 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 (Option 2, in Fig. 1.4);
  **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 (Option 3, in Fig. 1.4). 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.

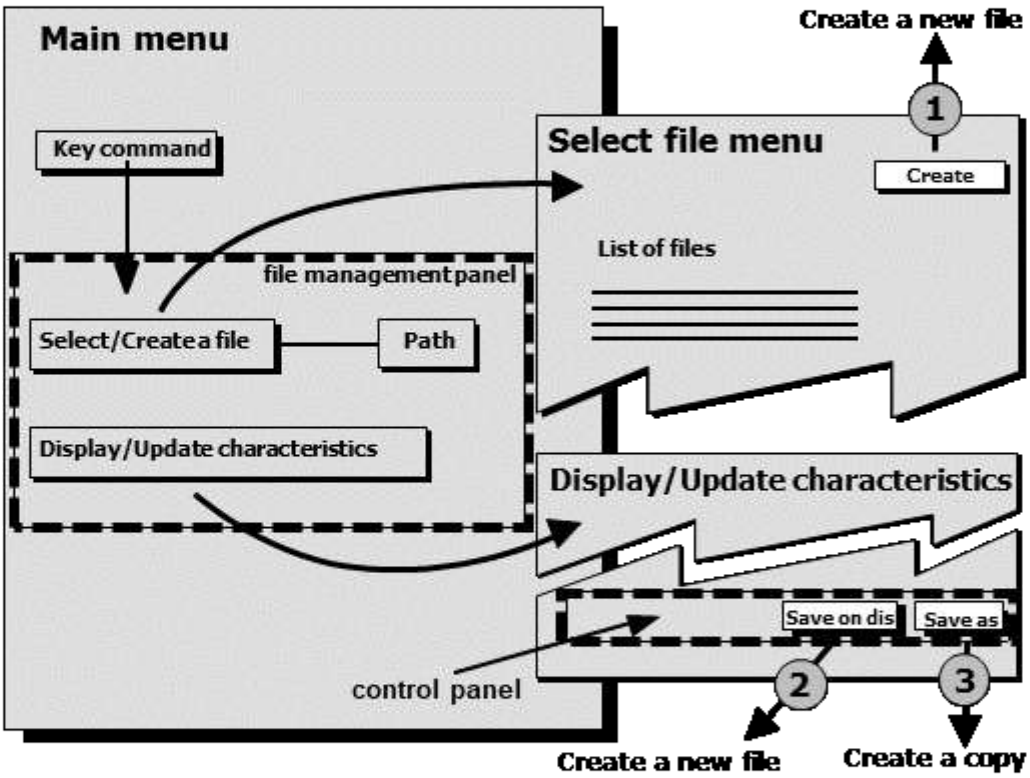



**Figure 1.4 – Options to create a new file by selecting (1) the <Create> command at the top of the *Select file* menu, and (2) the <Save on disk> command (if the characteristics were not retrieved from a file) or (3) the <Save as> command (if the characteristics were retrieved from a file), in the control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

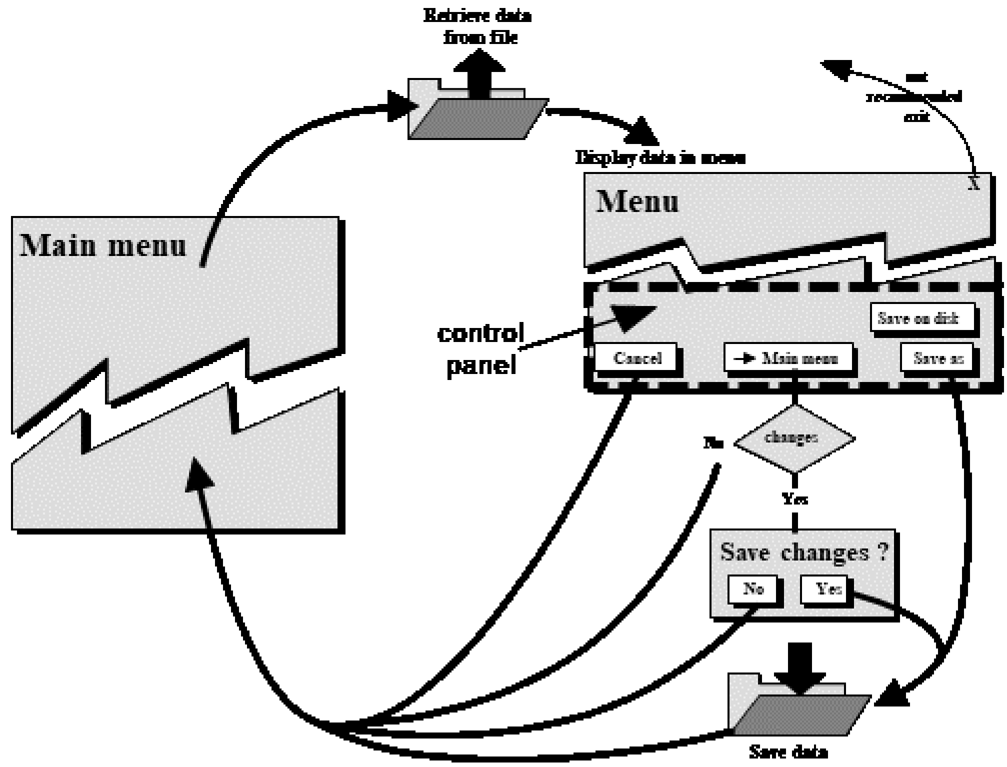



**Figure 1.5 – Options to exit and close a menu**

# 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.

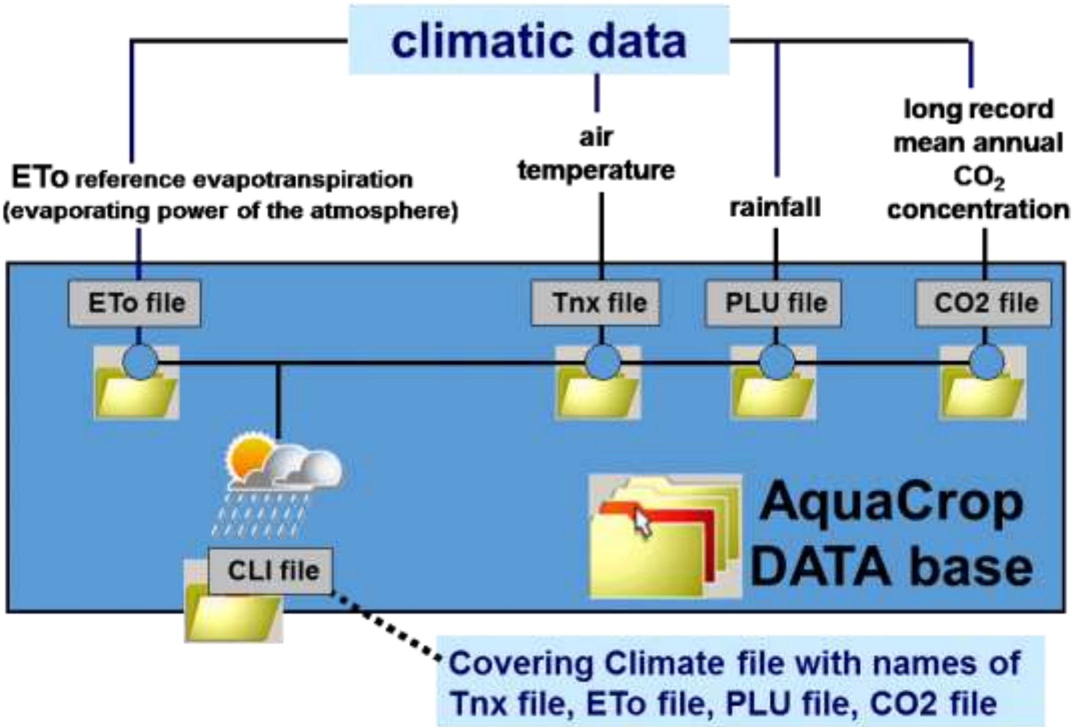



**Figure 2.1 – Climate files (*.CLI) and files with climatic data (*.ETo, *.Tnx, *.PLU, *.CO2) stored in AquaCrop data base.**

## 2.2 Creating air temperature, ETo and rainfall files

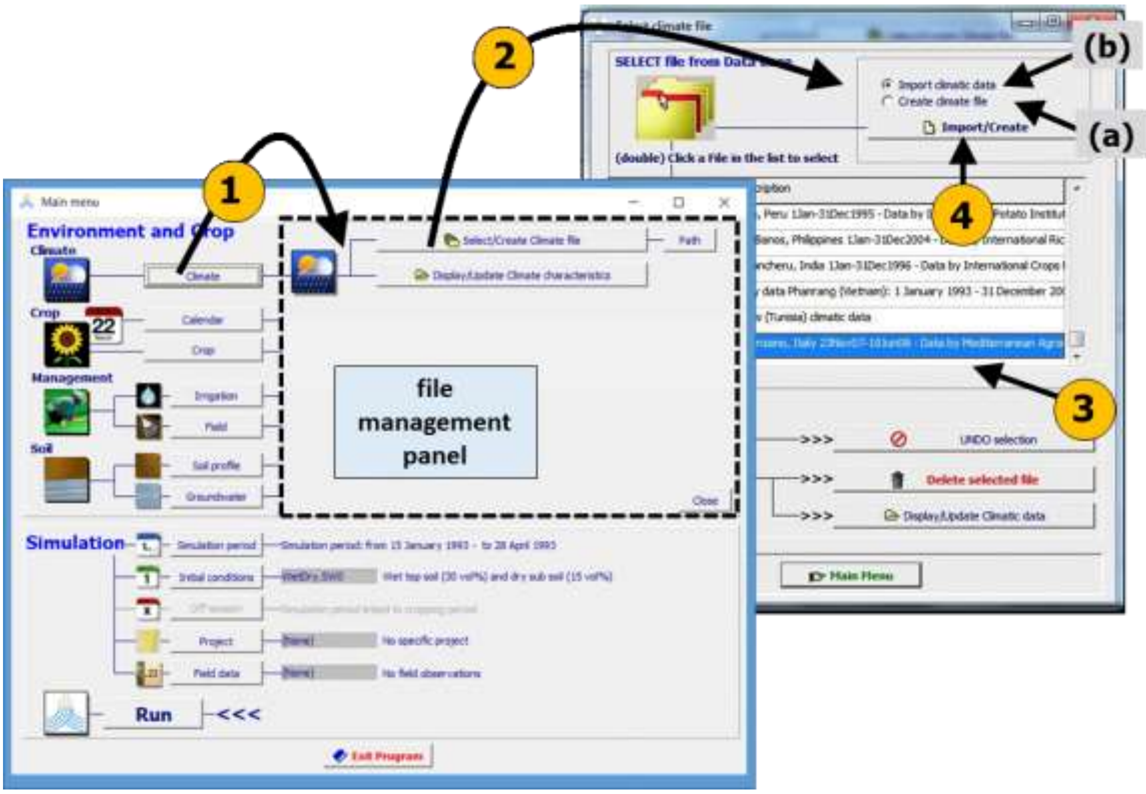



**Figure 2.2 – By selecting (1) the <Climate> command and subsequently (2) the <Select/Create Climate file> command in the file management panel in the *Main menu*, the user gets access to the *Select climatic file* menu, in which (3) one of the available CLI files, or (4) the command (a) to <Create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

### 2.2.1 Text files with climatic data that can be imported

☐ **Type of data**

Data that can be imported, consist of air temperature, ETo, 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);

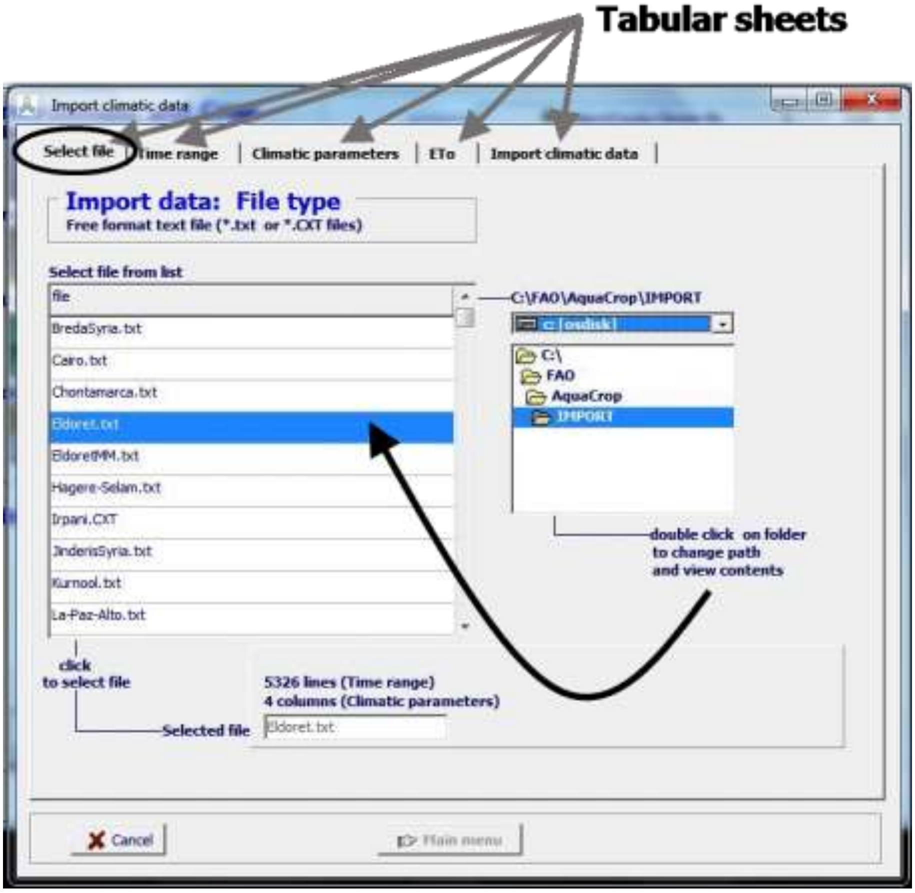



**Figure 2.3 – *Import climatic data* menu with its tabular sheets: 'Select file' (displayed), 'Time range', 'Climatic parameters', 'ETo', and 'Import climatic data'.**

- **'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.

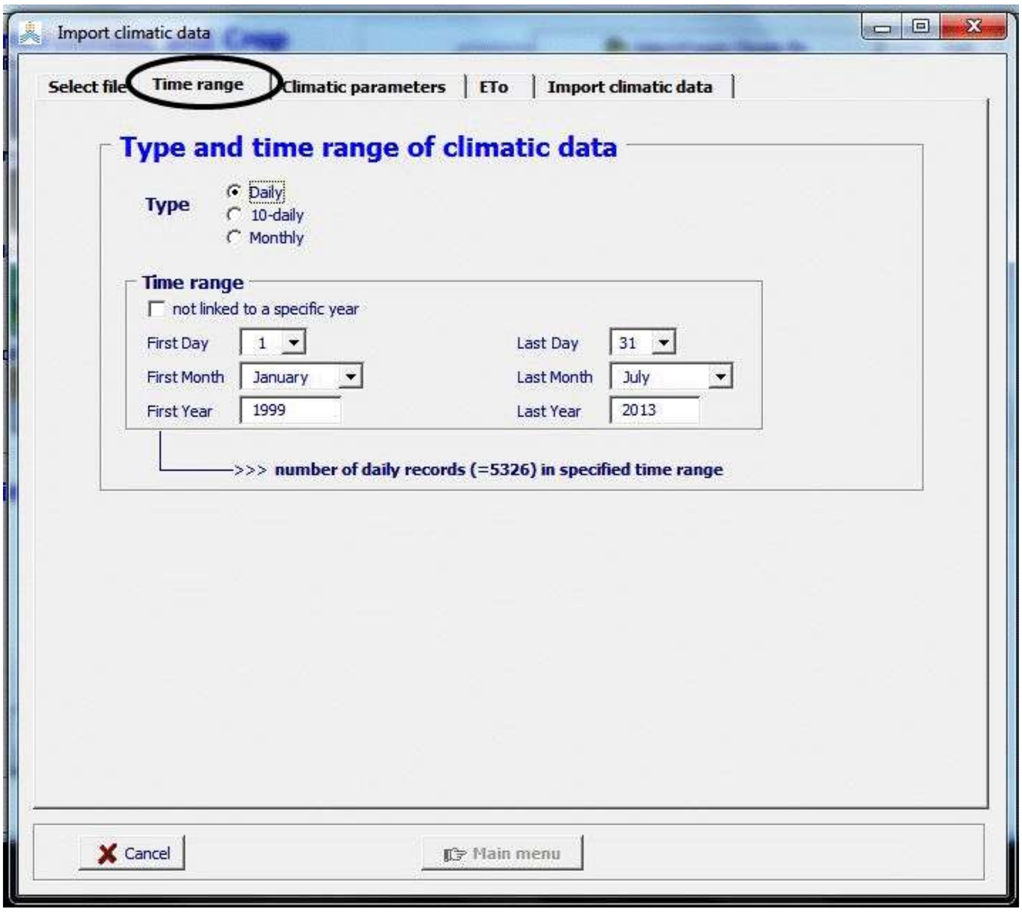



**Figure 2.4 – The 'Time range' tabular sheet of the *Import climatic data* menu: for 'Eldoret.txt' (containing a long record of daily temperature and rainfall data).**

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).

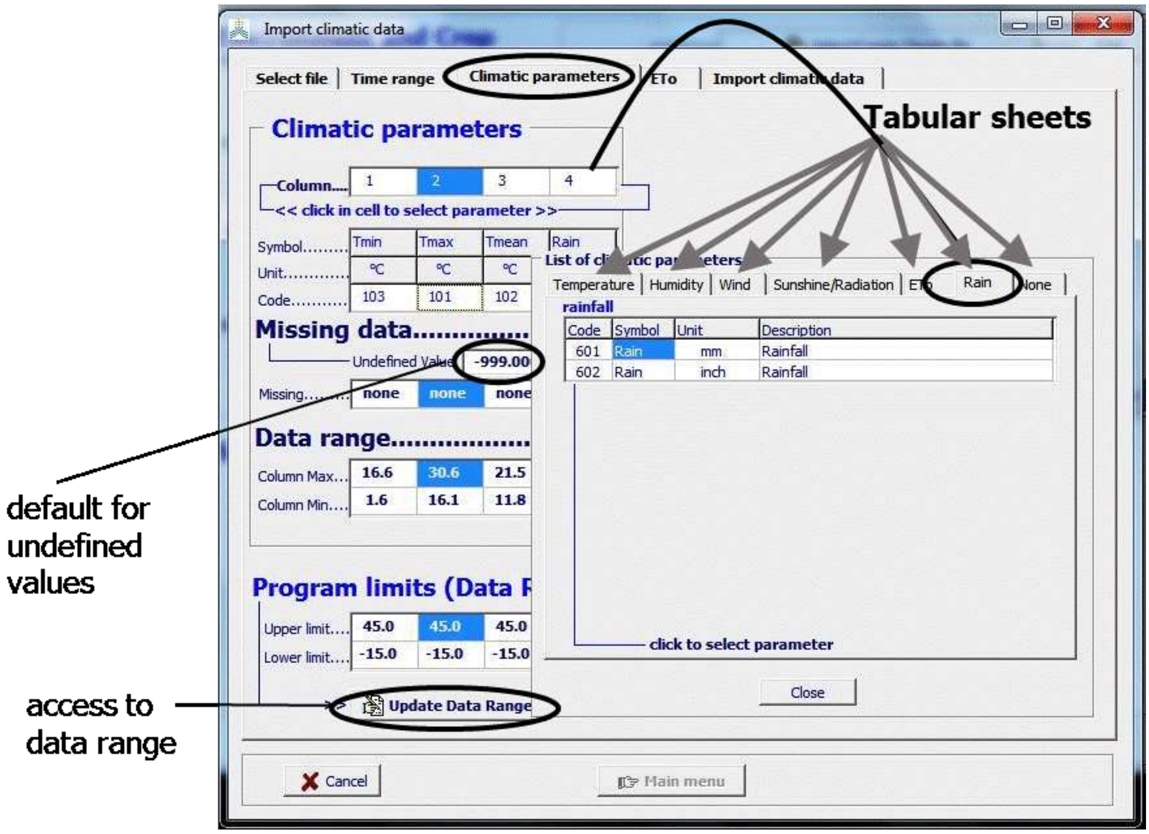



**Figure 2.5 – The 'Climatic parameters' tabular sheet of the *Import climatic data* menu for 'Eldoret.txt' (containing a long record of daily temperature (minimum, maximum and average) and rainfall data).**

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).

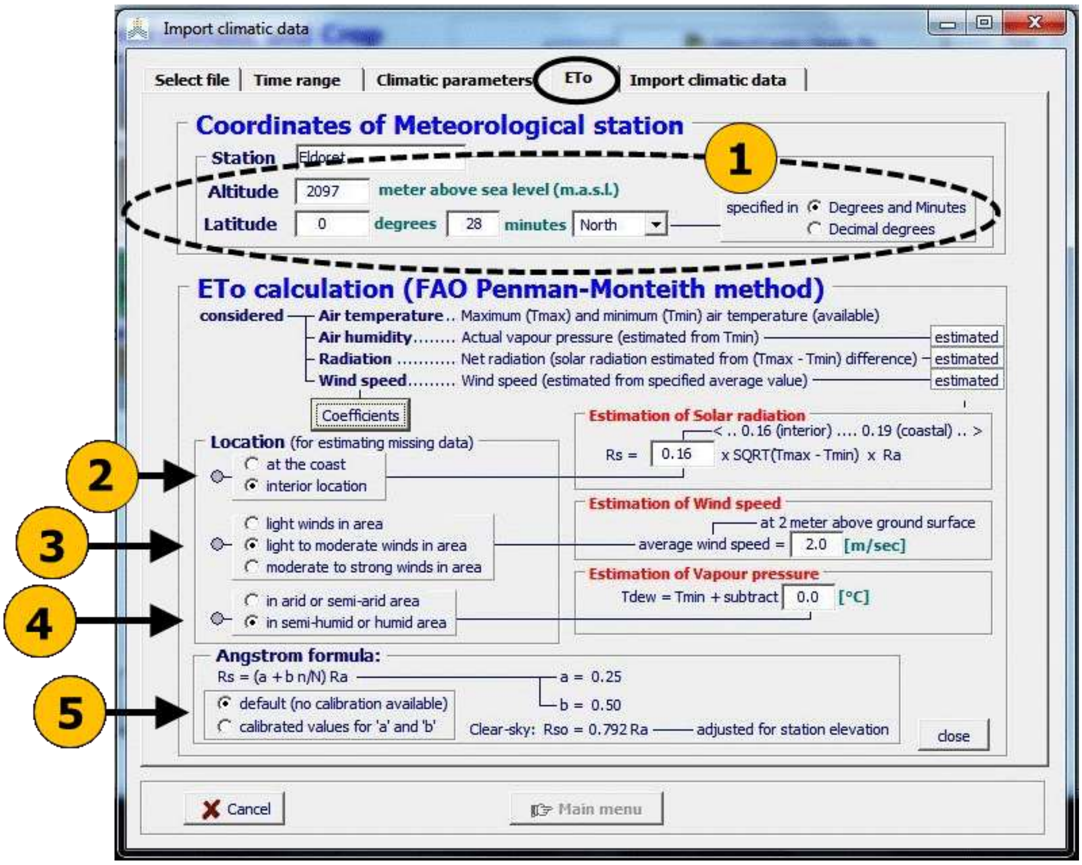



**Figure 2.6 – The 'ETo' tabular sheet of the *Import climatic data* menu for 'Eldoret.txt' (containing a long record of daily temperature and rainfall data), with (1) specification of the coordinates; choices made for estimating missing (2) solar radiation, (3) wind speed, and (4) vapour pressure; and (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<br>- interior location | $k_{Rs} = 0.19$<br>$k_{Rs} = 0.16$ | temperature difference method |
| Wind speed at 2 meter above ground surface ($u_2$) | - light winds<br>- light to moderate winds<br>- moderate to strong winds | $u_2 = 0.5$ m/sec<br>$u_2 = 2.0$ m/sec<br>$u_2 = 4.0$ m/sec | |
| Vapour pressure: dewpoint temperature | - in arid or semi-arid area<br>- in semi-humid or humid area | Tdew ≈ Tmin – 2°C<br>Tdew ≈ Tmin | |

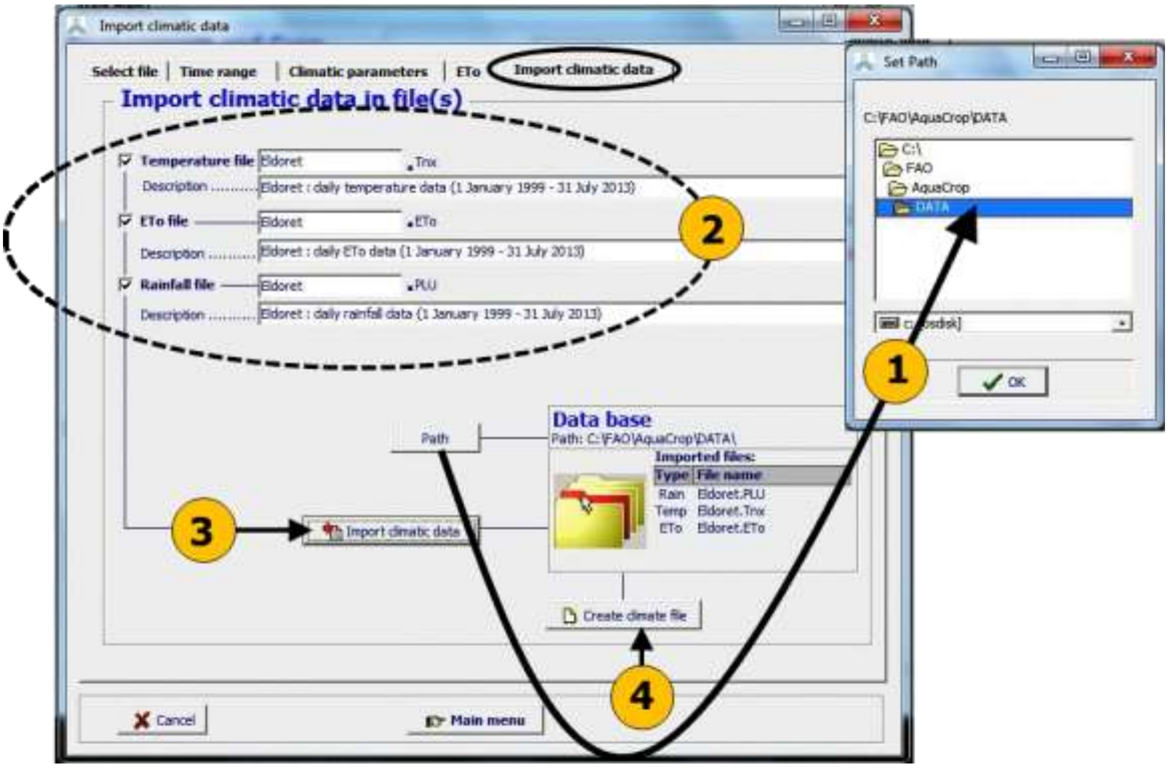



**Figure 2.7 – The 'Import climatic data' tabular sheet of the *Import climatic data* menu for 'Eldoret.txt' (containing a long record of daily temperature and rainfall data), with specification of (1) folder, and (2) names and description of files with climatic data. By selecting (3) the <Import climatic 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).

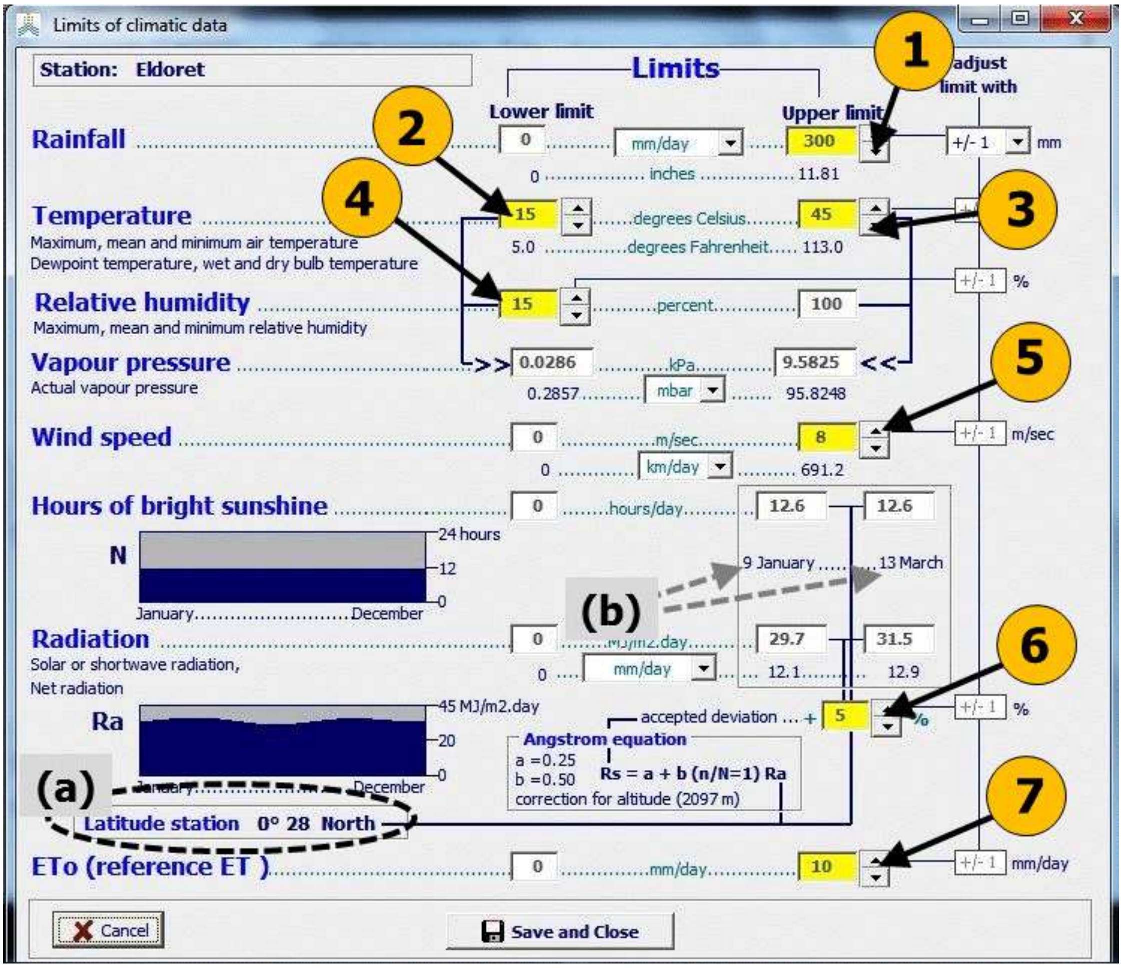



**Figure 2.8 – The *Limits of climatic data* menu in which upper and/or lower limits can be adjusted for (1) total rainfall, (2) and (3) air temperature, (4) relative humidity, (5) daily wind speed, (6) deviation from maximum possible daily radiation (given by (a) latitude and (b) time of the year), 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<br>1,000 mm/10-day<br>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 four different RCP's ('RCP2-6.CO2', RCP4-5.CO2', 'RCP6-0.CO2' and 'RCP8-5.CO2') are available in the DATA subdirectory of AquaCrop. 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. In 2021, IPCC released a new set of climate scenarios with respect to the sixth IPCC report. CO2 files for the five "Shared Socioeconomic Pathways" (SSPs) are added to the DATA subdirectory ('SSP1-1.9.CO2', 'SSP1-2.6.CO2', 'SSP2-4.5.CO2', 'SSP3-7.0.CO2' and 'SSP5-8.5.CO2'). They represent different socio-economic developments as well as different pathways of atmospheric greenhouse gas concentrations. Compared to the previous used RCPs, the new SSPs scenarios have been improved in a variety of ways. In Figure 2.9, the $CO_2$ concentrations of the new set of SSPs are plotted next to the RCPs.

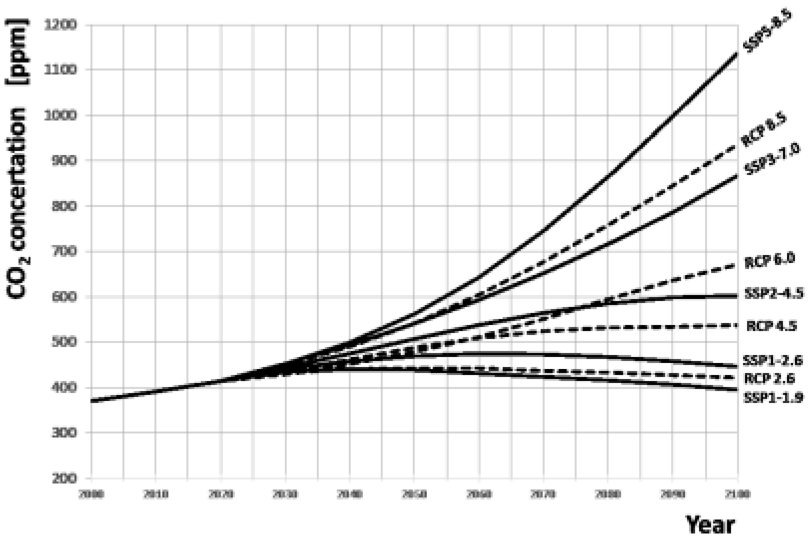



**Figure 2.9 – Projected $CO_2$ concentrations available in the database of AquaCrop, for 5 SSPs (solid line) and 4 RCPs (dotted lines).**

- 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).

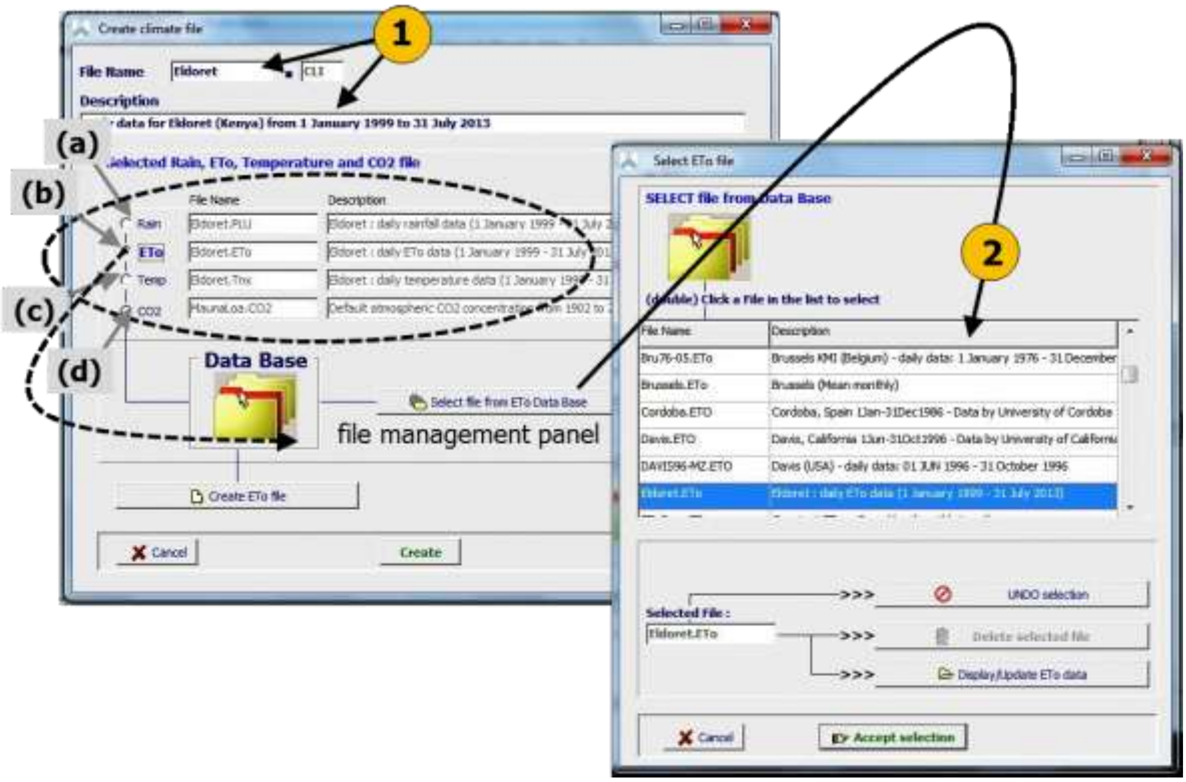



**Figure 2.10 – *Create climate file* menu in which the user composes the covering climate file (1) by specifying its name and description, and (2) by selecting a (a) rainfall, (b) ETo, (c) air temperature and (d) CO2 file from the Data Base.**

# 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.

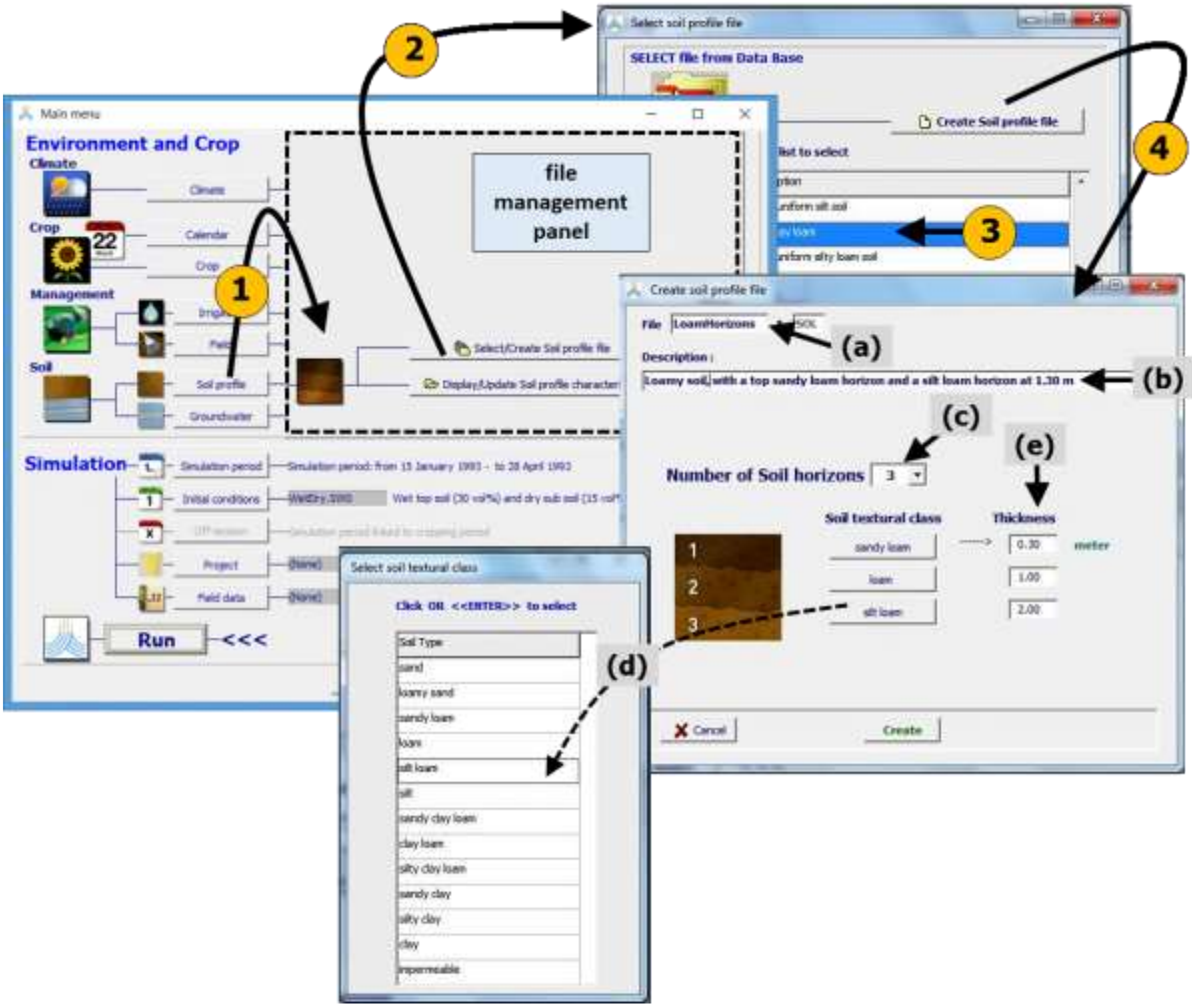



**Figure 3.1 – By selecting (1) the <Soil profile> command and subsequently (2) the <Select/Create soil profile file > command in the file management panel of the *Main menu*, the user gets access to *Select soil profile file* menu, in which (3) one of the available soil profile files or (4) the command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

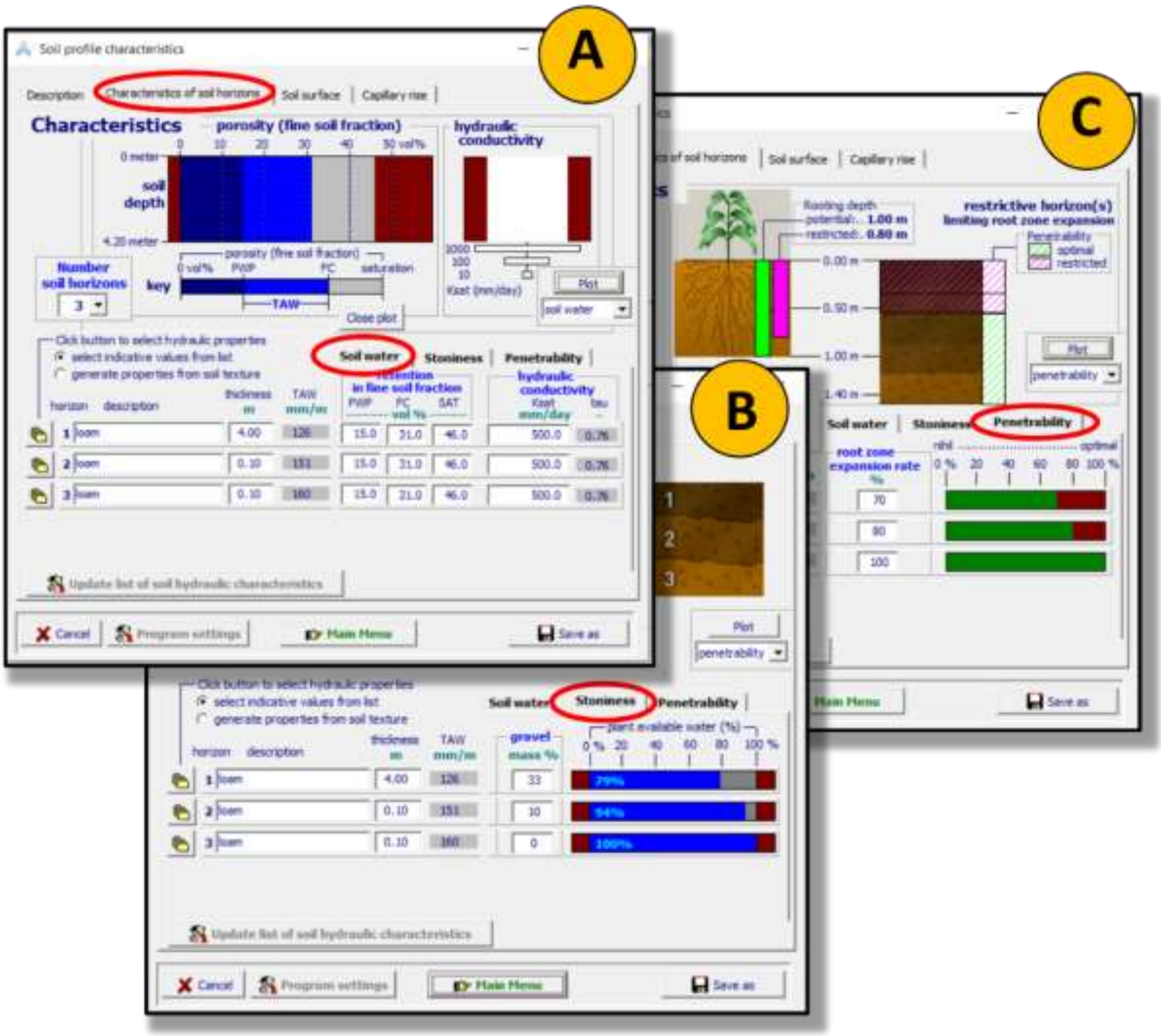



**Figure 3.2a – Specification of physical characteristics of the various soil horizons in the (A) 'Soil water', (B) 'Stoniness' and (C) 'Penetrability' tab-sheet in the *Soil profile characteristics* menu.**

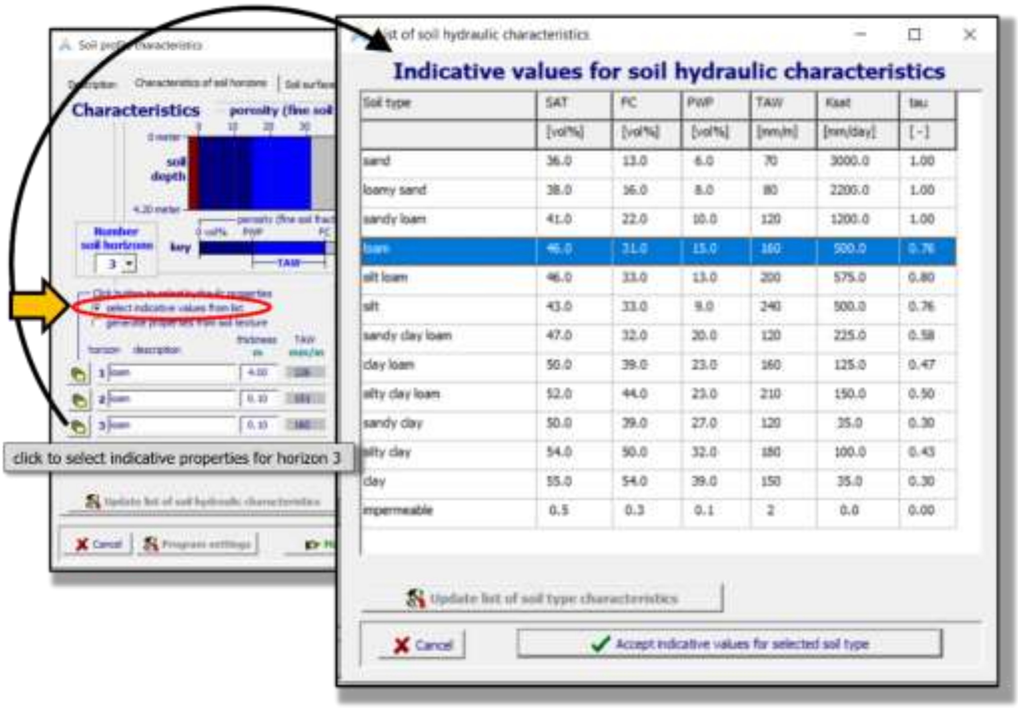



Figure 3.2b – Clicking one of the <Library> buttons in the *Soil profile characteristics* menu, displays the *List of soil hydraulic characteristics* menu where indicative values for soil hydraulic characteristics for various soil types can be selected.

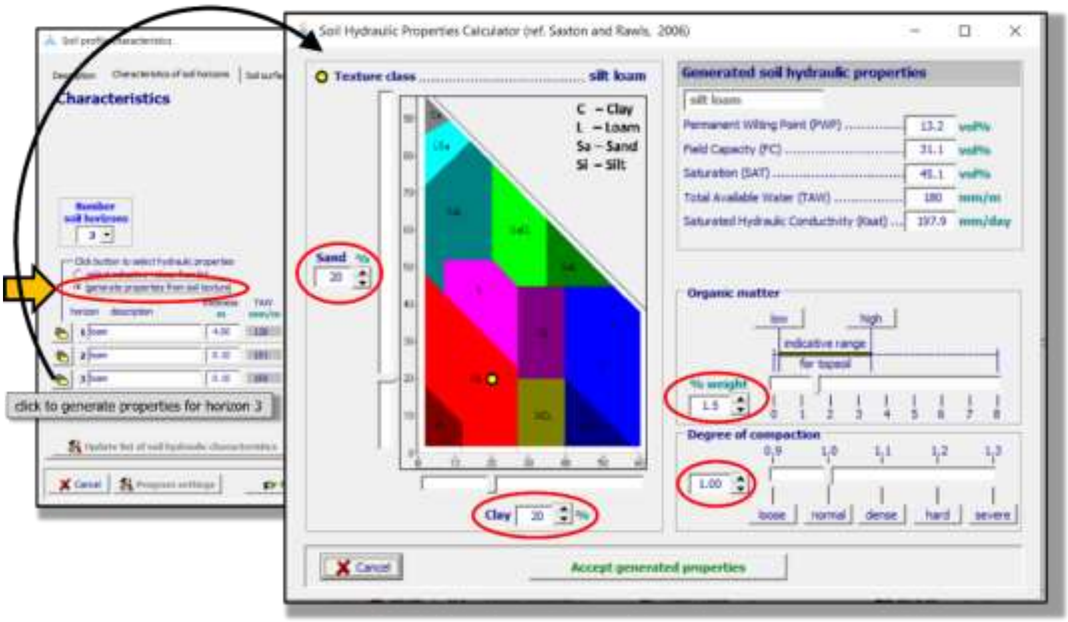



Figure 3.2c – Clicking one of the <Library> buttons in the *Soil profile characteristics* menu, opens the *Soil Hydraulic Properties Calculator* menu where soil hydraulic properties can be generated using the pedo-transfer functions of the Saxton and Rawls.

**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 ($\theta_{PWP}$), field capacity ($\theta_{FC}$) and at saturation ($\theta_{SAT}$)**:<br>- Together with the depth of the root zone (which is a crop characteristic), the difference between the $\theta_{FC}$ and $\theta_{PWP}$ 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;<br>- In the absence of locally determined values for $\theta_{PWP}$, $\theta_{FC}$ and $\theta_{SAT}$ 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):**<br>- Indicative values provided by AquaCrop for the various soil textural classes can be used;<br>- 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)**:<br>- 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;<br>- 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:**<br>- The default values for the parameters used for the simulation of capillary rise for each soil horizon, are obtained by considering $\theta_{PWP}$, $\theta_{FC}$, $\theta_{SAT}$ and Ksat;<br>- 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;<br>- 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);<br>- When running a simulation, the magnitude of the capillary rise can differ from the calibrated maximum value:<br>o 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);<br>o 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. |

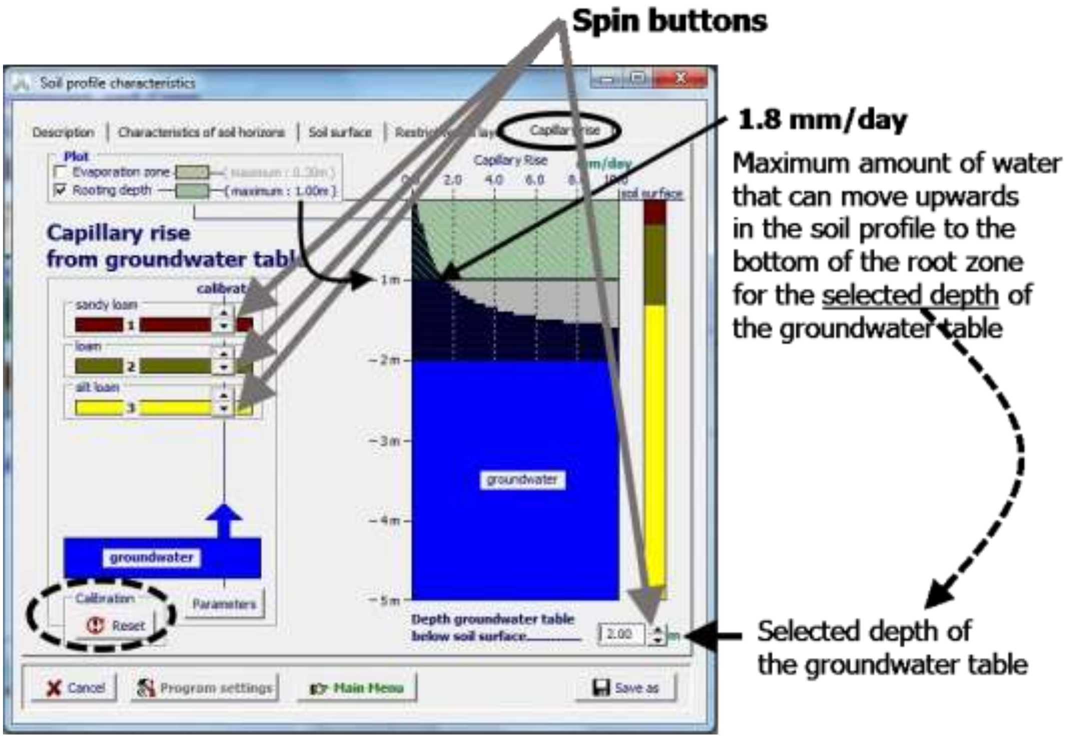



**Figure 3.3 – The 'Capillary rise' tabular sheet of the *Soil profile characteristics* menu in which the maximum amount of water that can be transported upwards to the bottom of the root zone (for the specified crop), can be calibrated with the help of spin buttons, for a selected groundwater table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

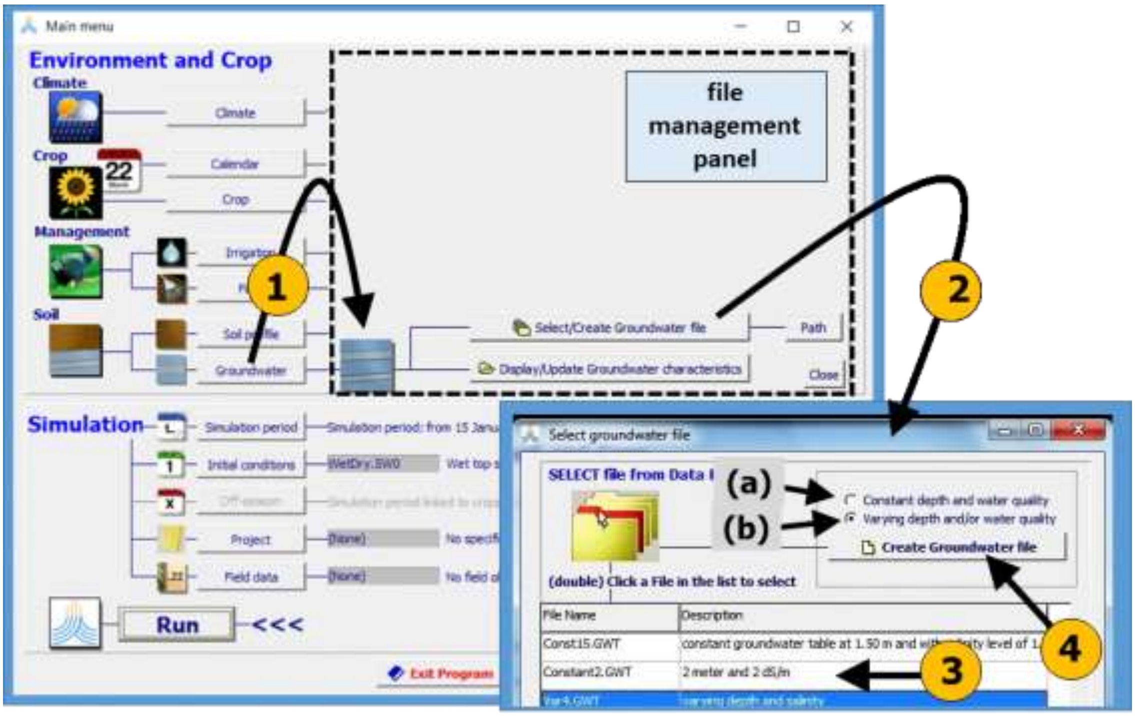



**Figure 3.4 – By selecting (1) the <Groundwater> command and subsequently (2) the <Select/Create Groundwater file> command in the file management panel of the *Main menu*, the user gets access to the *Select groundwater file* menu, in which (3) one of the available groundwater table files or (4) the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

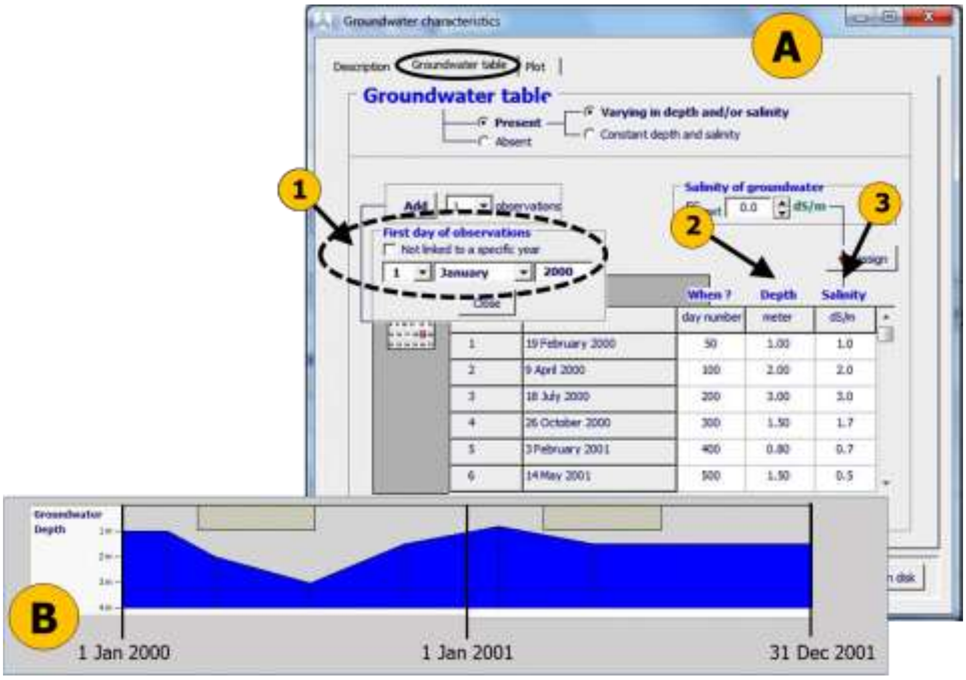



**Figure 3.5 – (A) Specifying (1) the first day of observations and the (2) depth and (3) salinity of the groundwater table at specific days in the *Groundwater characteristics* menu. (B) Plot of the groundwater table depth below the soil surface in 2000 and 2001 corresponding to the specifications in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

# Chapter 4. Crop

## 4.1 Planting/sowing date

### 4.1.1 Specifying the planting/sowing date

In irrigated agriculture, the planting/sowing date changes little over the years, but in rainfed cropping, crops will only be sown or planted when the topsoil is sufficient wet at the start of the rainy season. In a cool climate, crops are typically sown or planted when the weather has warmed up sufficiently.

To determine the likely time of planting in the various years of a simulation run, the onset (a) can be specified directly or (b) a crop calendar file can be loaded in which the onset day is generated based on one or another Rainfall or Air temperature criterion, or can be fixed on a pre-set day (Fig. 4.1).

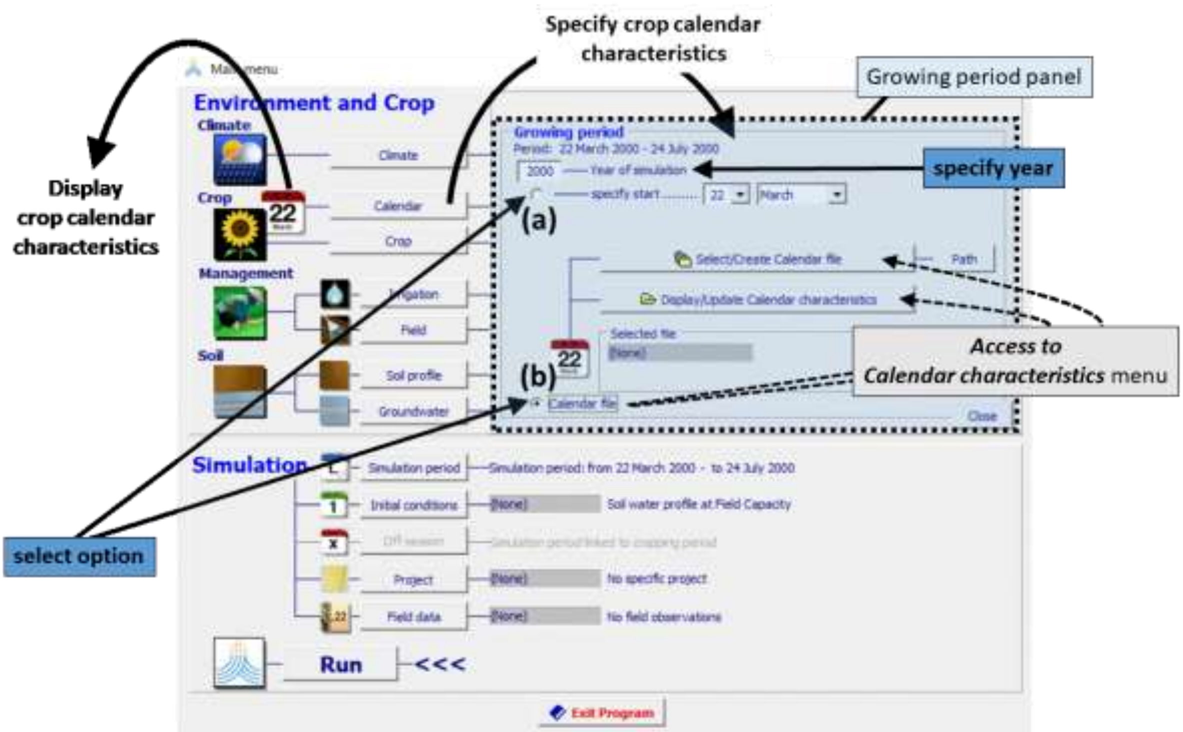



**Figure 4.1 – The 'Growing period' panel in the *Main menu*, in which the Year of simulation is specified, and an option is selected (a) to either directly specify the start of the growing period or (b) to select or create a calendar file by which the onset will be generated for a planting/sowing year.**

### 4.1.2 Crop calendar file

A crop calendar file contains either a pre-set fixed Onset Day or information to generate an Onset Day by a Rainfall or Air temperature criterion for the year in which the annual/perennial crop is sown/planted. Since the information in a crop calendar file is not linked to a specific year, the generated Onset Day will automatically adjust to the weather conditions each time the simulation year in the 'Growing period' panel of the ***Main menu*** is changed. After selecting or creating a Crop calendar file in the ***Main menu*** (Fig. 4.1), the calendar characteristics are displayed and can be updated in the ***Crop calendar characteristics*** menu (Fig. 4.2).

☐ **Options to determine the onset in a planting/sowing year (Fig. 4.2)**

- **Specified by a calendar day**: If a pre-set Onset Day (Day & Month) is saved in the calendar file, the growing period will always start at the same day in each year of the simulation;
- **Generated by a Rainfall criterion**: This option might be useful for determining a likely sowing or planting date for rainfed crops at the start of the rainy season, since the decision to sow or plant is typically determined by rainfall events;
- **Generated by a Temperature criterion**: This option might be useful for simulations in a cool climate, where crops are typically sown or planted when the air temperature rises above a minimum value.

The two options to generate on onset day are suitable not only for estimating the planting date for current years but also for future years, since climate change is likely to increase the air temperature and alter the rainfall pattern in many regions.

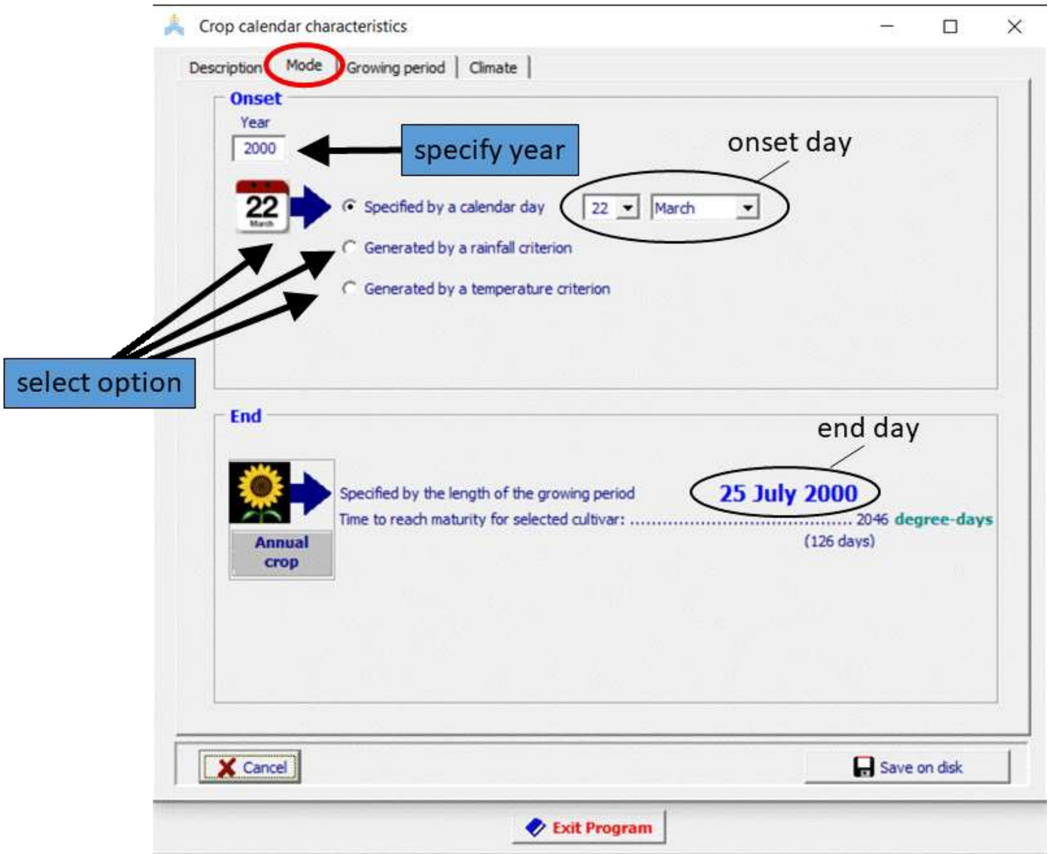



**Figure 4.2 – The 'Mode' tabular sheet of the crop calendar characteristics menu, in which a year can be specified, options to specify the Onset can be selected, and the corresponding Onset and End of the growing period for the specified year are displayed.**

☐ **Onset generated based on climatic data (rainfall or air temperature)**

In case the planting/sowing date is unknown, AquaCrop offers the possibility to generate a date, based on climatic data (Fig 4.2). By selecting a criterion in the ***Onset based on rainfall or temperature*** tab sheet an onset date is determined by automatic assessment of the rainfall or the temperature data before planting/sowing (Fig. 4.3). By specifying the start day and length of the 'time window', only rainfall or air temperatures within the specified window are evaluated.

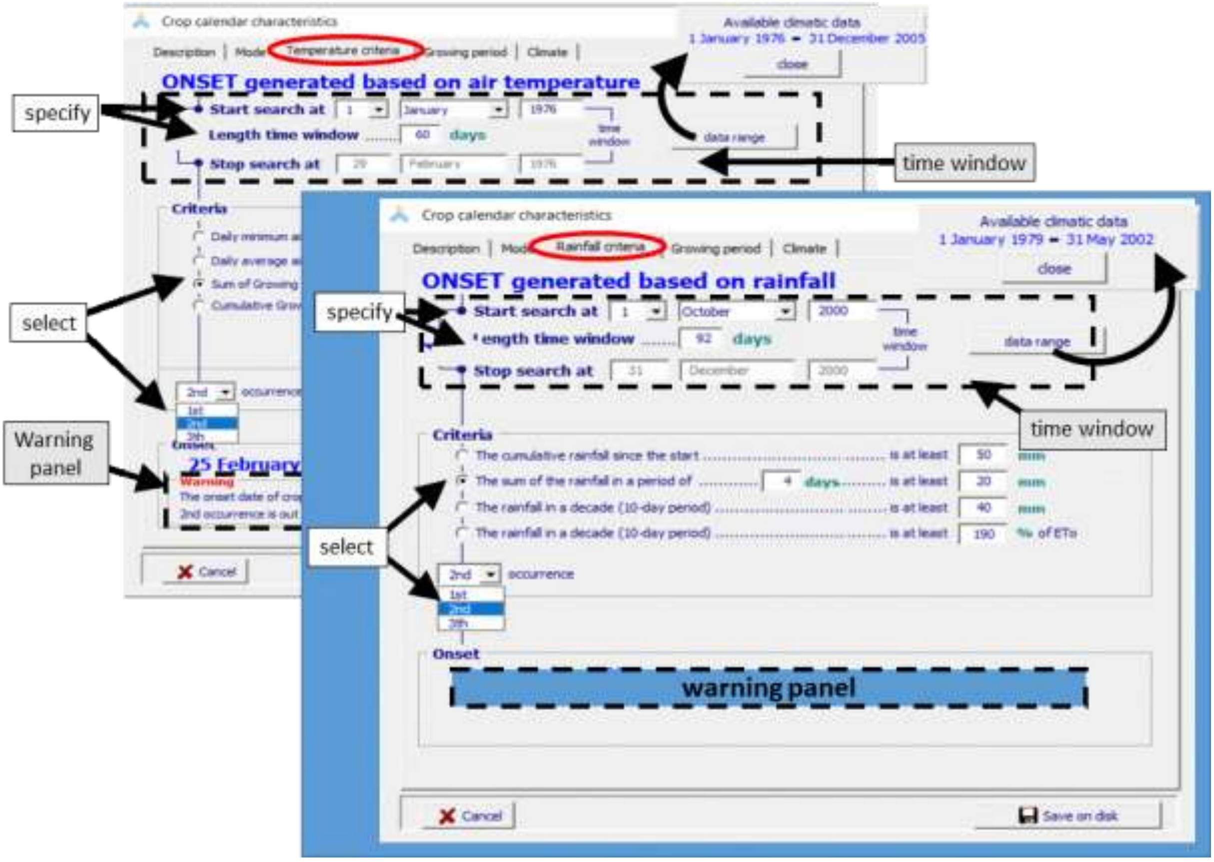



**Figure 4.3 – The 'Temperature criteria' and 'Rainfal criteria' tabular sheets in which the Onset of the growing period is determined by a selected criteria and occurrence.**

**<u>Generation based on rainfall</u>**: the option might be well suited for rainfed cropping where sowing or planting is typically determined by rainfall events.

**<u>Generation based on temperature</u>**: the option might be well suited to estimate the planting dates for spring crops in cool climates.

**<u>Occurrence</u>**: The first occurrence of the onset date is the first date for which the selected criterion holds. When the start of the rainy season or spring is uncertain at the first occurrence of the selected criterion, specifying a more stringent criterion might avoid early canopy senescence or a complete crop failure after germination. AquaCrop offers also the option to select the 2$^{nd}$ or even a 3th occurrence, to avoid the selection of a too early onset date (when the rainy season is not well on its way or air temperature might still drop sharply).

## 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. 4.4). 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:

**Description:** to adjust the description of the crop file;

**Mode**: to switch from Calendar days to Growing degree-days at the end of the tuning process (see section 4.2.5);

**Development:** to adjust cultivar specific parameters and parameters affected by planting, management, and conditions in the soil profile;

**Production:** to adjust the Harvest Index;

**Fertility-stress:** to calibrate the crop biomass response to soil fertility and/or soil salinity stress;

**Calendar:** to get an overview and/or adjust the calendar of the growing cycle.

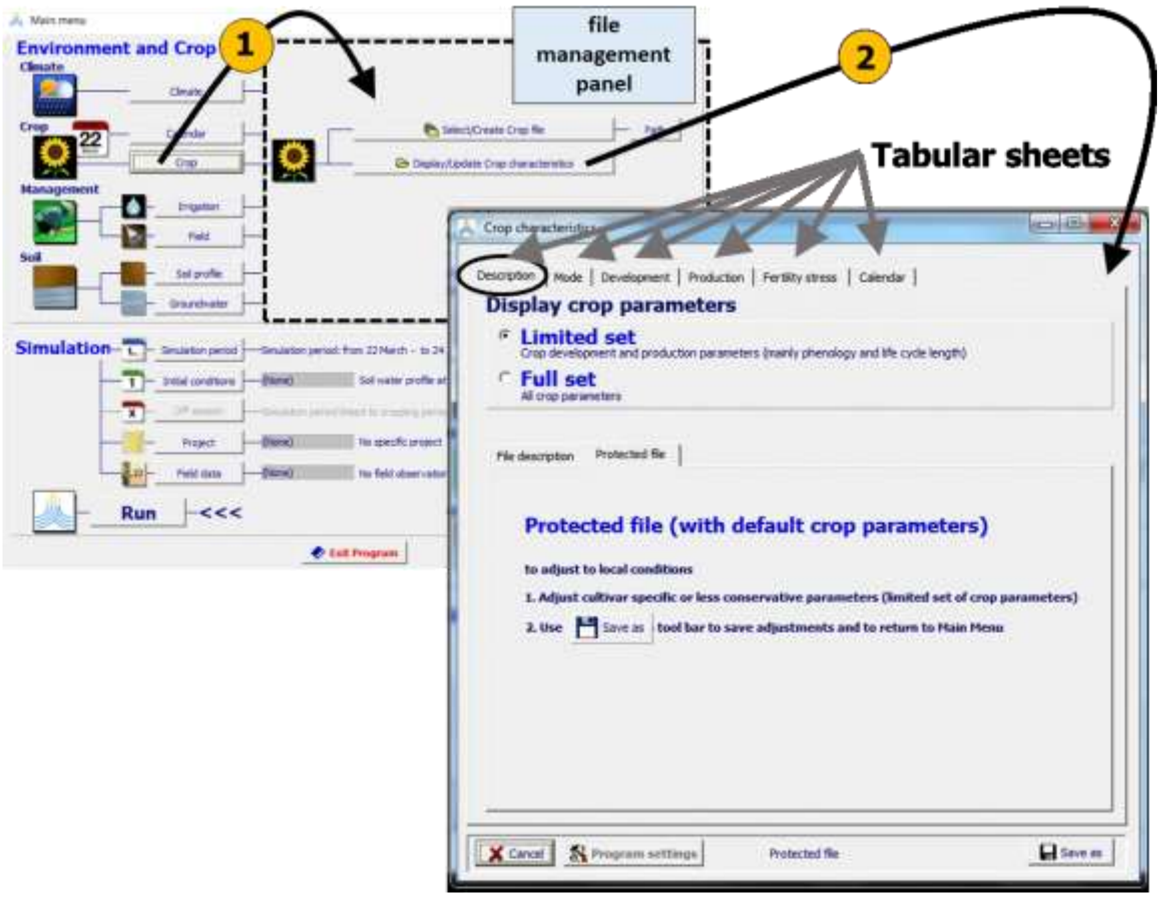



**Figure 4.4 – By selecting (1) the <Crop> command and subsequently (2) the <Display/Update Crop characteristics> command in the file management panel of the Main menu, the user gets access to the Crop characteristics menu in which the crop parameters can be fine-tuned to the environment.**

### 4.2.1 Parameters affected by planting and management:

- **Type of planting method** (Fig. 4.5, 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. 4.5):
    - 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. 4.6);
- **Time to reach 90% seedling emergence** (depends on field preparation and soil temperature) (Fig. 4.6).

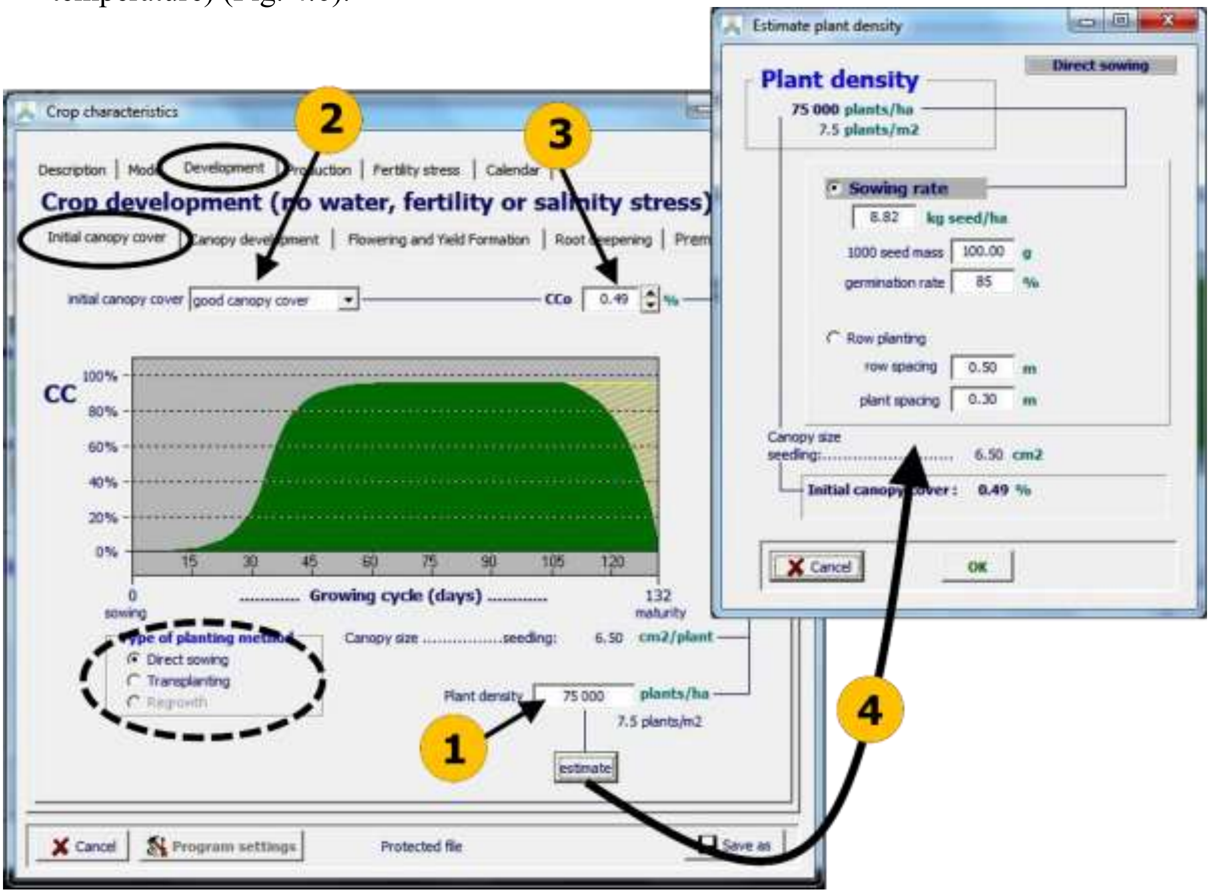



**Figure 4.5 – The 'Initial canopy cover' tabular sheet of the 'Development' tabular sheet of the *Crop characteristics* menu in which the type of planting method (dotted oval) and the initial canopy cover ($CC_o$) is determined (1) by specifying plant density, (2) by selecting a predefined $CC_o$ class, (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. 4.6):

- **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.

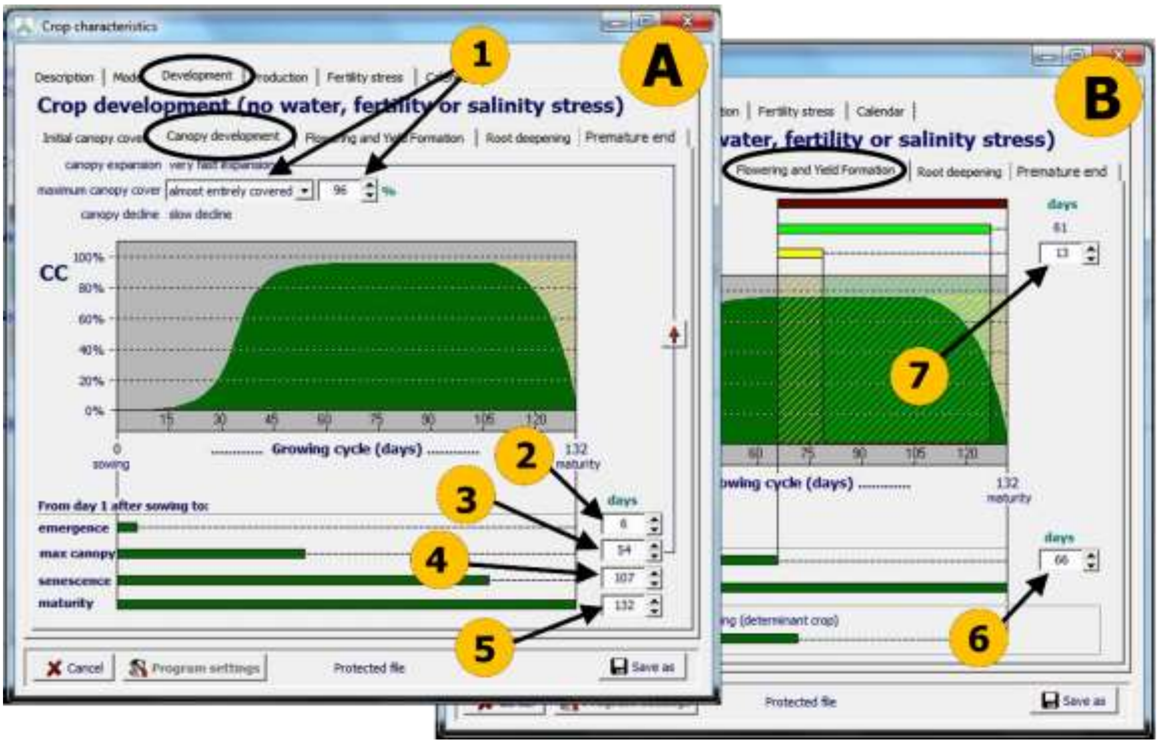



**Figure 4.6 – The (A) 'Canopy development' and (B) 'Flowering and yield formation' tabular sheet of the 'Development' tabular sheet of the *Crop characteristics* menu including: (1) the maximum canopy cover ($CC_x$) by selecting a class or specifying the percentage, and the time to reach (2) 90% seedling 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. 4.7):

- **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).

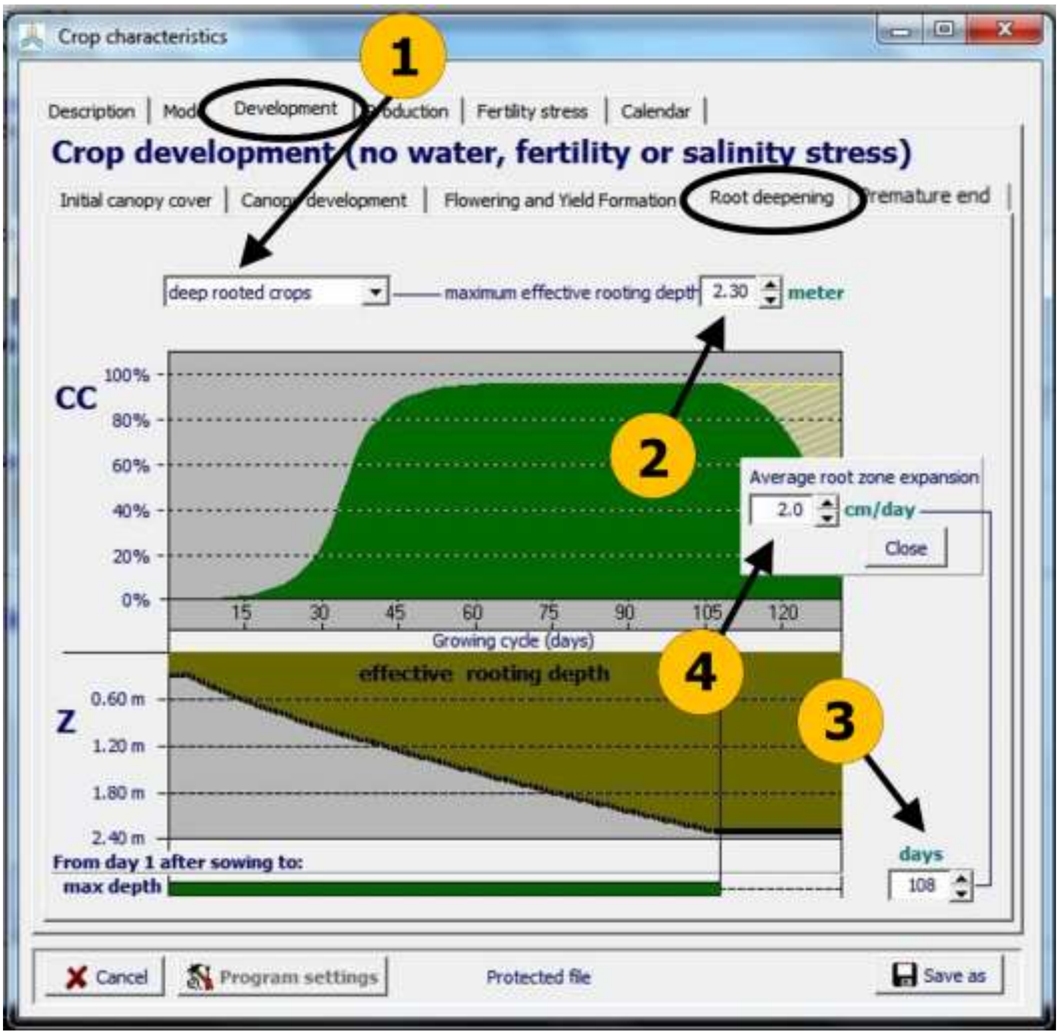



**Figure 4.7 – The 'Root deepening' tabular sheet of the 'Development' tabular sheet of the *Crop characteristics* menu including: the maximum effective rooting depth (Zx), specified by (1) selecting a predefined class, or (2) by entering the value in meter, and the time to reach $Z_x$ specified by (3) 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. 4.8-1,A). 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.

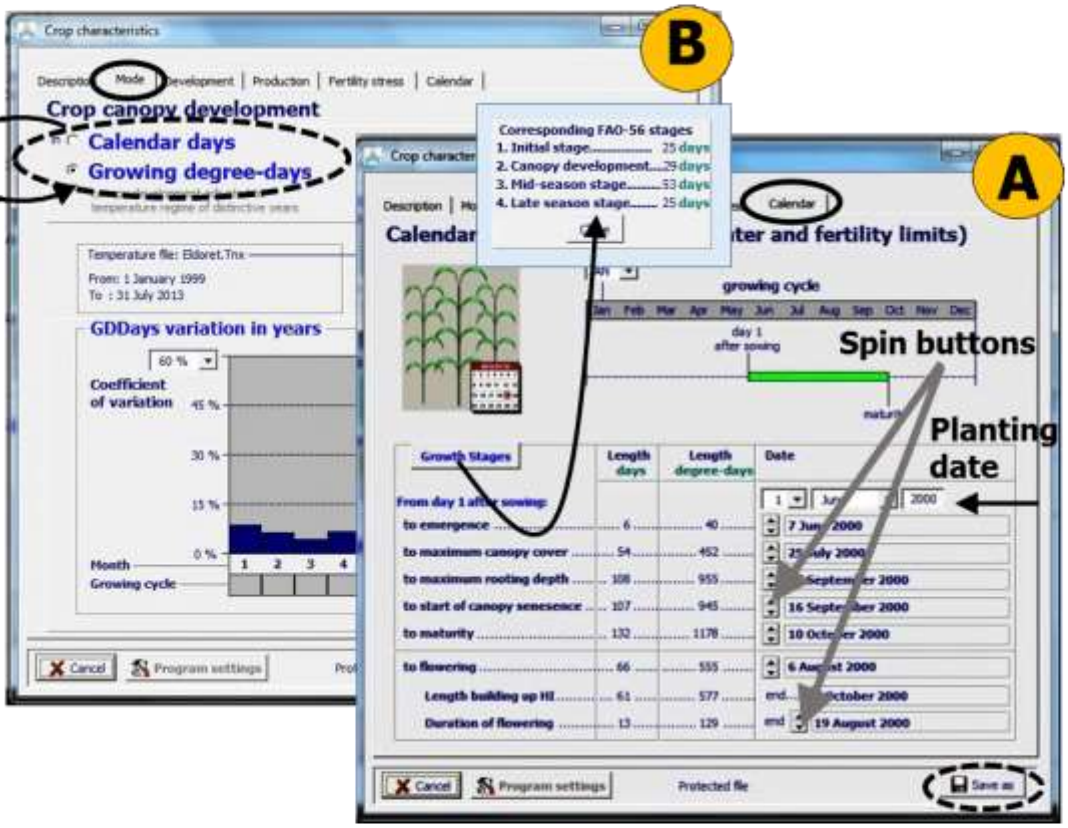



**Figure 4.8-1 – (A) The ‘Calendar’ tabular sheet, to inspect or adjust the calendar of the growing period, and (B) The ‘Mode’ tabular sheet of the *Crop characteristics* menu to switch between calendar and thermal time. With the <Save as> command the fine-tuned crop characteristics can be saved in a new crop file.**

**Premature end of the growing period**

A premature end of the growing period is specified in the “Premature end” tab-sheet of the “Development” tab-sheet of the ***Crop characteristics*** menu (Fig. 4.8-2). The display for the selected climate of (a) the mean daily minimum and maximum air temperature or (b) the mean daily Growing Degree Days (GDD) and the corresponding range of cold stress, can provide valuable information to consider whether or not an early termination of growth.

If the annual crop is unlikely to survive a cold winter period, the option of a premature end of the growing period needs to be considered (Fig. 4.8-2). The user specifies the date at which the crop cannot survive in the ***Crop characteristics*** menu (in Fig. 4.8-2, i.e. 20 November of the planting year). As a result, AquaCrop will terminate the growing period prematurely if not enough growing degrees can be collected to reach maturity before the specified end date (Fig. 4.8-2,B).

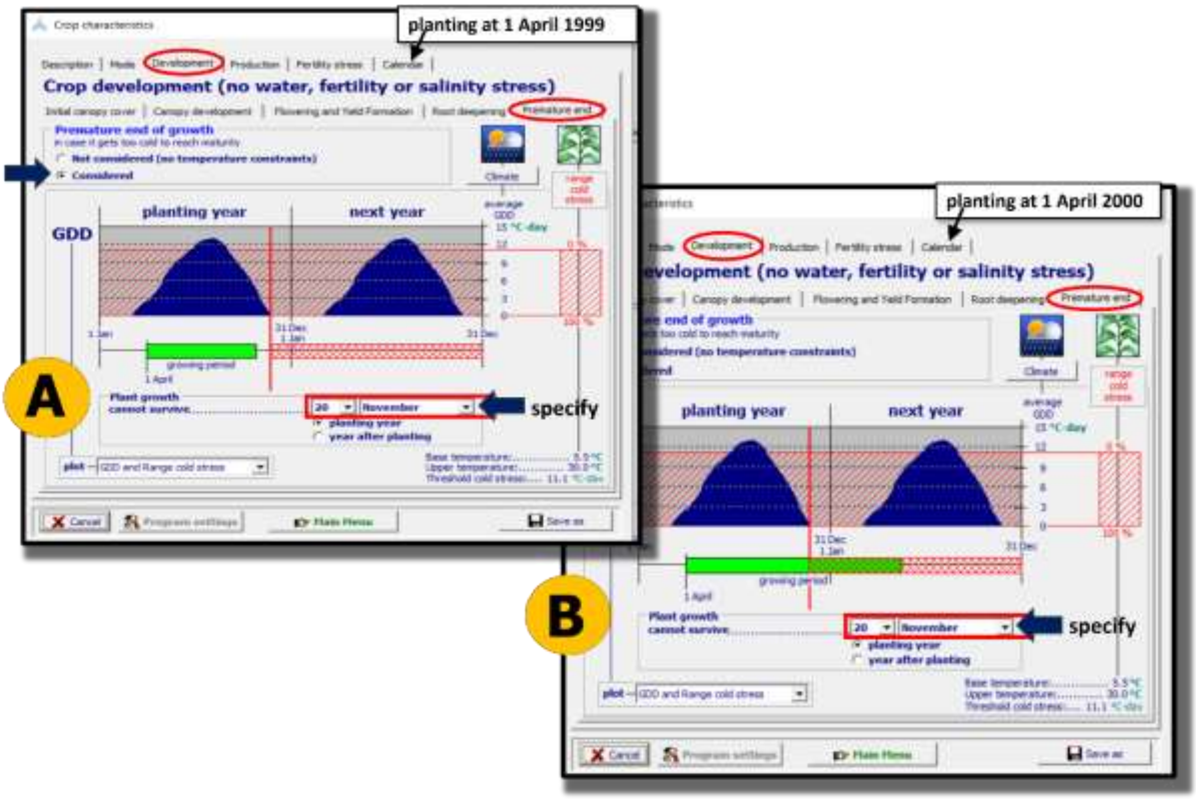


**Figure 4.8-2 – The selection of the date (20 November of the planting year) at which plant growth cannot survive if a premature end of growth is considered in the *Crop characteristics* menu. Depending on the temperature regime of the selected planting year (A: 1999 or B: 2000), AquaCrop specifies whether the length of the growing period will be terminated prematurely (B) or not (A).**

To avoid over calibration, the premature end is specified by a specific date and not by a temperature criterion. For such a criterion, for example, account will have to be taken of (i) the minimum number of growing degrees, (ii) that can still be collected during a series of consecutive days, and (iii) which is valid after a certain date. Since this information might not be readily available the user needs to specify only a date. Because cold stress is likely to be already very severe around that date, the accuracy of the chosen date is not so important. The simulation results will not differ much for different chosen dates, because crop growth and production are already very low during that period.

Because in the Southern Hemisphere annual crops are typically planted at the end of the calendar year, the option exists to select the premature end date in the "year after planting".

## 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. 4.8-1,B). Make sure to select a representative climate file and sowing date for the conversion.

## 4.3 Perennial herbaceous forage crops

### 4.3.1 Crop development in the planting/sowing year and years of regrowth

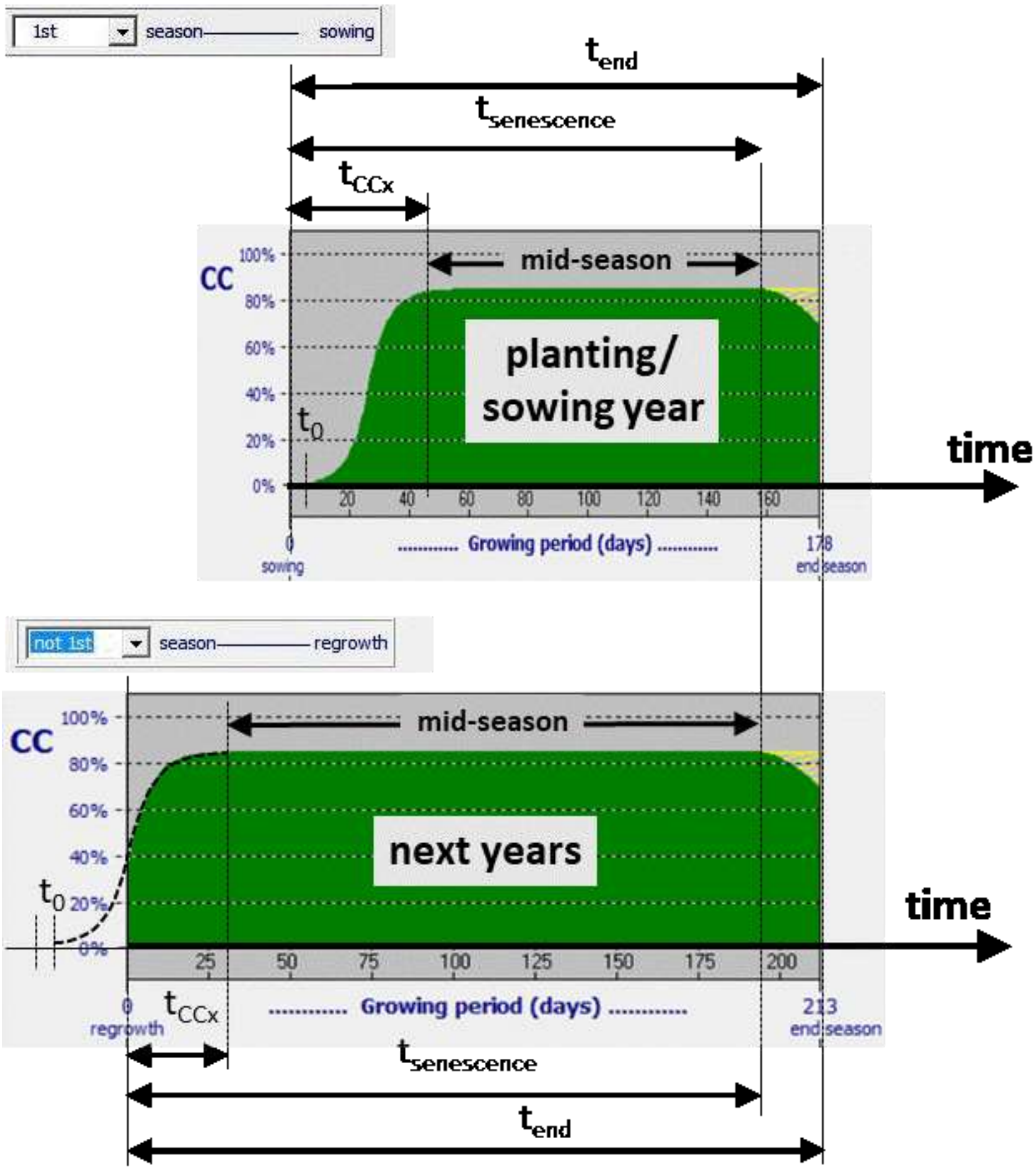



**Figure 4.9 – Canopy development for perennial herbaceous forage crops in a 1st year (sowing/planting year) and not 1st season (next years)**

The canopy development in the 1st season starts at sowing or transplanting and increases from CCo to CCx in the crop development stage ($t_{CCx}$). In not a 1st season (next years), the canopy starts as regrowth with an initial canopy cover CCini which might be larger than CCo (Fig. 4.9). The start of regrowth and the end of the season in a 1st year or not, are determined by the internal crop calendar. Root deepening is only considered in the planting/sowing year. For the other years, the rooting depth is assumed to be constant and equal to the maximum rooting depth.

## 4.3.2 (Natural) self-thinning

The initial plant population of perennials progressively self-thins over the years. In AquaCrop this natural self-thinning (induced by climatic factors such as killing frost) is specified in the crop file. There are two alternative ways to calibrate the natural self-thinning in the ***Perennial cop characteristics menu:*** by specifying (i) the drop in biomass production (Fig. 4.10) or (ii) the drop in maximum canopy cover over the successive years.

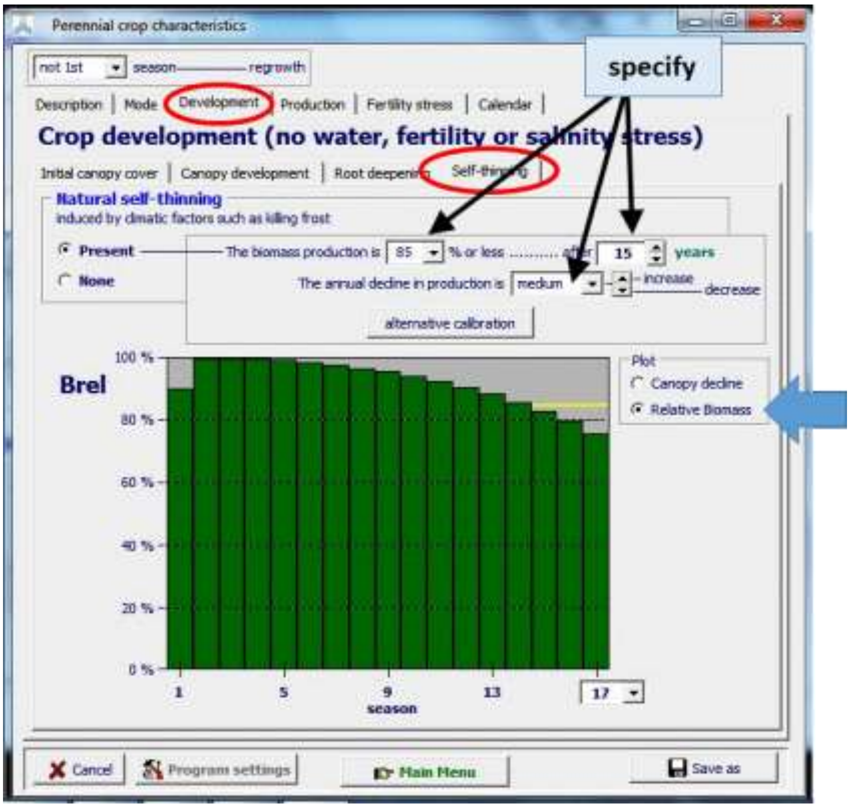



**Figure 4.10 – Calibrating the self-thinning of perennial herbaceous forage crops, by specifying the drop in biomass production over the successive seasons.**

## 4.3.3 Transfer of assimilates

Perennial herbaceous forage crops transfer a considerable fraction of the assimilates to their root system after mid-season. At the start of the next season, a fraction of the stored assimilates are mobilized by transferring them from the root system to the above ground parts of the crop. The rest is assumed to be lost during the off-season by respiration and natural self-thinning, or remain stored in underground organs.

In the Transfer assimilates tab-sheet of the Production tab-sheet in the ***Crop characteristics*** menu, the seasonal transfer of the assimilates between the above and below ground parts of the crop is specified (Fig. 4.11).

If the transfer of assimilates is considered, the user can change (Fig. 4.11):

1. The **duration of the transfer period** in which assimilates are stored in the root system at the end of the season, by specifying (1.a) the number of days or (1.b) the starting date (day and month) of the storage stage. By knowing the total length of the crop cycle and the

specified duration of the storage stage, AquaCrop obtains from the input, the time in calendar days at which the transfer starts;
2. **The fraction of produced assimilates that are stored in the root system during the storage stage**, by specifying the percentage at the last day of the storage stage (when the storage is at its maximum);
3. The **percentage of the stored assimilates that are mobilized** at the start of the next season.

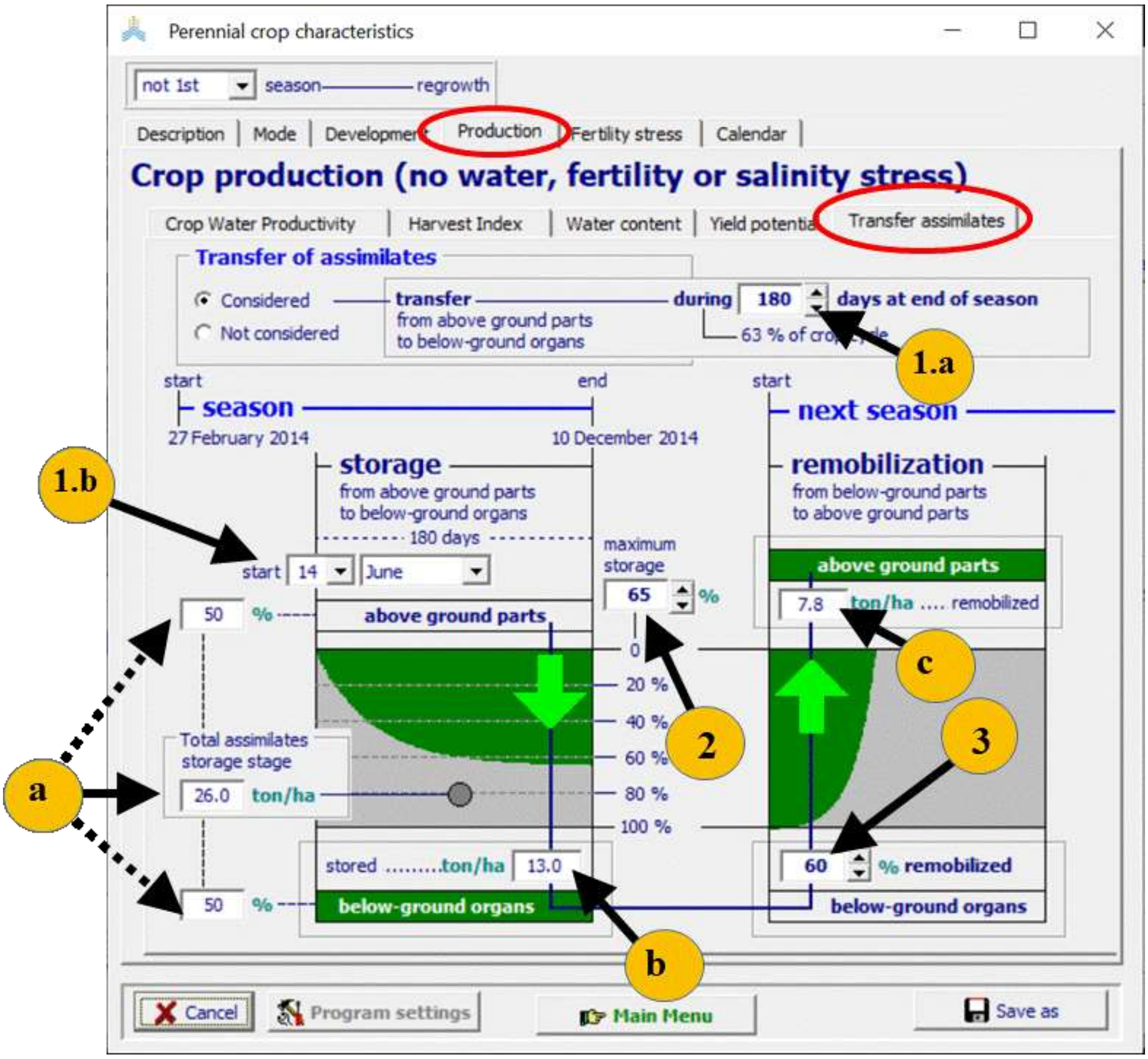



**Figure 4.11 – Input (1 to 3) and information (a to c) on the transfer of assimilates in the "Transfer assimilates" tab-sheet in the *Crop characteristics* menu**

With this information AquaCrop calculates and displays (Fig 4.11):

a) the total mass of assimilates than can be produced during the storage stage in the absence of water, fertility or salinity stress, and the percentages stored in the above ground parts and root system;
b) the mass of assimilates that were stored to the root system;
c) the mass of assimilates that will be transferred from the root system to the above ground parts, at the start of the next season.

### 4.3.4 Internal crop calendar

For perennial crops (herbaceous forage crops), the restart and end of growth is determined by crop characteristics and weather conditions for the selected year. Only for the planting/sowing year, the observed or planned sowing/planting of the crop can be explicitly specified (in the absence of a calendar file), or generated with the help of a calendar file (See 4.1 Planting/sowing date).

For non-planting/sowing years, the restart and end of growth are automatically adjusted to the thermal regime of the simulation year by rules embedded in an internal calendar integrated in the crop file (Fig. 4.12).

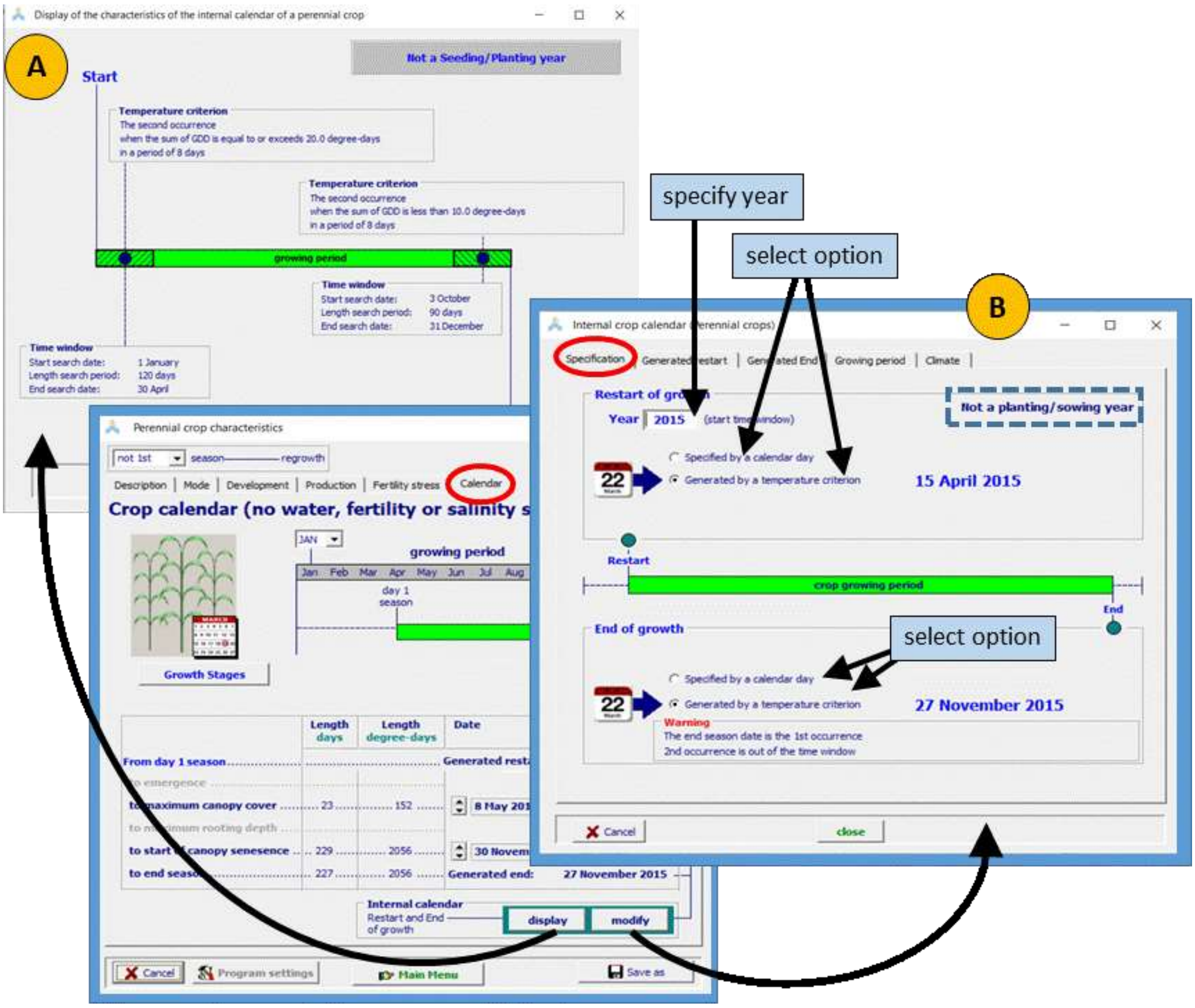



**Figure 4.12 – (A) Display of the embedded rules in the internal crop calendar and (B) Access to the *Internal crop calendar* menu by selecting respectively the <display> command and the <modify> command in the calendar tabular sheet of the *Perennial crop characteristics* menu.**

## 4.4 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. 4.13). 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.

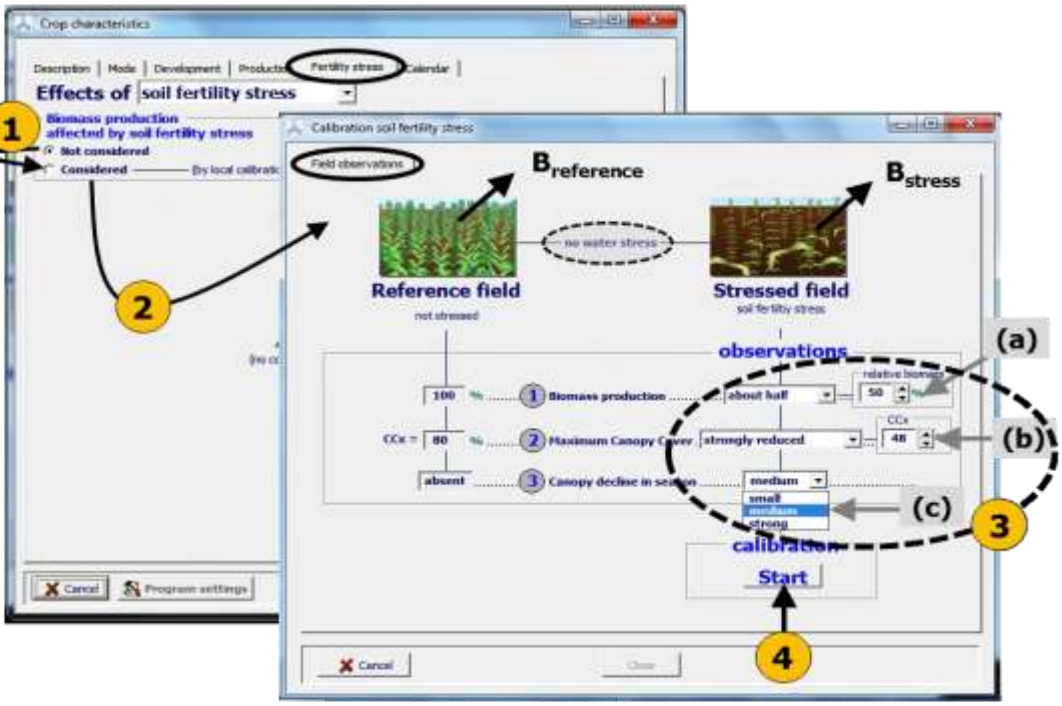



**Figure 4.13 – (1) By selecting 'Considered' in the 'Fertility-stress' tabular sheet, (2) the 'Field observations' tabular sheet of the *Calibration soil fertility stress* menu becomes available in which the user (3) specifies the observed or expected (a) relative biomass production, (b) maximum canopy 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. 4.13).

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. 4.13). 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. 4.14).

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.

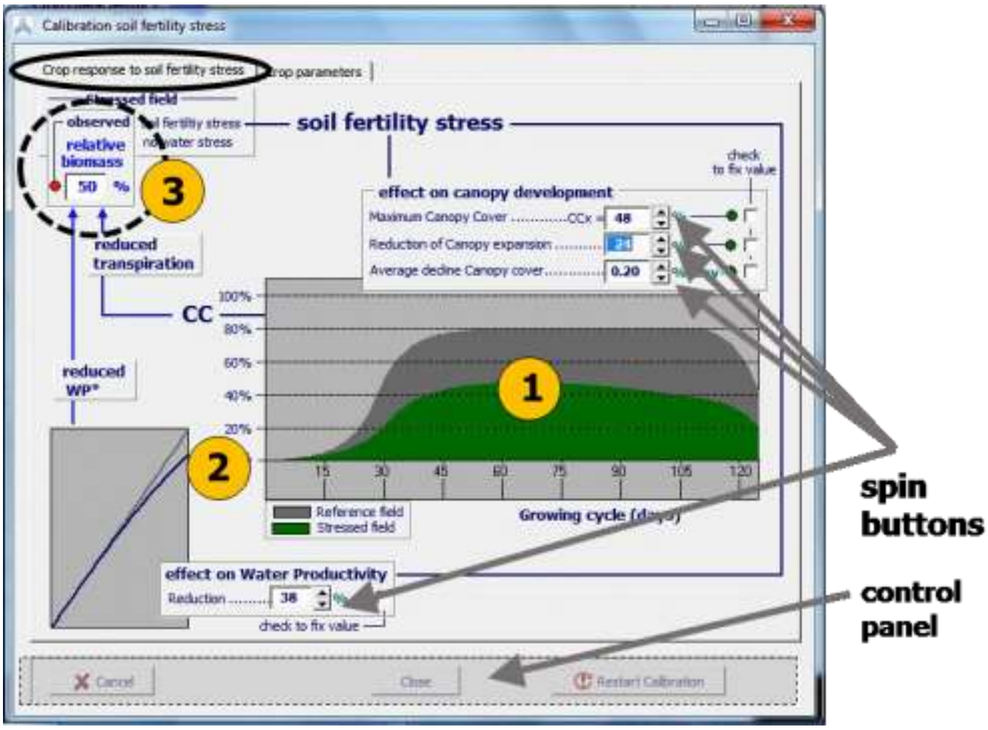



**Figure 4.14 – The 'Crop response to soil fertility stress' tabular sheet of the *Calibration soil fertility stress* menu in which the effect of soil fertility stress (1) on canopy cover and (2) on the decline of WP* during the season, is plotted and is fine-tuned by means of the four spin buttons and (3) by respecting the specified relative biomass.**

## 4.5 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.

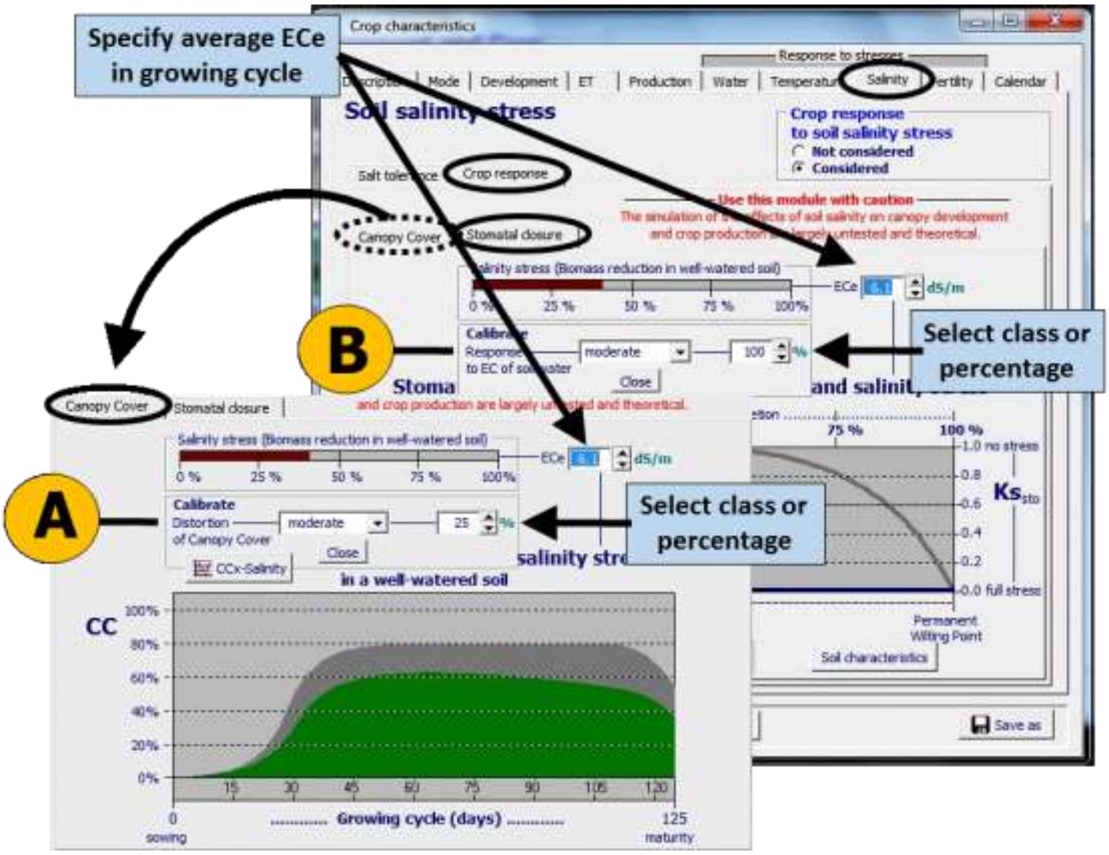



**Figure 4.15 – The ‘Crop response’ in the ‘Salinity’ tabular sheet of the *Crop characteristics* menu in which the effect of soil salinity stress on (A) Canopy Cover in a well-watered soil and (B) Stomatal closure in a water depleted soil, can be updated**

- **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. 4.15A). 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. 4.15B).

## 4.6 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. 4.8A).

# 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).

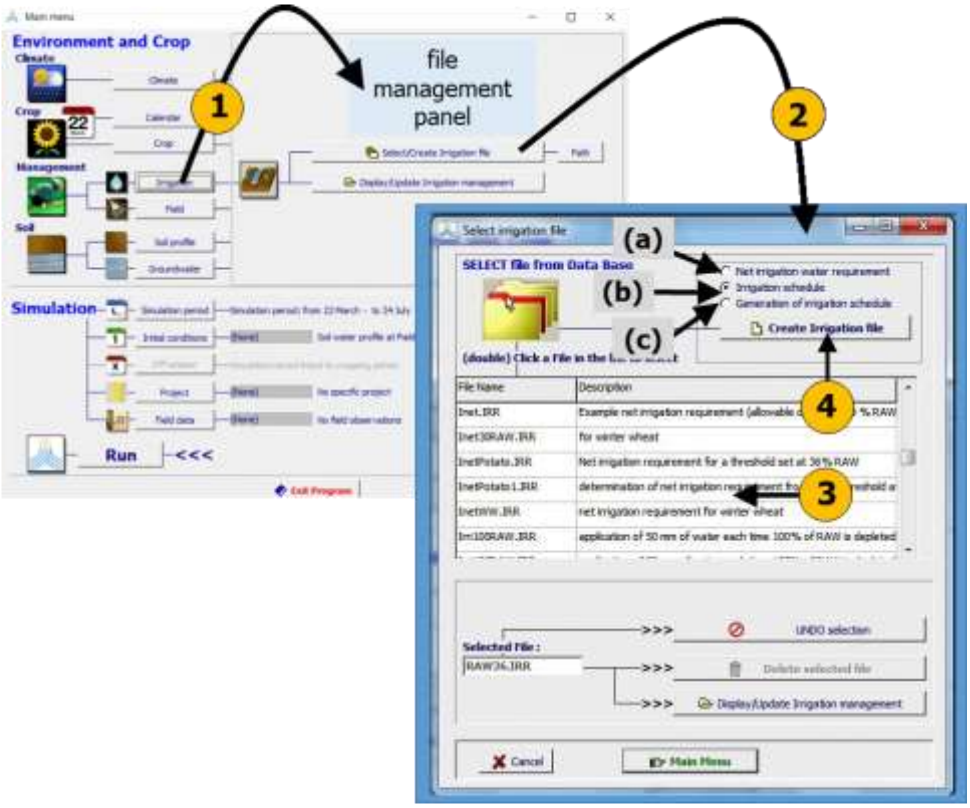



**Figure 5.1 – By selecting (1) the <Irrigation> command and subsequently (2) the <Select/Create Irrigation file> command in the file management panel of the Main menu, the user gets access to the Select irrigation file menu, in which (3) one of the available irrigation files or (4) the option to <Create 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.

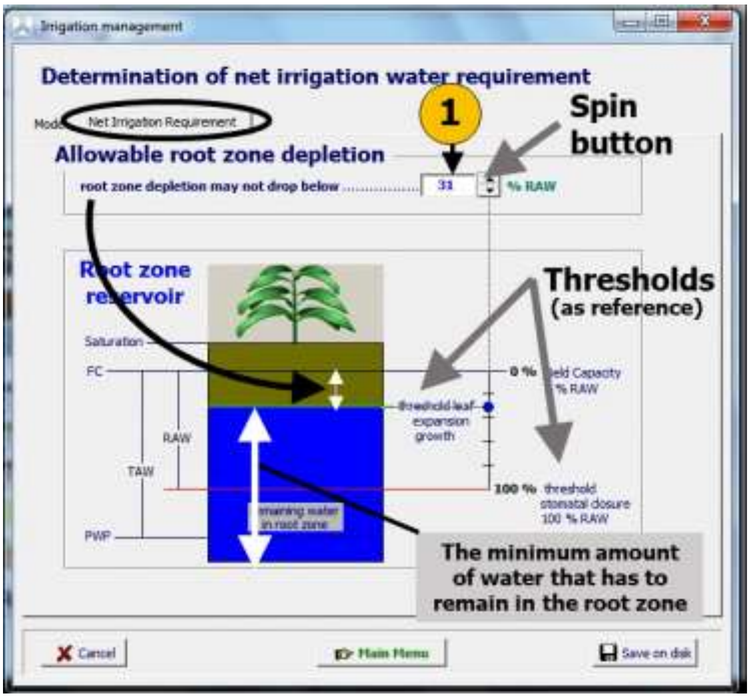



**Figure 5.2 –Specified (1) allowable root zone depletion, for the determination of the net irrigation water requirement, in the 'Net Irrigation Requirement' tabular sheet of the *Irrigation management* menu.**

### 5.1.3 Assessing an Irrigation schedule

The irrigation schedule mode is used to assess an existing irrigation schedule. For each irrigation event the user specifies (Fig. 5.3):

1. **Time of application**: The time is entered as the number of days after a particular reference date. The reference date can be:
   - o ***the onset of the growing period***. With this option the irrigation events are not linked to a specific year, but relative to the specified or generated start of the growing period in the year of simulation. If the onset is generated by a temperature or rainfall criterion, the start of the growing period varies with the temperature of rainfall regime of the year, and the irrigation dates will be shifted accordingly (Fig. 5.3);
   - o ***a day in a particular year***. This option is useful when the irrigation applications are observed events.

   The number of days after the reference date are 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**: The electrical conductivity (EC) of the irrigation water is specified if low quality water was used.

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

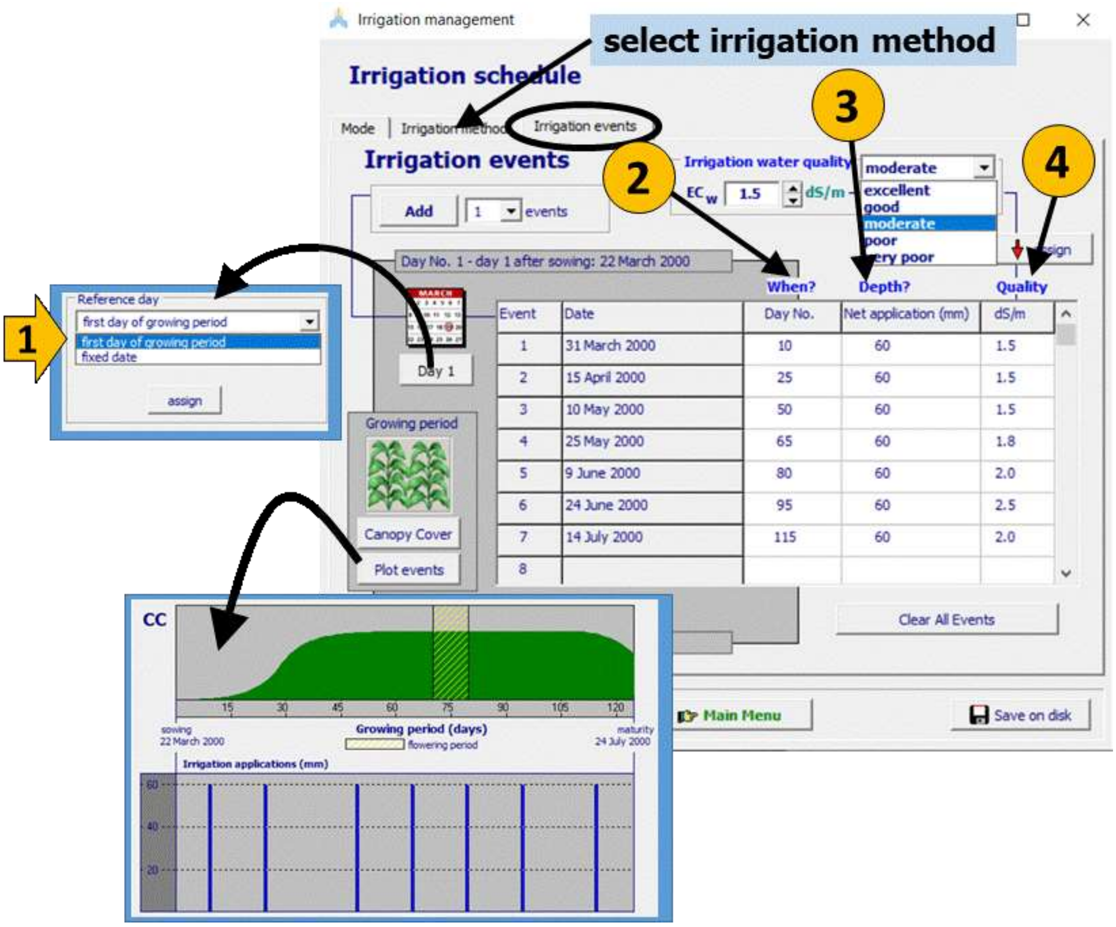



**Figure 5.3 – Specified (1) reference day and (2) time of application, (3) irrigation application depth, and (4) water quality, for the assessment of an irrigation schedule in the 'Irrigation events' tabular sheet of the *Irrigation management* menu. The irrigation method is determined in the 'Irrigation 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.
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.
5. **Last irrigation:** If applicable, the last day of irrigation (expressed as days before the end of the growing period) can be specified.

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

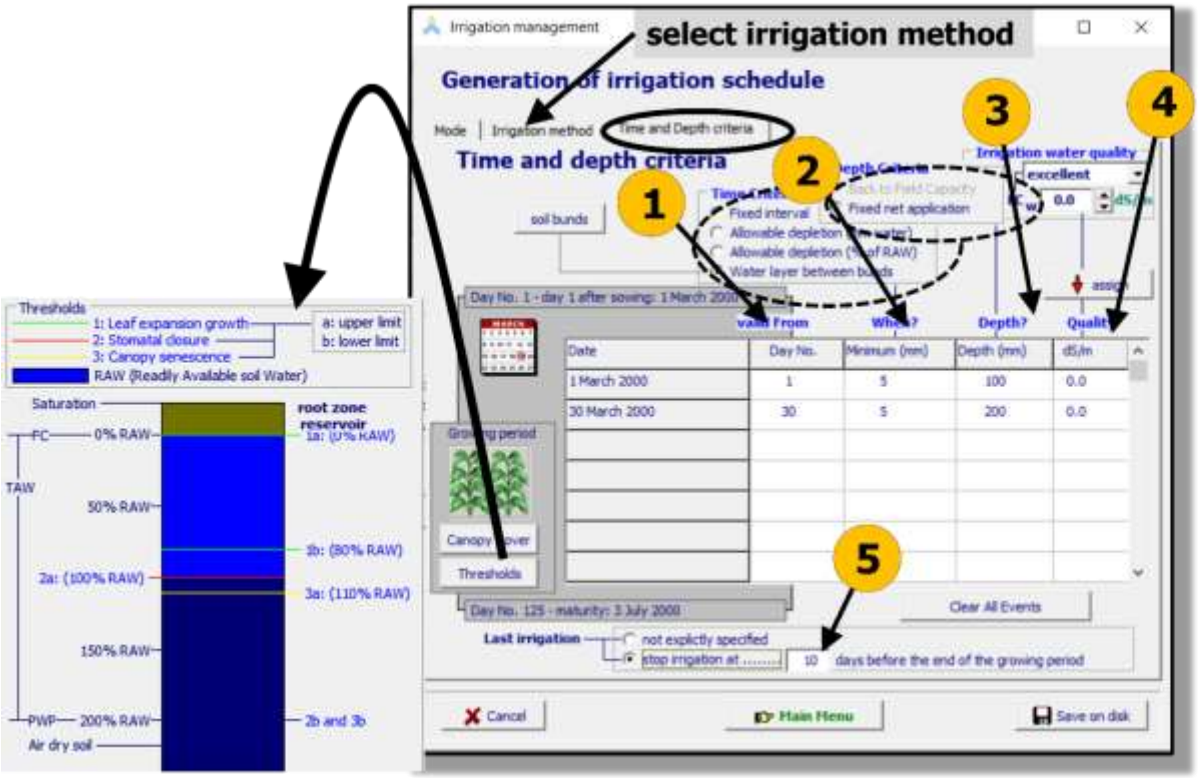



**Figure 5.4 – Specified (1) day from which the selected criteria are valid, (5) day of last irrigation, and values for the (2) time criterion, (3) depth criterion and (4) water quality, for the generation of an irrigation schedule in the 'Time and Depth criteria' tabular sheet of the *Irrigation management* menu. The irrigation method is determined in the 'Irrigation method' tabular sheet.**

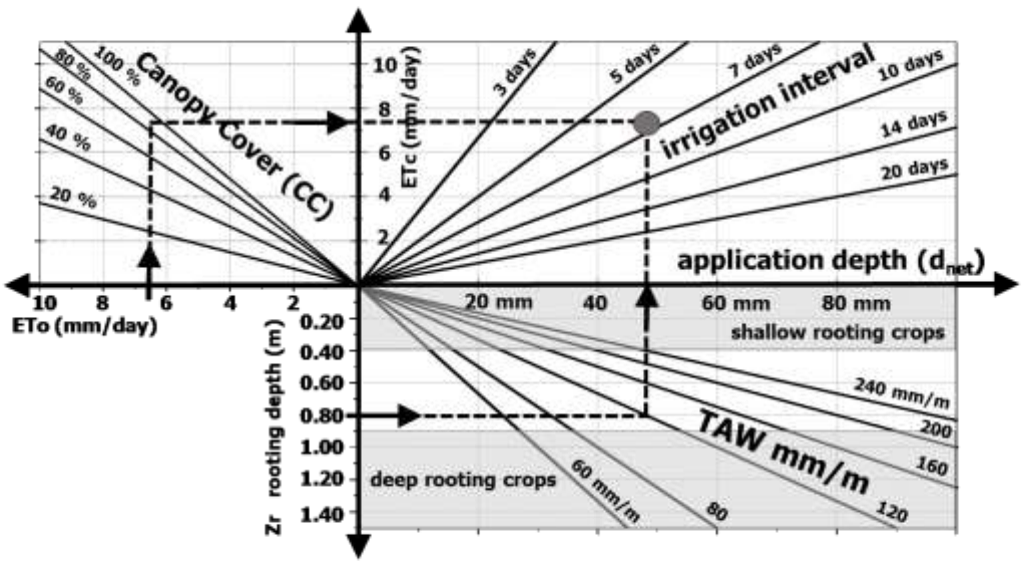
**Table 5.1 – Types of time and depth criteria used for generating irrigation schedules**

| 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:<br>▪ zero : the applied irrigation will bring the soil water content in the root zone at Field Capacity (reached at the end of the day);<br>▪ positive: an over irrigation is planned for example for leaching salts out of the root zone (for example + 20 mm);<br>▪ 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 5.11).

### 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 5.11):

- **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;
- **Multiple harvests**: to specify multiple harvests during the season.

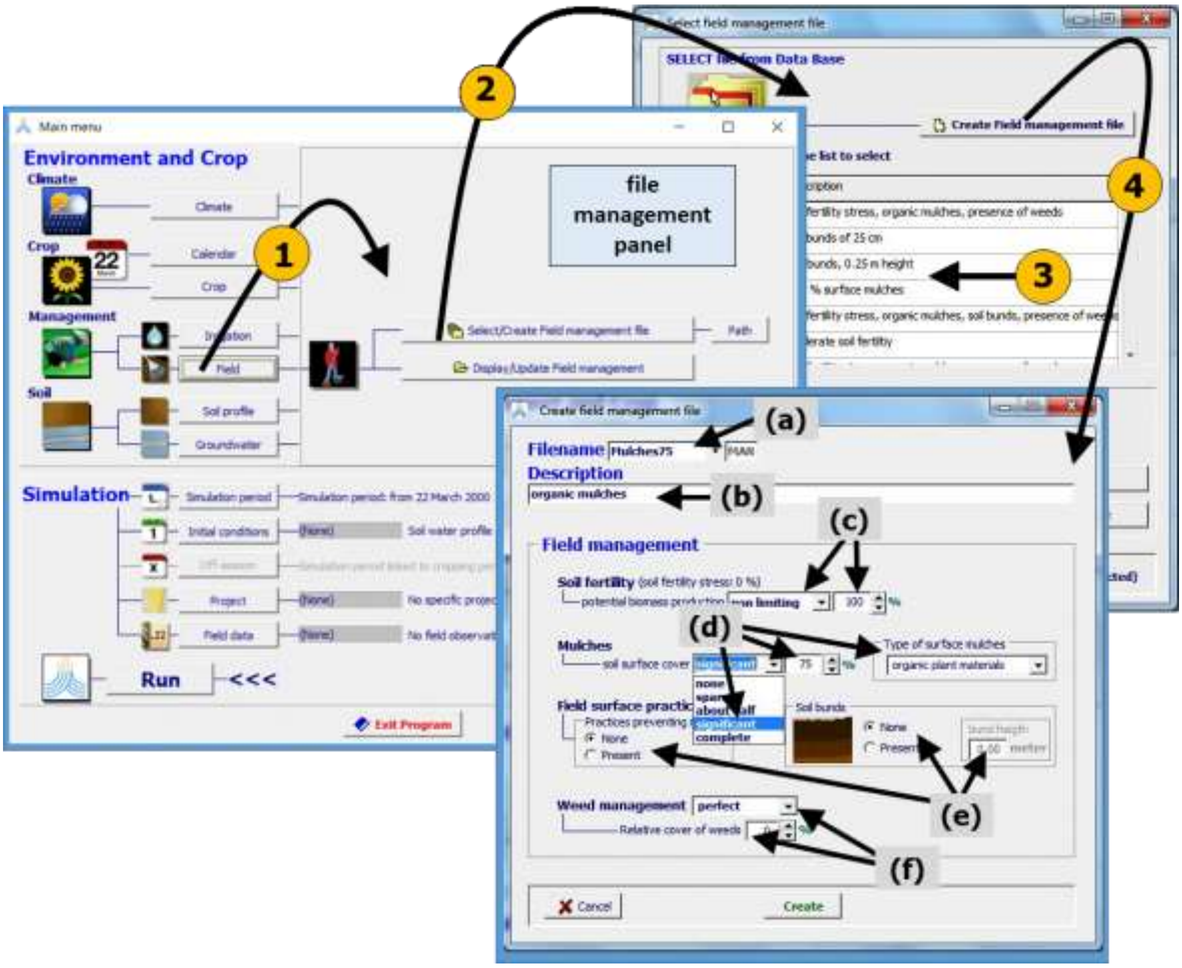



**Figure 5.5 – By selecting (1) the <Field> command and subsequently (2) the <Select/Create field management file> command in the file management panel of the *Main menu*, the user gets access to *Select field management file* menu, in which (3) one of the available files or (4) the command to <Create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


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

☐ **Soil fertility:**

Only if the crop for soil fertility stress is calibrated (Chapter 4, section 4.4), 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.

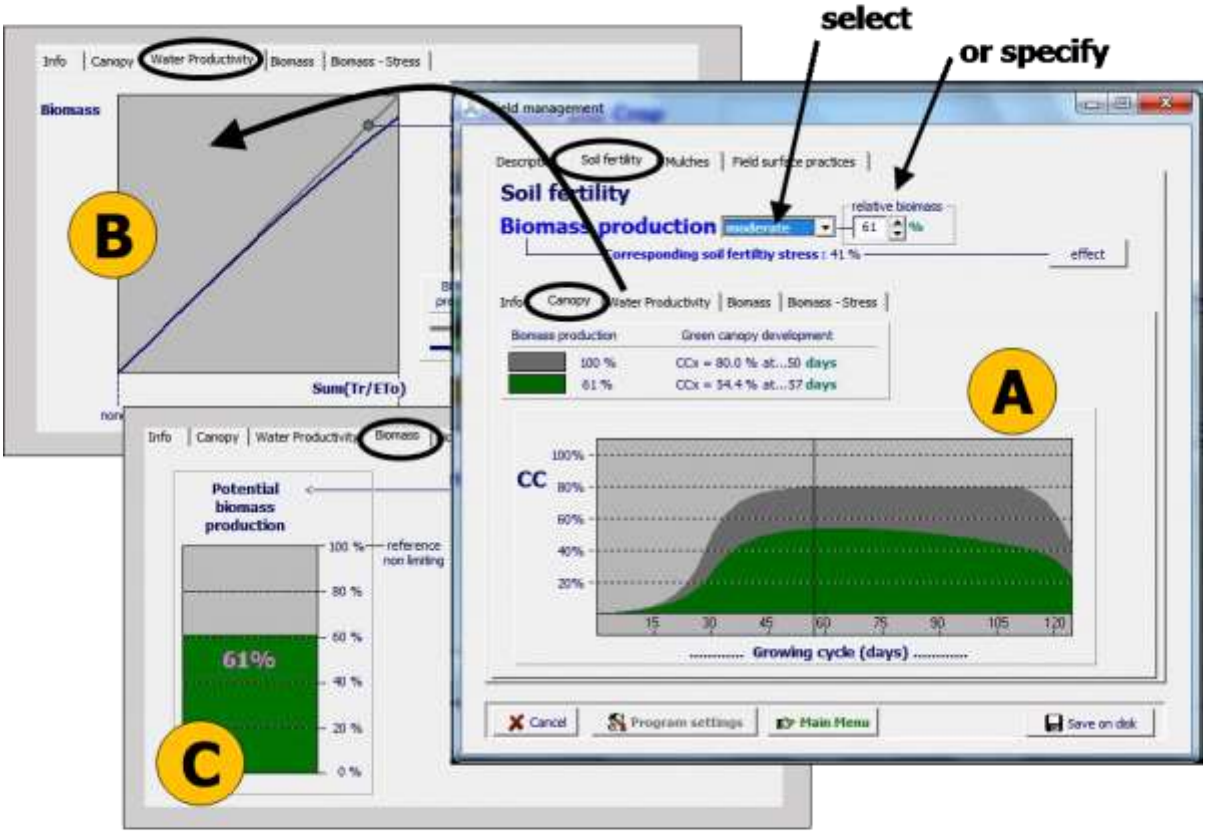



**Figure 5.7 – The 'Soil fertility' tabular sheet of the *Field management* menu in which the maximum relative dry aboveground biomass that can be expected in the soil fertility stressed field is specified, and the corresponding effect on (A) canopy cover, (B) water productivity, and (C) potential biomass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

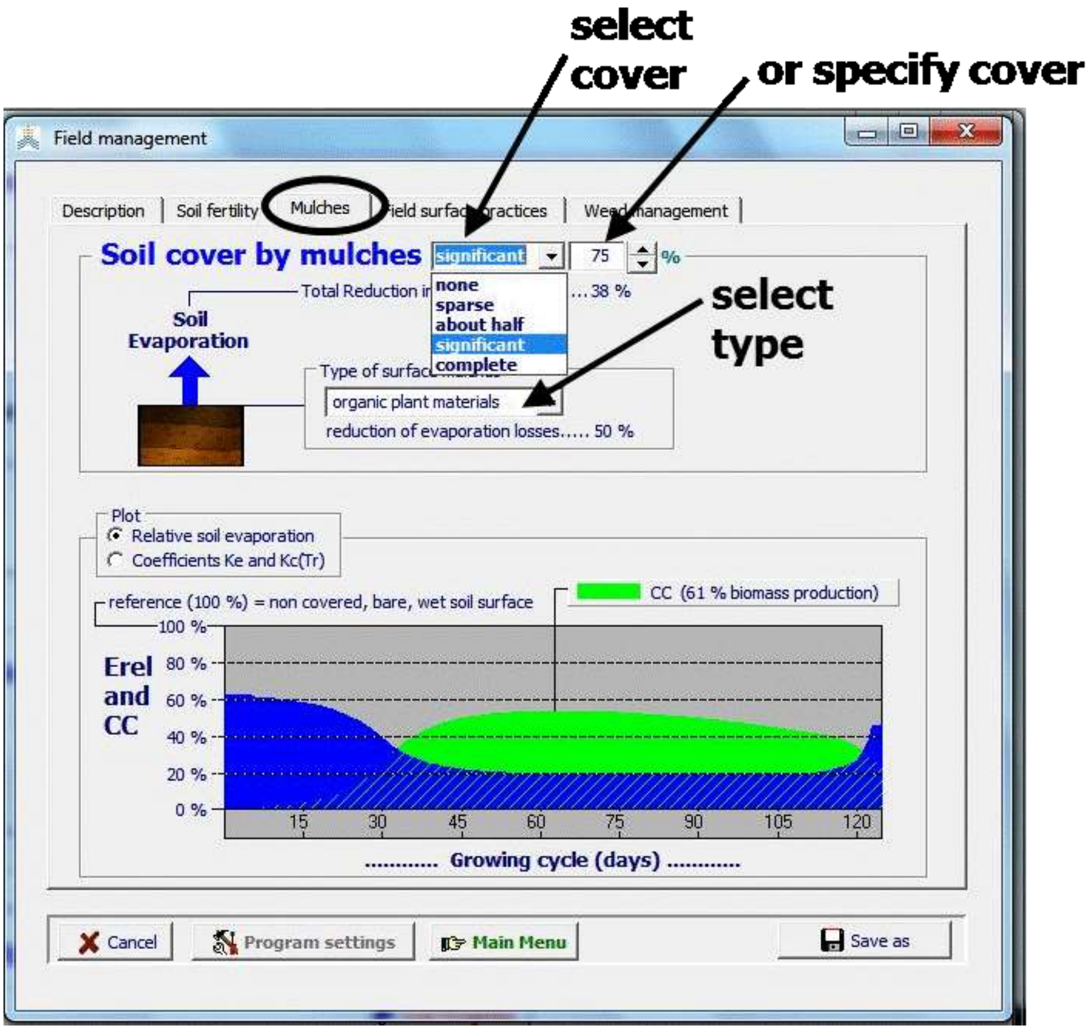



**Figure 5.8 – The 'Mulches' tabular sheet of the *Field management* menu in which the soil cover by mulches and the type of mulches are specified, and the corresponding effect on soil evaporation is displayed.**

☐ **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. 5.9). 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.

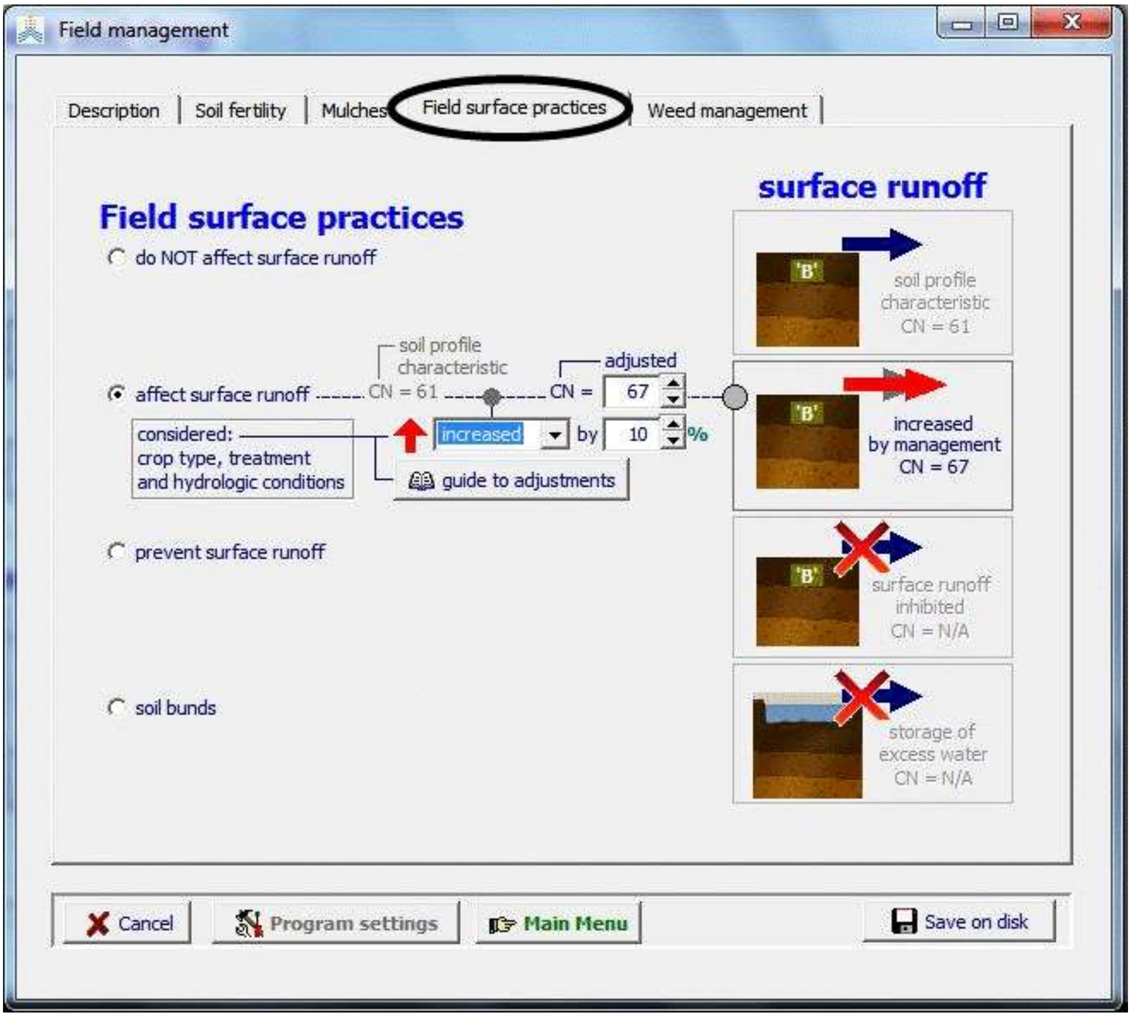



**Figure 5.9 – The 'Field surface practices' tabular sheet of the *Field management* menu in which the effect of field surface practice on surface runoff is specified.**

☐ **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.

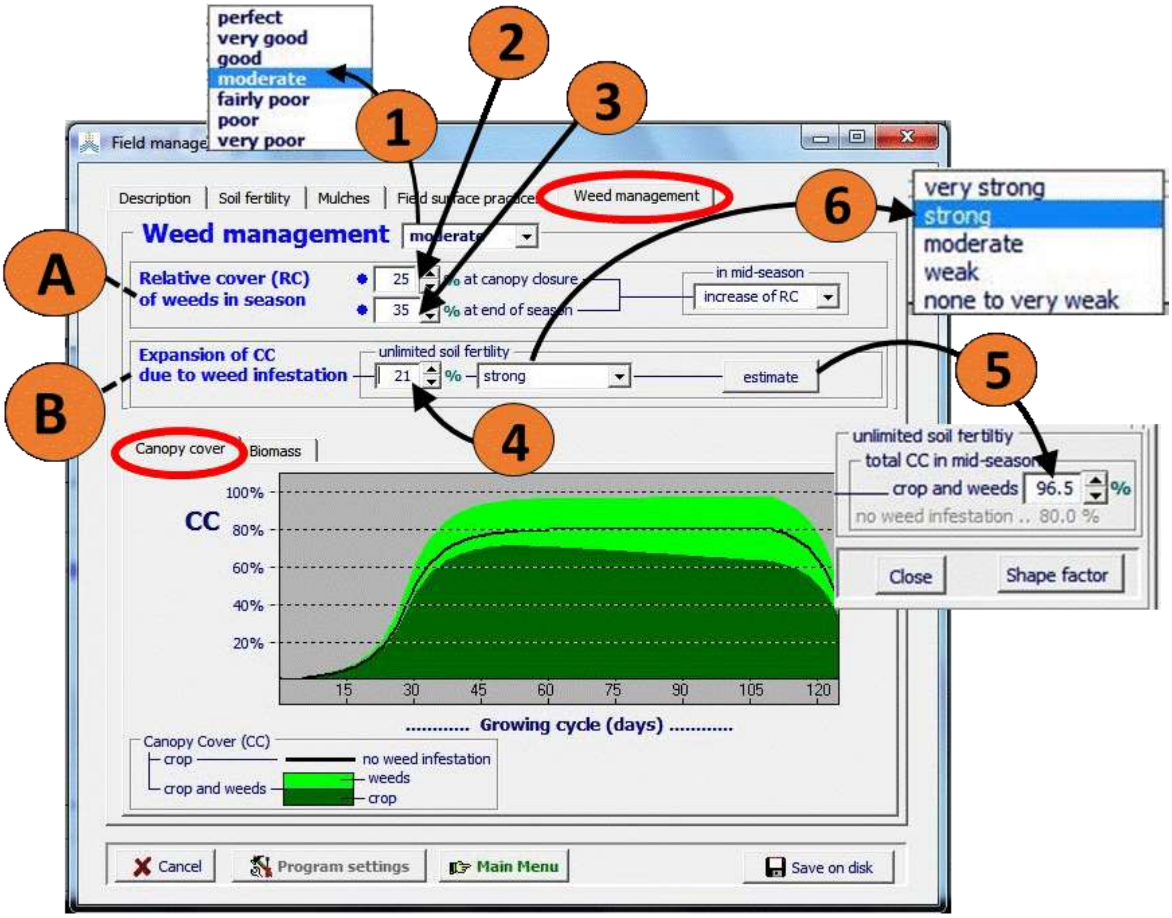



**Figure 5.10 – The 'Weed management' tabular sheet of the *Field management* menu in which (A) the relative cover of weeds and (B) the expansion of the Canopy Cover (CC) due to weed infestation is specified.**

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.

- ☐ **Multiple harvests:**

In the ***Field management*** menu (Fig. 5.11), the user:

1. Specifies the canopy cover after cutting (CCini);
2. Select the option to specify the timing of harvest;
   - By specifying the days of harvests with reference to a specific date (First day of the growing period or a specific day in a particular year)
   - By generating harvests events with one or another criterion.:
     - Fixed interval in days;
     - Fixed interval in GDD;
     - Mass (ton/ha) of dry above ground biomass produced;
     - Mass (ton/ha) of dry yield produced;
     - Mass (ton/ha) of fresh yield produced.
3. Displays the ***Canopy development and crop production in the cutting interval*** menu (Fig. 5.11), in which (a) the canopy development, (b) the time to reach maximum canopy cover and (c) the production in the absence of water or salinity stress and weed infestation is displayed (for the selected CCini and month). This might be valuable information to fine-tune the values of CCini and if field observations are available.

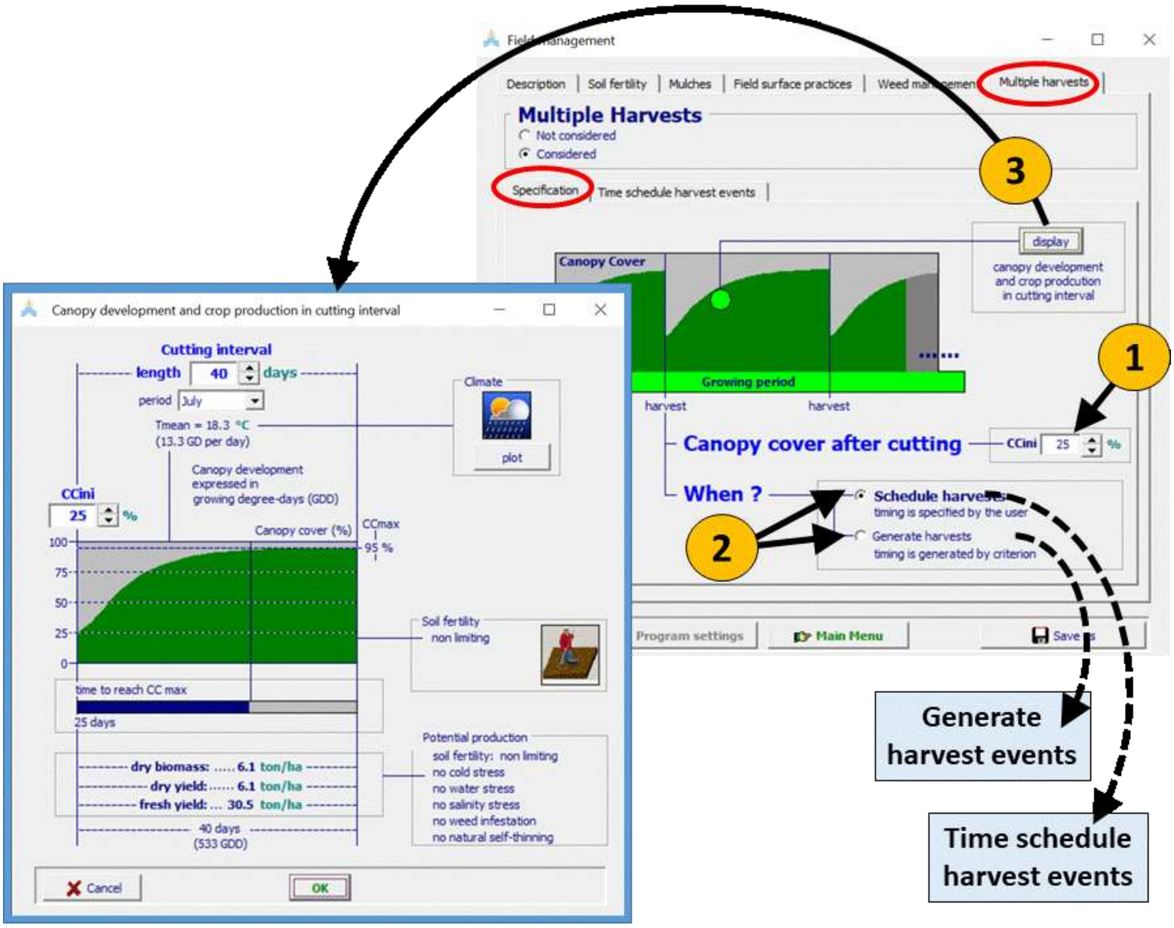



**Figure 5.11 – Specification of multiple harvests in the *Field management* menu**

# 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.

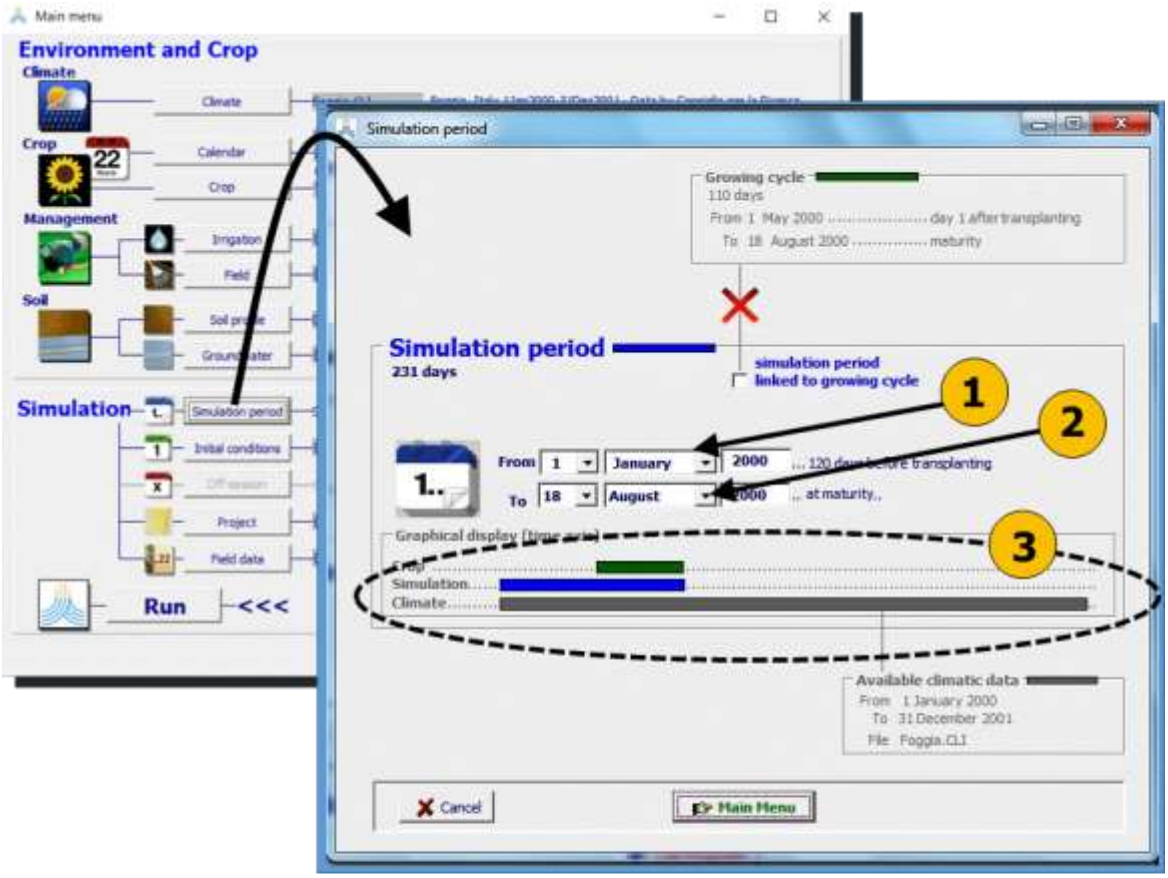



**Figure 6.1 – By selecting the <Simulation period> command in the *Main menu*, the user gets access to the *Simulation period* menu, in which (1) the start and (2) end date of the simulation period are specified and (3) the growing period (green), simulation period (blue) and time range of available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

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

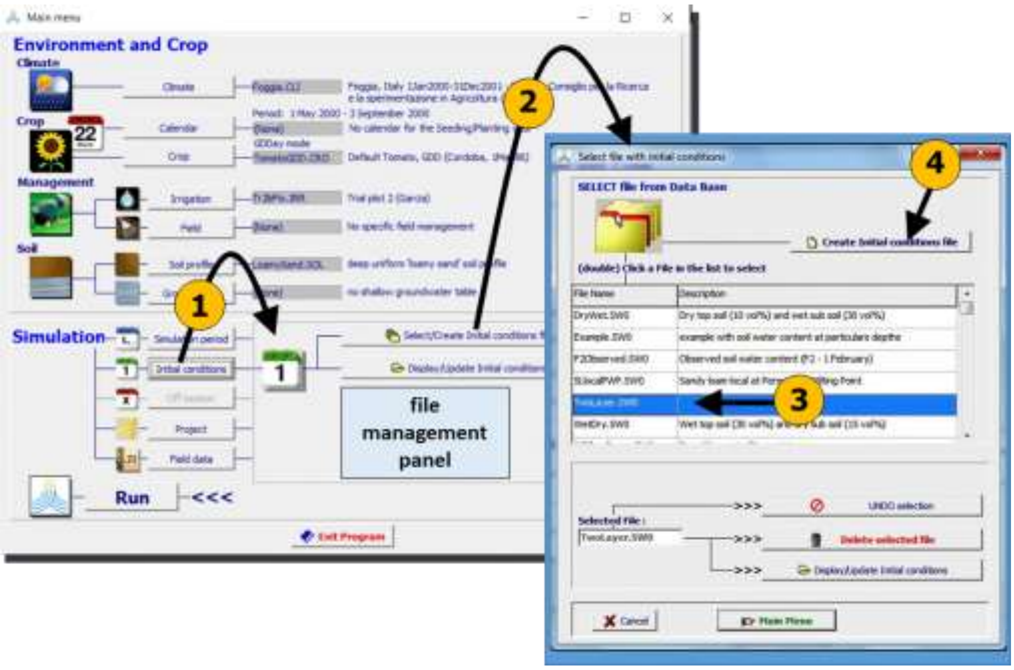



**Figure 6.2 – By selecting (1) the <Initial conditions> command and subsequently (2) the <Select/Create file Initial conditions> command in the file management panel of the *Main menu*, the user gets access to the *Select file with initial conditions* menu, in which (3) one of the available files with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

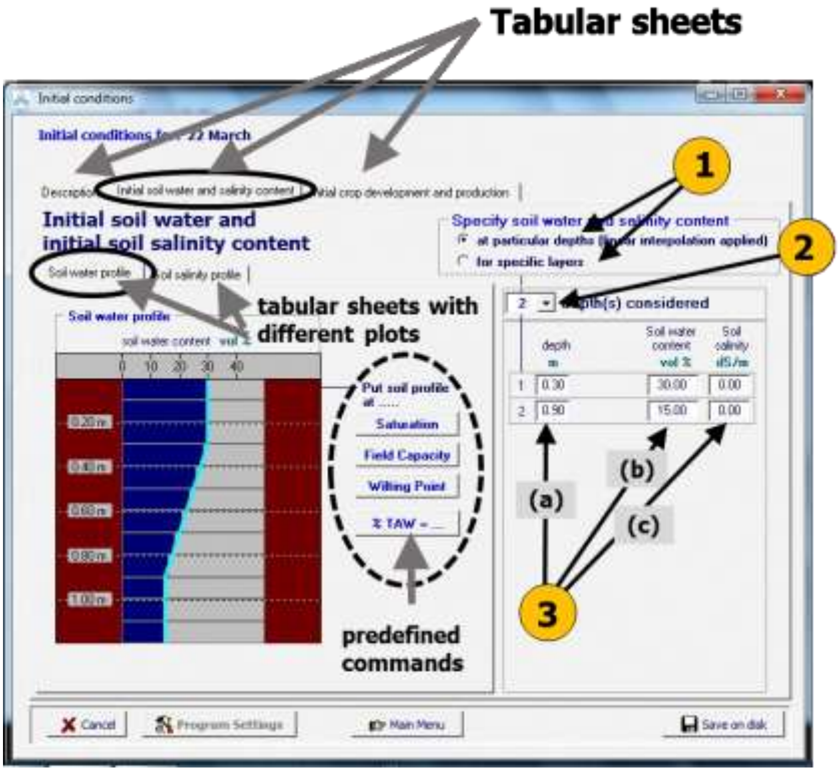



**Figure 6.3 – The *Initial conditions* menu with its tabular sheets: 'Description', 'Initial soil water and salinity content' (displayed), and 'Initial crop development and production'.**

### 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.

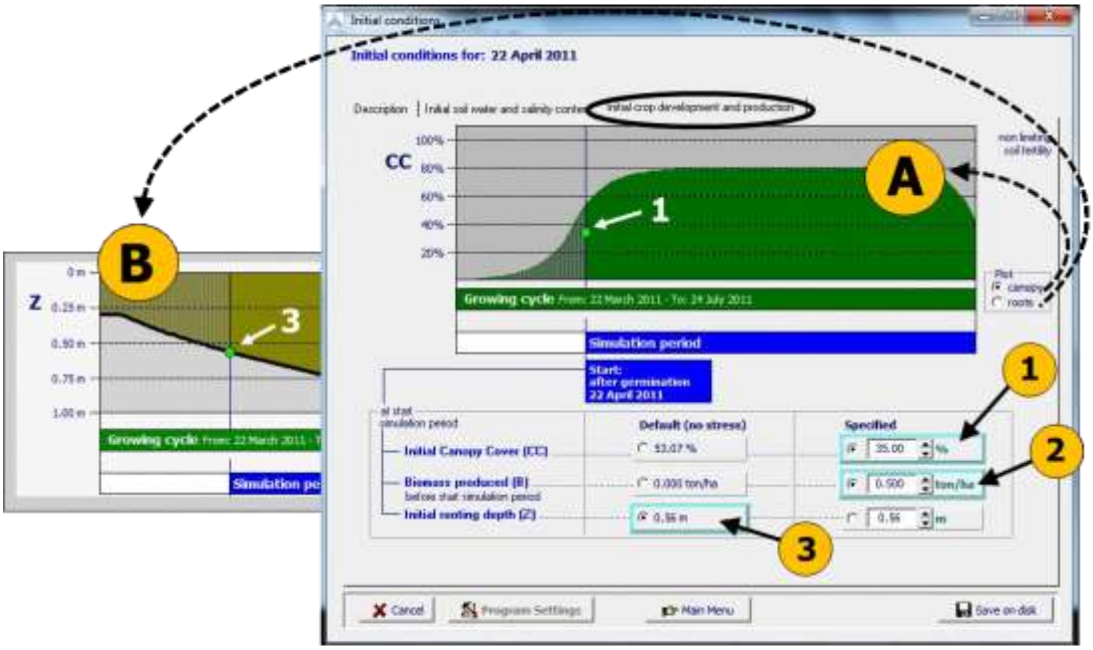


**Figure 6.4 – Specified (1) canopy cover, (2) biomass produced, and (3) rooting depth at the start of the simulation period, in the 'Initial crop development and production' tabular sheet of the *Initial conditions* menu, with indication of the specified canopy cover and rooting depth in the corresponding 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 run parameters* menu, in which the (1) KEEP or RESET option, or (2) Default setting for simulation program parameters can be selected for the successive simulations enveloping the growing cycle**

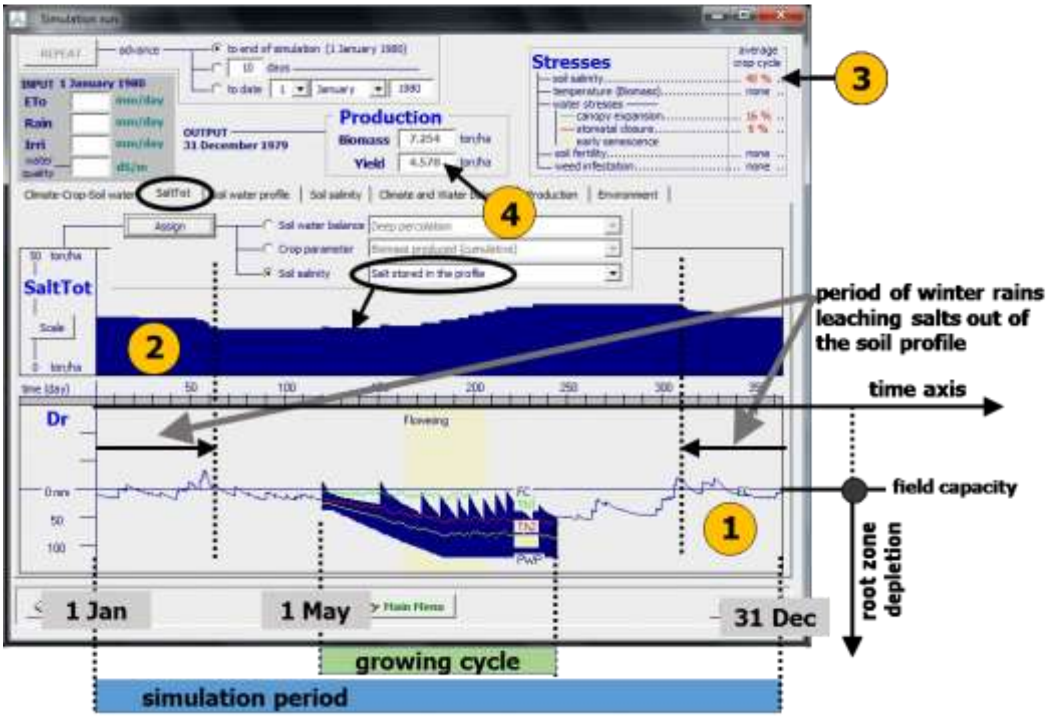



**Figure 6.6 – Display, in the *Simulation run* menu, of (1) root zone depletion, (2) salt stored in the soil profile, (3) soil salinity stress and (4) crop yield, as a result of irrigating with water of poor quality and the leaching effect of winter rains in the off-season. Runs were repeated for a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

## 6.4 Projects

### 6.4.1 Project file

When running a simulation, initial conditions applicable at the start of the simulation period and environmental conditions relevant during the simulation period are considered. If the simulation period does not fully coincide with the growing cycle of the crop, off-season conditions valid outside the growing period will be considered as well.

Before running a simulation, the user can select in the Main menu the sowing date or crop calendar, the simulation period and the appropriate environmental, initial and off-season files (Project file is 'None'). 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.

### 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, and (c) the names of files (climate, calendar, crop, environment, initial conditions and field data) 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 the growing cycle for the first run** | |
| 3 | Year number of cultivation (always 1 for annual crops, and 1, 2, 3 … for perennials), with 1 being the Seeding/planting year |
| 4 | Day number(1) for the first day of the simulation period |
| 5 | Day number(1) for the last day of the simulation period |
| 6 | Day number(1) for the first day of the growing cycle |
| 7 | Day number(1) for the last day of the growing cycle |
| **c. – The names(2) and directories(3) for the 14 files containing the characteristics of the fine-tuned crop, crop calendar, environment (climate, management and soil), initial and off-season conditions, and field data** | |
| 8 up to 49 | - Climate (CLI) file and the enveloped:<br>- air temperature (Tnx or TMP) file,<br>- reference ET (ETo) file,<br>- rainfall (PLU) file, and<br>- atmospheric CO2 concentration (CO2) file;<br>- Calendar (CAL) file<br>- Crop (CRO) file;<br>- Irrigation management (IRR) file;<br>- Field management (MAN) file; |

| | |
|---|---|
| | - Soil profile (SOL) file;<br>- Groundwater table (GWT) file;<br>- Initial conditions (SW0) file;<br>- Off-season conditions (OFF) file.<br>- Field data (OBS) file |
| In case of **multiple projects**, section ‘b’ and section ‘c’ are specified for each of the successive runs (in the next 47 lines). | |
| (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);<br>(2) File name: in the absence of a file (None), the default conditions (see Tab. 1.1) are considered;<br>(3) Directory (path): in the absence of a file, (None) is specified as directory. | |

### 6.4.3 Creating project files

Creating a project becomes straight forward, when before launching the creation, the files containing the characteristics of the crop, calendar, environment (climate, management, and soils), initial conditions and field data for the specific run are already selected in the ***Main menu***. This is however not required since still other files in the ***Create project*** menu can be selected. 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).

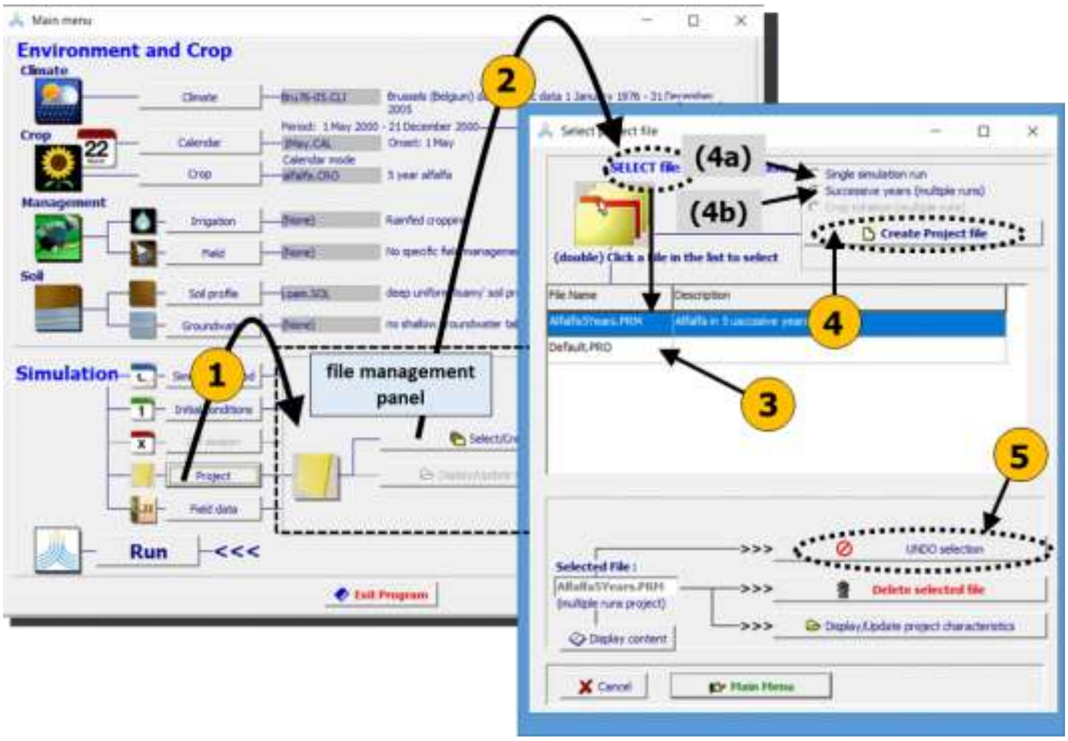



**Figure 6.7 – By selecting (1) the <Project> command and subsequently (2) the <Select/Create Project file> command in the file management panel of the *Main menu*, the user gets access to the *Select project file* menu, in which (3) one of the available project files can be selected, (4) the <Create project file> command can be selected and its type can be specified: ‘4a’ (Single simulation run), or ‘4b’ (Successive years (multiple runs)), and (5) the project selection can be undone.**

After selecting the **<Create project file>** command, the ***Create project*** 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*** menu, a corresponding information and/or file management panel is displayed with indication of the selected file and required information if relevant (Fig. 6.8). Another file can be selected, or the selection can be undone in the ***Select file*** menu when selecting the **<Select file>** command. If no file is selected (File name is '(None)'), default conditions are considered (see Table 1.1). The data specified in the information and/or file management panel differ depending on the selected key command, and consists of:

- **Climate**: Selected files containing the rainfall, ETo, air temperature and CO2 data and the name of the enveloping climate file;
- **Calendar:** The name and description of the selected crop calendar file are displayed;
- **Crop**: The name and description of the selected crop file, with specification of the sowing/planting date, or the way it is determined, are displayed (Fig. 6.8). The information differs if a calendar file is selected or not and if an annual or perennial crop is selected
- **Irrigation**: The name and description of the selected irrigation management file;
- **Field**: The name and description of the selected field management file;

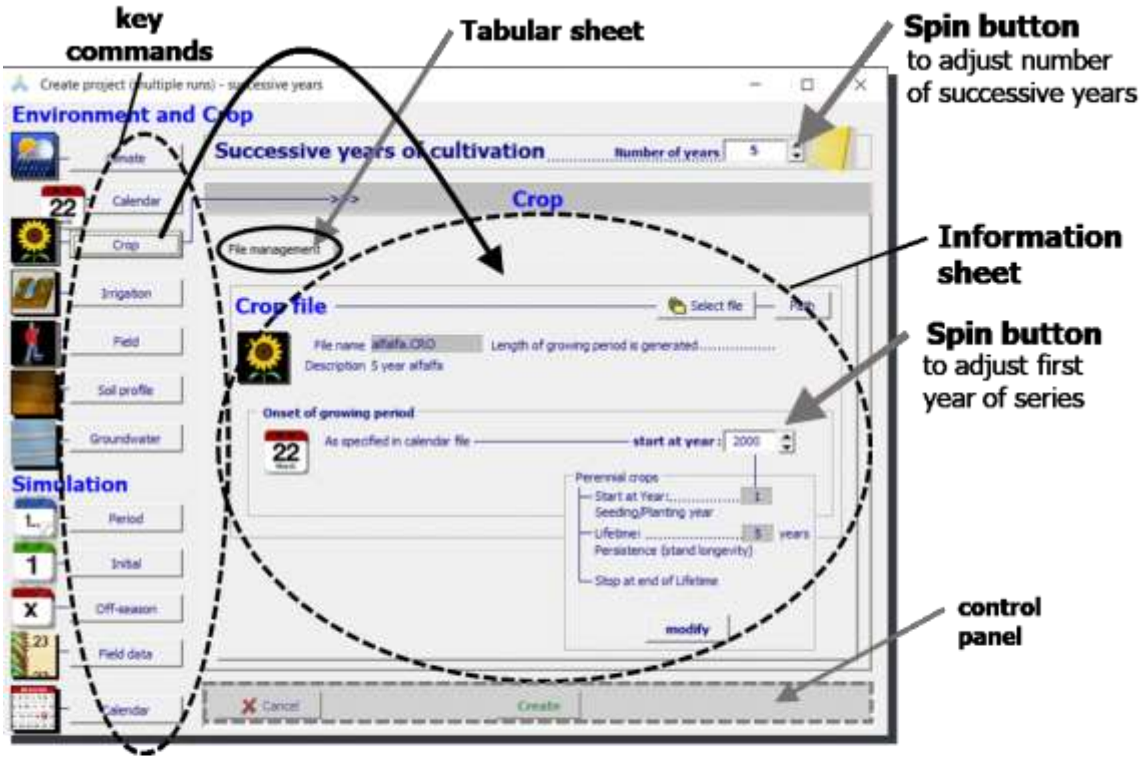



**Figure 6.8 – The key commands in the *Create project* menu, with which information sheets can be displayed for file management and other data.**

- **Soil profile**: The name and description of the selected soil profile file;
- **Groundwater**: The name and description of the selected groundwater table file;
- **Period**: The simulation period, which can be:
    - o linked to the growing cycle;

- o 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:
    - o linked to the growing cycle;
    - o start at a specific date for each year;
    - o linked to the simulation run of the previous year (the ‘KEEP’ option for the initial conditions applies for this case. See section 6.3);
- **<u>Initial</u>**: The name and description of the selected file with the initial conditions;
- **<u>Off-season</u>**: The name and description of the selected file with the off-season conditions;
- **<u>Calendar</u>**: 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).

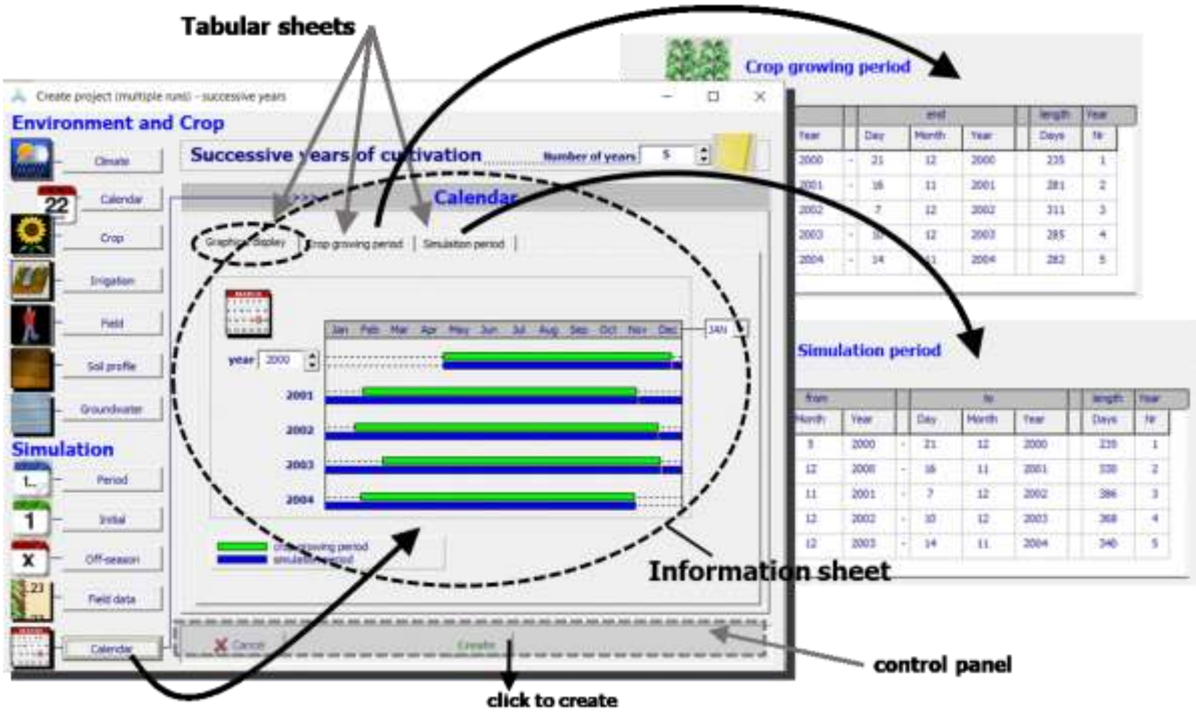



**Figure 6.9 – The ‘Calendar information sheet’ in the Create project menu, with the graphical and numerical display of the start, end and length of the growing cycle (green bars) and simulation period (blue bars) in the various tabular sheets.**

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).

**<u>General remarks</u>**

1. If no file is selected default conditions are considered (see Table 1.1).
2. Once a project is created, its content can be displayed in the ***Display of project characteristics*** menu and the growing and simulation period, and the selection of files can be adjusted in the ***Project characteristics*** menu (see 6.4.5).

### 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, and the update of the content of the selected files. 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 a multiple run 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 Table 1.1), and
- all program parameters are rest to their default value

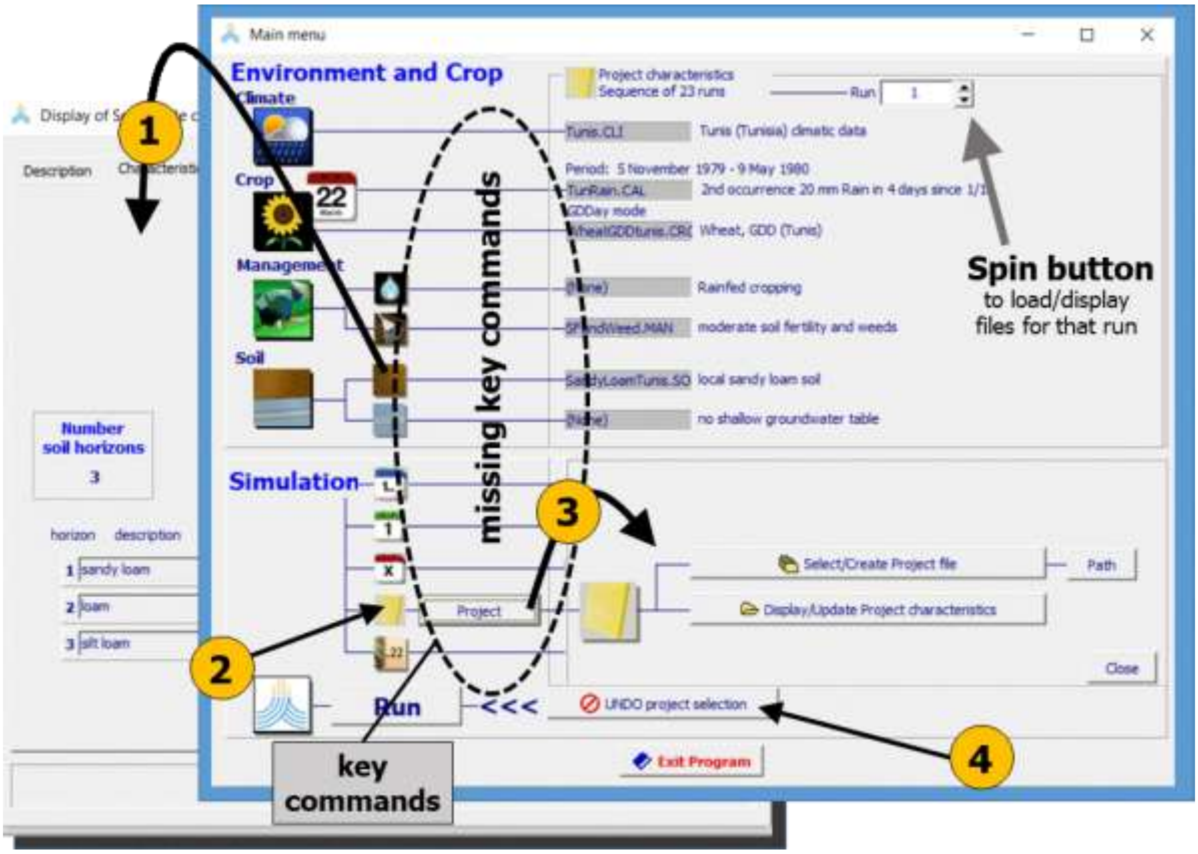



**Figure 6.10 – The *Main* menu in project mode (with missing key commands), in which (1) characteristics of the input can be displayed, (2) characteristics of projects can be displayed (by clicking on the icon), (3) characteristics of projects can be updated (section 6.4.5) and/or other projects can be created (section 6.4.3) 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):

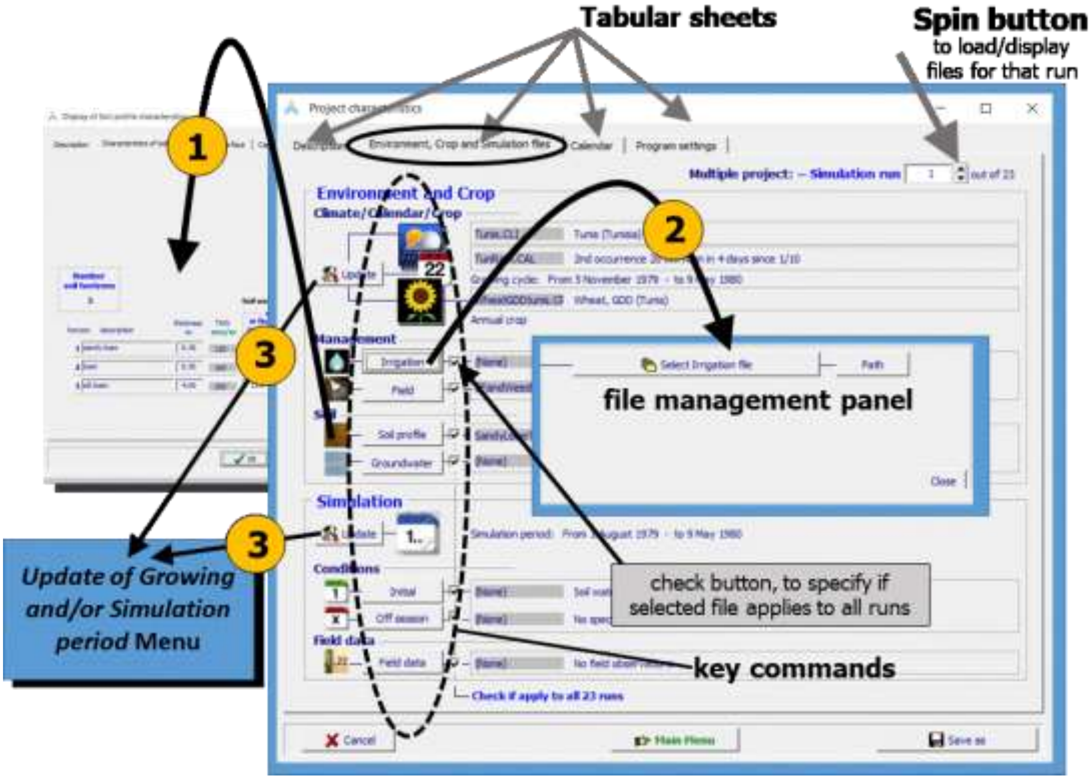



**Figure 6.11 –The Project characteristics menu with its tabular sheets: 'Description', 'Environment, Crop and Simulation files' (displayed), 'Calendar', and 'Program settings'. In the 'Environment, Crop and Simulation files' tabular sheet (1) characteristics of the selected input files can be displayed, and (2) other input files can be selected in the appropriate file management panels, and (3) the growing and simulation period can be updated.**

**Tabular sheets:**

- **<u>Description</u>**: to adjust the description of the project file;
- **<u>Environment and simulation files</u>**: In case of multiple run projects, each specific run can be selected with the spin button (Fig. 6.11). The planting date, simulation period and set of files might differ between the runs.
  - to display the characteristics of the input by clicking on their icon (Fig. 6.11 – 1);
  - to select another soil profile file, irrigation file(s), field management file(s), groundwater file(s), file(s) with initial conditions and with off-season conditions and field data file(s) in the corresponding file management panels (Fig. 6.11 - option 2):
    - Only the Soil profile file has to be common between the simulation runs of a multiple runs project;
    - The irrigation file(s), field management file(s), groundwater file(s), file(s) with initial conditions and with off-season conditions, and field data file(s), need not to be common between the simulation runs of a multiple runs project. Use the corresponding check buttons if the selected files are common or not in all runs of a multiple runs project;

- to update the growing and simulation period, and the corresponding climate, crop calendar and crop file, in the ***Update of growing and/or Simulation period*** menu, after clicking on the **<update>** command in the ***Project characteristics*** menu (Fig. 3.11 - 3).
- **Calendar**: to display the start, end and length of the growing cycle and simulation period;
- **Program settings**: to alter the settings of program parameters.

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

By respecting the structure of the project file (Tab. 6.1), the user can alter its content by making the required changes directly in the text file (providing more flexibility than via the software interface). This is useful for making a quick adjustment in multiple runs projects. 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).

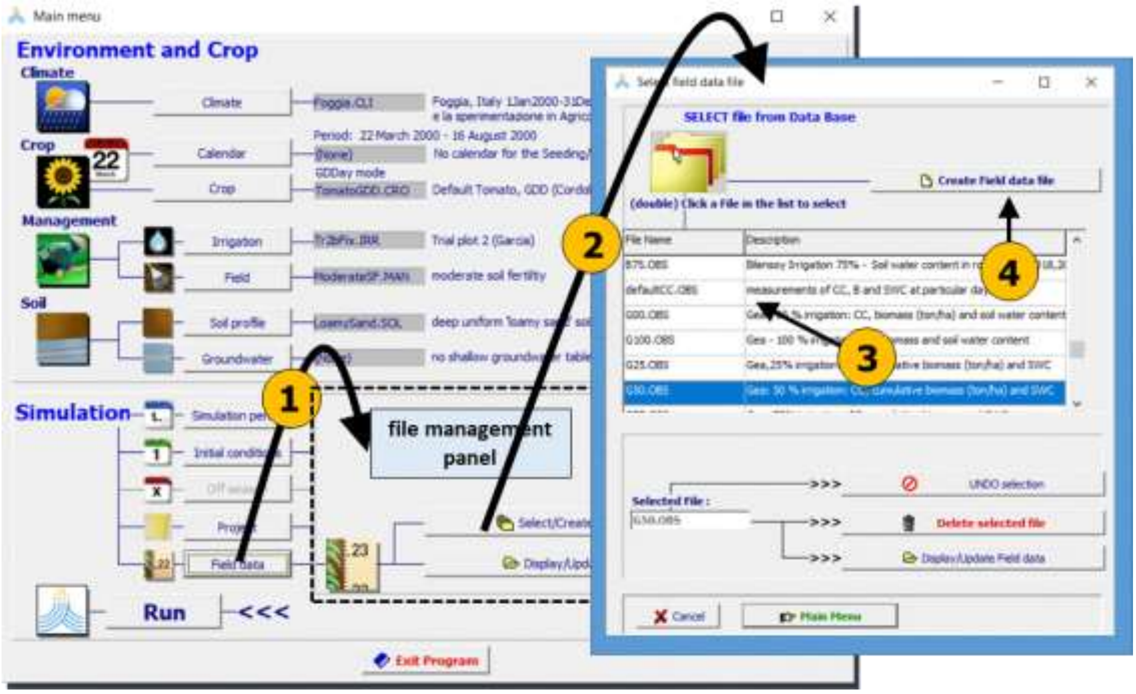



**Figure 6.12 – By selecting (1) the <Field data> command and subsequently (2) the <Select/Create Field data file> command in the file management panel of the *Main menu*, the user gets access to the *Select field data file* menu, in which (3) one of the available field data files or (4) the command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

- **Description**: to adjust the description of the file containing the field data;
- **Field data**: 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.

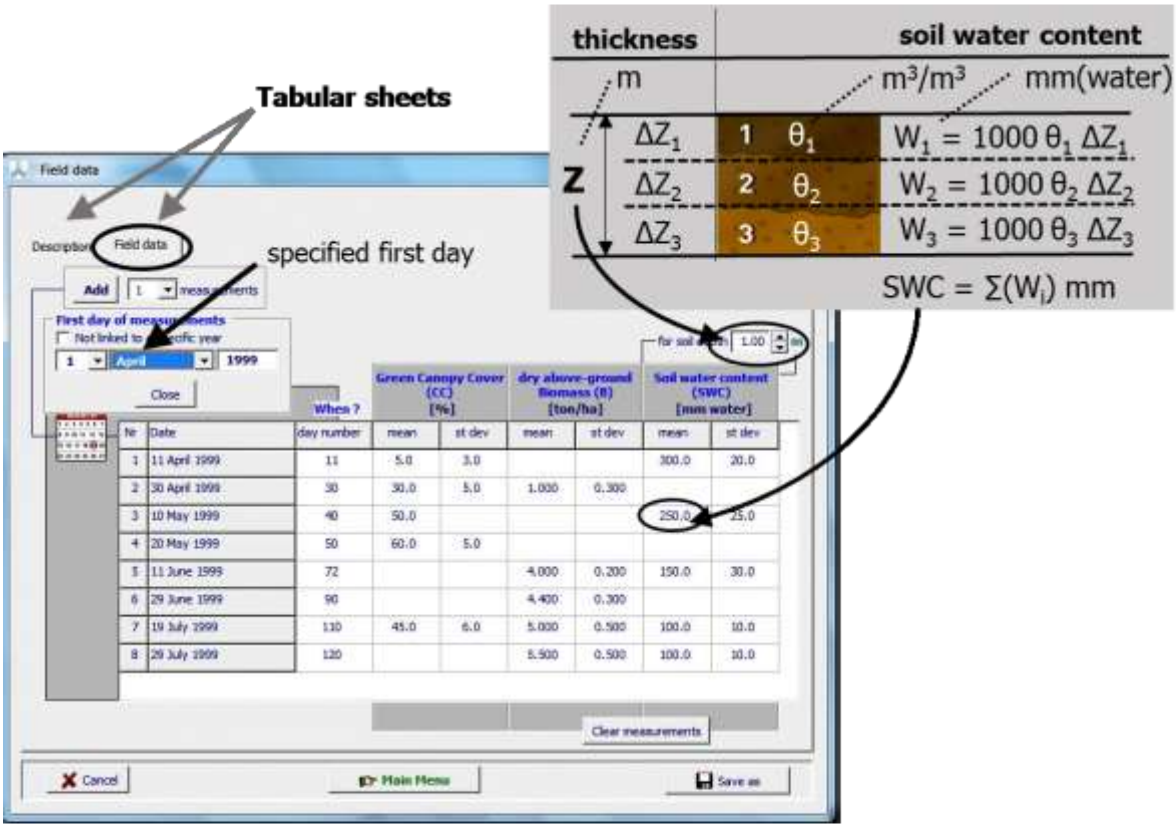



**Figure 6.13 – The *Field data* menu with its tabular sheets 'Description' and 'Field data' (displayed) in which the first day of observations and field data (green canopy cover, dry above-ground biomass and/or soil water contents) at particular days are specified.**

## 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.

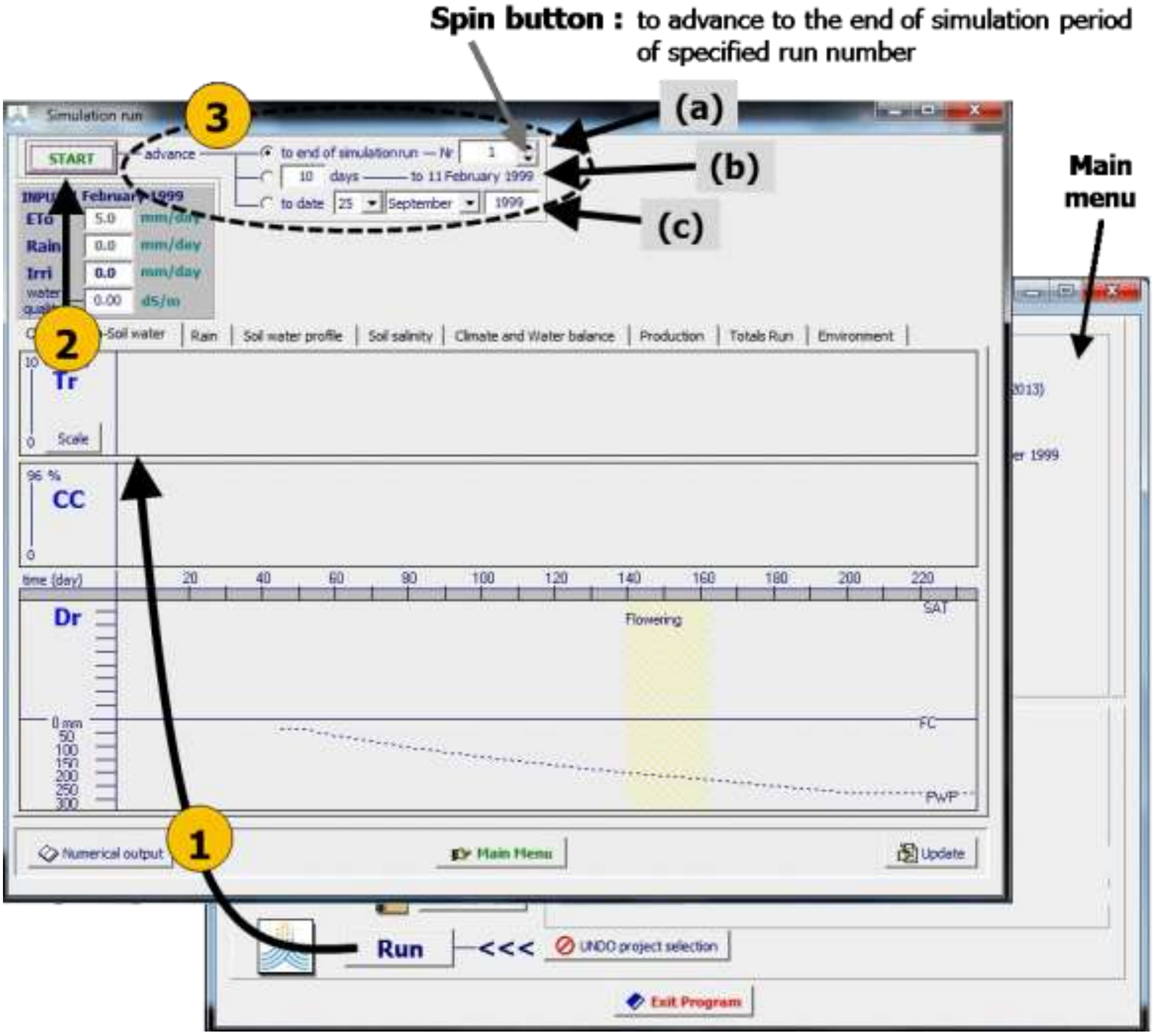



**Figure 6.14 – By selecting (1) the <Run> command in the *Main menu*, the user gets access to the *Simulation run* menu, in which (2) the simulation can be started. Depending on (3) the selected advance option the simulation will (a) run to the end of the simulation period, (b) advance by a specified 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. The capacity of simulating in short time steps and switching between several folders is particularly useful if one wants to study the effect of a particular event on a specific parameter.

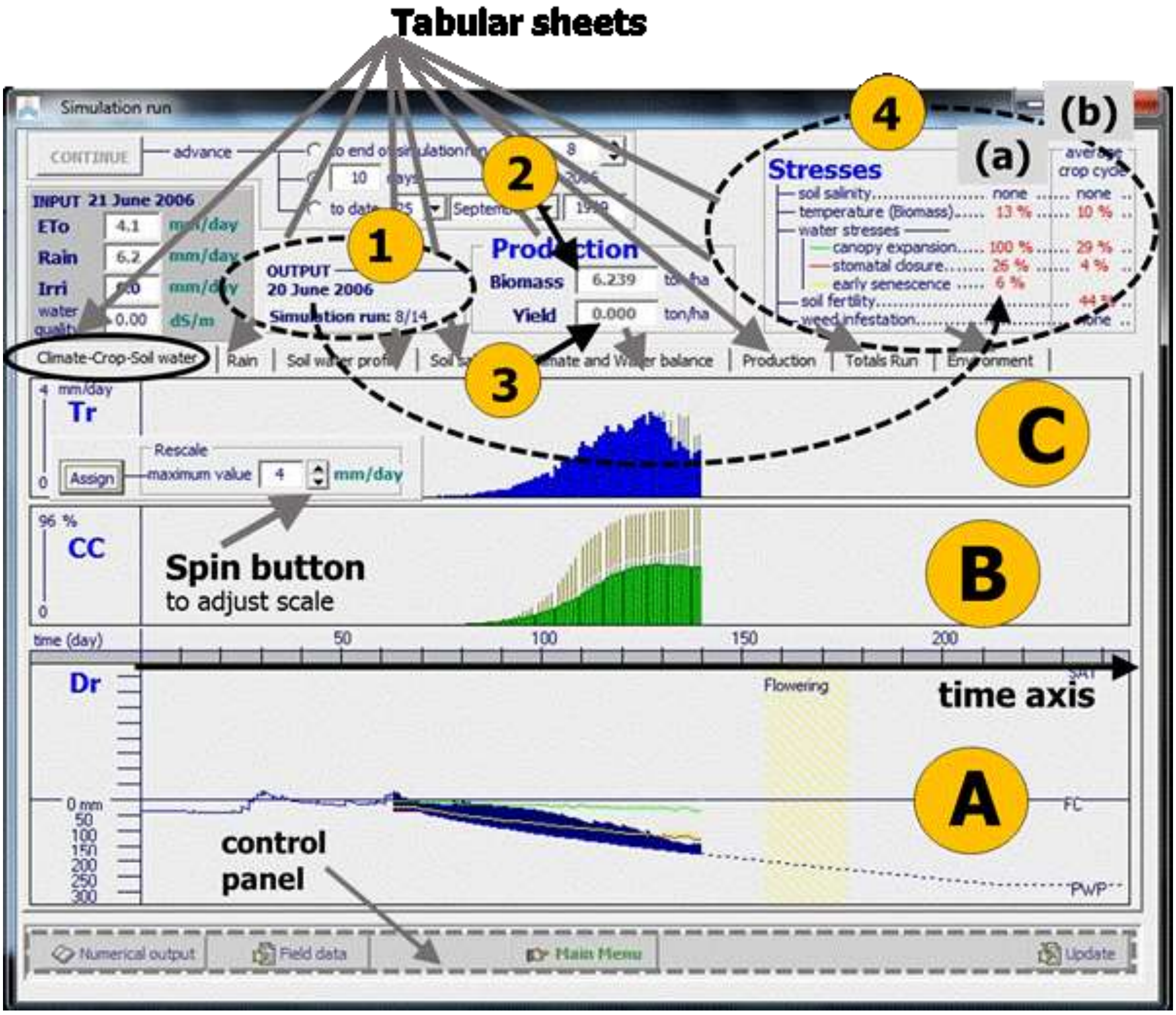



**Figure 6.15 – Display of simulation results in the *Simulation run* menu (1) for the day to which the simulation has advanced. Total (2) biomass and (3) crop yield produced so far at the end of that day, (4) stress levels occurring (a) on that day and (b) averages of stresses over the growing cycle 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.

When running a simulation for perennial herbaceous forage crops, also the biomass that was mobilized at the start of the season and stored at the end of the season is displayed. By selecting the <**Harvest events**> command, the crop production (Dry biomass, Dry Yield and Fresh yield) at the several harvest events is displayed in the ***Harvest events*** menu.

☐ **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):

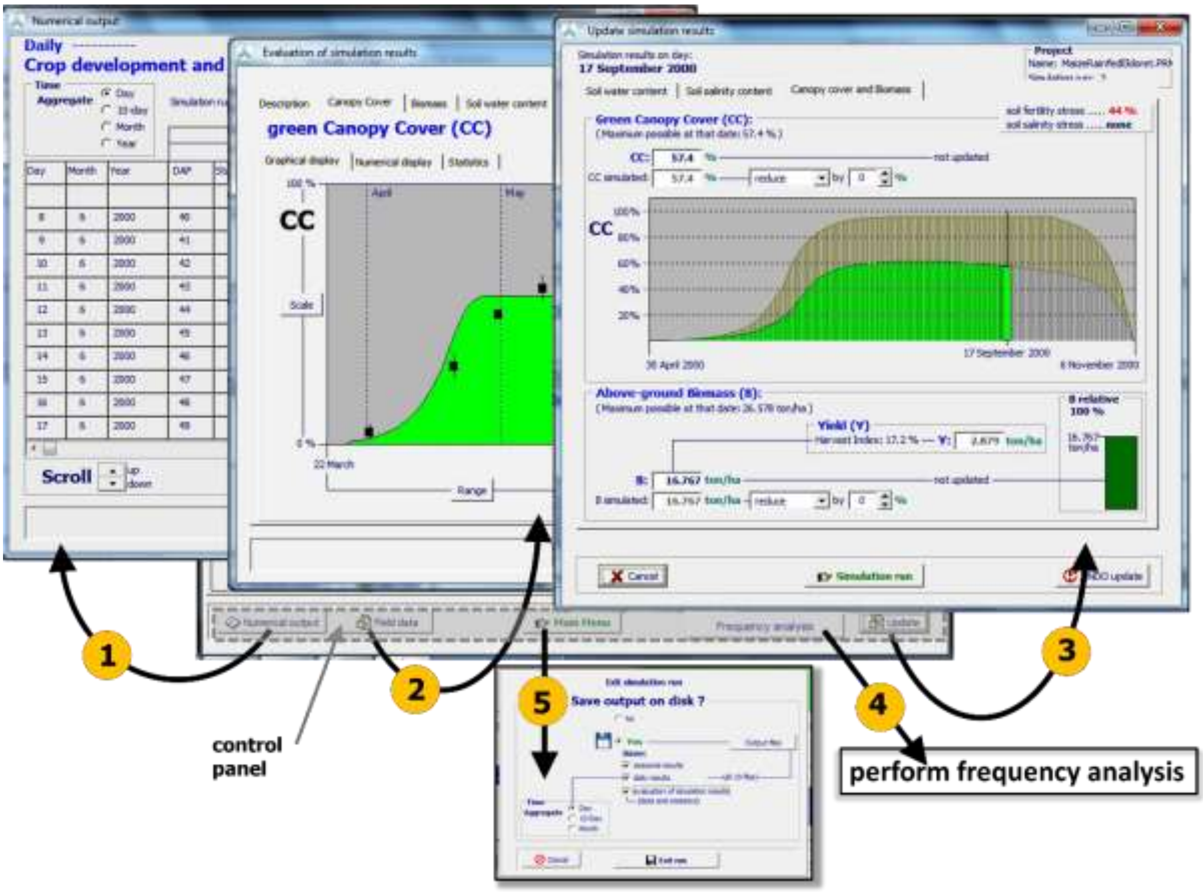



**Figure 6.16 – By selecting the (1) <Numerical output>, (2) <Field data>, (3) <Update>, (4) <Frequency analysis> or (5) <Main menu> command in the control panel at the bottom of the *Simulation run* menu, the user gets access to respectively the *Numerical output* menu, *Evaluation of simulation results* menu, *Update simulation results* menu, a set of *Frequency analysis* menus 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.

☐ **Perform frequency analysis**

The <**Frequency analysis**> button (Fig. 6.16) is only available when multiple run projects (of at least 4 successive years) are run. Before performing a frequency analysis, the appropriate option for the time aggregation of the simulation results must be selected in the ***Goal of frequency analysis*** menu (Fig. 6.17). The selection varies depending on the purpose of the frequency analysis:

- to design irrigation schedules, the time aggregation of daily data in 10-daily or monthly time steps is most suitable,
- to improve irrigation and/or field management, the aggregation of the simulation results over the entire growing period can give valuable information,
- to analyse climate data (rainfall, ETo, air temperature), a time aggregation over a month, season or year can be very useful.

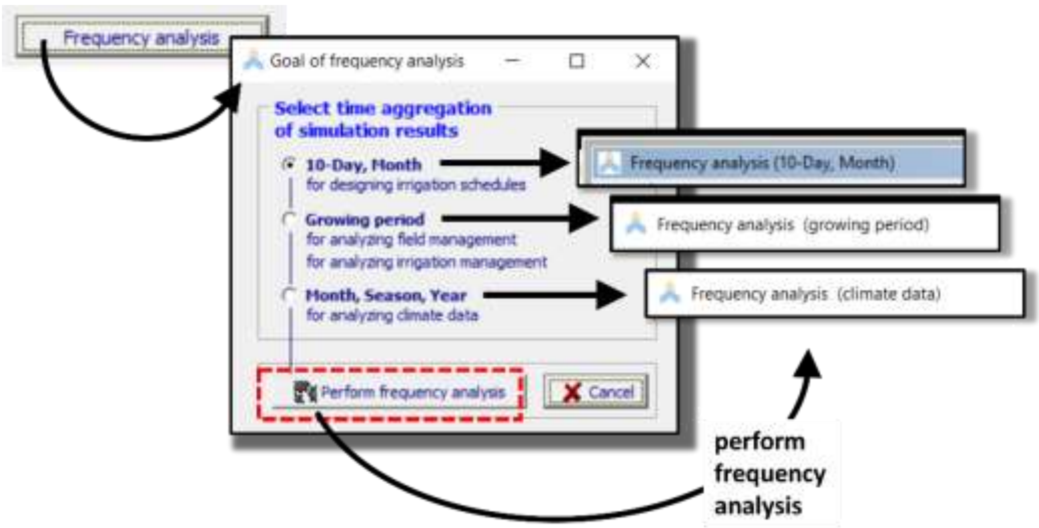



**Figure 6.17 – Selection of the purpose and corresponding time aggregation of the simulation results in the *Goal of frequency analysis* menu.**

☐ **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.