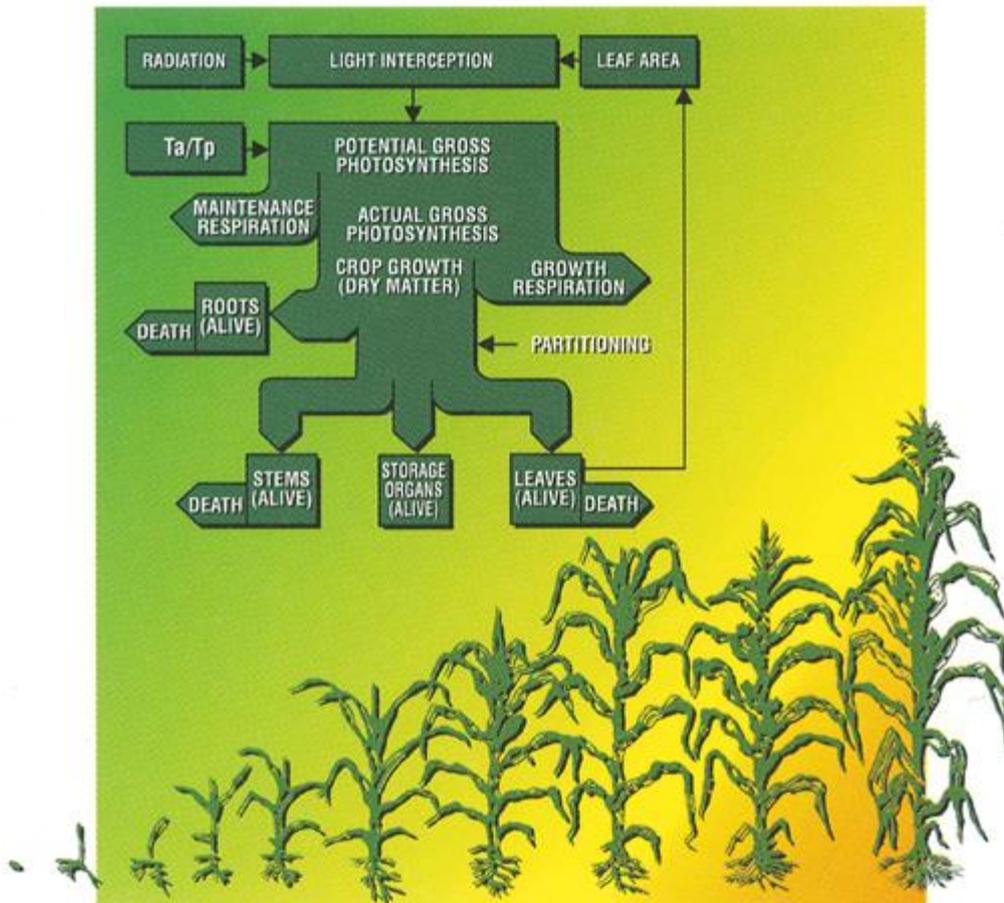


WOFOST Control Centre 2.1 and WOFOST 7.1.7



<http://www.wageningenur.nl/wofost>

WOFOST Control Centre 2.1 and WOFOST 7.1.7

User's guide for the WOFOST Control Centre 2.1 and WOFOST 7.1.7 crop growth simulation model

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**Alterra, Wageningen University & Research Centre,
Wageningen, 2014 (update spring 2021)**

ABSTRACT

H.L. Boogaard, A.J.W. De Wit, J.A. te Roller, C.A. Van Diepen, 2014 (update spring 2021). *WOFOST CONTROL CENTRE 2.1; User's guide for the WOFOST CONTROL CENTRE 2.1 and the crop growth simulation model WOFOST 7.1.7*. Wageningen (Netherlands), Alterra, Wageningen University & Research Centre.

WOFOST version 7.1.7 is a computer model that simulates the growth and production of annual field crops. All the run options are operational through a graphical user interface named WOFOST Control Centre version 2.1 (WCC). WCC facilitates selecting the production level, and input data sets on crop, soil, weather, crop calendar, hydrological field conditions, soil fertility parameters and the output options. The files with crop, soil and weather data are explained, as well as the run files and the output files. A general overview is given of the development and the applications of the model. Its underlying concepts are discussed briefly.

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1 Introduction

1.1 Scope of this user's manual

This guide is an introduction to WOFOST Control Centre 2.1 and WOFOST version 7.1.7. To facilitate dealing with a large number of options the current version of WOFOST is accompanied with a graphical user interface named WOFOST Control Centre (WCC) version 2.1 managing the various input and run options. This manual will guide you through all options available in the WCC. The different data files used in WOFOST: the input files, the run files and the output files are discussed as well.

To be able to use WOFOST in a meaningful way, a general knowledge of plant growth and development and of the environmental factors by which these are influenced is a prerequisite. In this guide, WOFOST is treated as a 'black-box'. You will be explained how to provide input to WOFOST and how to have it calculate the type of output you desire. The guide does not discuss all concepts on which the model is based, nor its algorithms. For further information on WOFOST, we strongly suggest reading the following material:

- Wit, Allard de, Hendrik Boogaard, 2021. A gentle introduction to WOFOST. Wageningen Environmental Research.
- Wit, Allard de, Hendrik Boogaard, Davide Fumagalli, Sander Janssen, Rob Knapen, Daniel van Kraalingen, Iwan Supit, Raymond van der Wijngaart, and Kees van Diepen. 25 Years of the WOFOST Cropping Systems Model. *Agricultural Systems* 168 (January 1, 2019): 154–67. <https://doi.org/10.1016/j.agsy.2018.06.018>.
- Wit de, A.J.W., H.L. Boogaard, I. Supit, M. van den Berg (editors). 2020. System description of the WOFOST 7.2 cropping systems model. Wageningen Environmental Research. May 2020. Updated description of Supit, I., A. A. Hooijer, and C. A. Van Diepen. System description of the WOFOST 6.0 crop simulation model implemented in CGMS, vol. 1: Theory and Algorithms. Joint Research Centre, Commission of the European Communities, EUR 15956 (1994): 146. The latest version is available on <https://wofost.readthedocs.io>.

1.2 Conditions of use and distribution

The copyright holder of WOFOST Control Centre 2.1 and WOFOST 7.1.7 is Wageningen Environmental Research. The software can be downloaded via <http://www.wageningenur.nl/wofost>.

The source code of the WOFOST 7.1.7 model (in FORTRAN77) can be obtained from the same website and is licensed under the European Union Public License¹.

¹ <https://joinup.ec.europa.eu/software/page/eupl>

1.3 Main changes in relation to WCC 1.8 and WOFOST version 7.1.3

The main changes compared to WOFOST Control Centre 1.8 and WOFOST 7.1.3 are:

- The option to use monthly weather data has been removed from the WOFOST Control Centre, for two reasons:
 - The use of monthly weather data is strongly discouraged and is not necessary given that daily weather data is generally available.
 - The use of monthly weather data lead to strange results in WOFOST and given the point above we decide not to spend time fixing this problem.
- Improved charts in the WOFOST Control Centre correctly handling the case when simulations cross the year boundary. WOFOST itself has no problem with year boundaries whatsoever but the charts could be awkward in certain cases.
- Additional tab menu for setting parameters for the Timer (start of simulation, etc.)
- Small bug fixes in the WOFOST source code related to calculation of summary statistics for multi-year runs.

1.4 Main changes in relation to WCC 1.5 and WOFOST version 7.1.2

The main changes compared to WOFOST Control Centre 1.5 and WOFOST version 7.1.2 are:

- Windows 7 compatible installer and structure:
- Executables and documentation are placed under "Program files"
- Crop, Soil, weather and log files are placed under "All Users"
- FSEOPT removed from source tree
- Platform independent source code distribution. WOFOST has been compiled on Windows (XP), Linux 32/64 bit and Mac OSX (Tiger) using the GNU gfortran compiler.
- Bug fixes:
 - ASTRO module was adapted to allow simulation at high latitudes with daylength=0 or 24 hours
 - Start days of waterbalance (ISDAYB) is now interpreted in a different way. If the start day is before the sowing/emergence day it is applied for the same year. If the start day is after the sowing/emergence day the water balance is started the year before
- Path names up to 250 characters are now allowed.
- 8:3 Filename convention for weather, crop and soil files has been removed

1.5 Main changes in relation to WOFOST version 6.0

The main changes since WOFOST version 6.0 are:

- The method to enter input data is changed: the user has to provide all input data via graphical user interface: WCC (WOFOST Control Centre) or via files WCCTI.TIM (timer), WCCSI.SIT (site), WCCRE.RER (rerun) and RUNOPT.DAT (run options) when running in MS-DOS mode.
- Introduction of the following variable in the crop file:
 - DVSI = DVS at start of simulation. This is important for transplantation of rice.
 - Change of the following variable in the crop file:
- SSA becomes SSATB (specific stem area against DVS).
- KDIF becomes KDIFFTB (extinction factor for diffuse visible light against DVS).
- EFF becomes EFFTB (light use efficiency single leaf against DTEMP)
- The site file (WCCSI.SIT) has been extended with the variables SSI and SMLIM (see Section 4.5.2). These variables can also be changed in WCC.
- Descriptions formerly found in W60MENU.DAT have been incorporated in the data files (crop, weather and soil files). Data files in respective directories will be automatically read in WCC. Therefore a number of 'fixed' data fields have to be filled in the data files (see Section 4.2, 4.3, 4.4).
- The Ångström coefficients were given in W60MENU.DAT. In WOFOST version 7.1 the W60MENU.DAT is removed and the Ångström coefficients always appear in the weather files. So in the WOFOST weather format (monthly and climate) Ångström coefficients are given. They are added as the fourth and fifth values (just after elevation). In the CABO weather format the Ångström coefficients are already in the file. The indicator whether measured radiation or sunshine duration is given in the CABO weather file consists of a minus sign. Negative values of the Ångström coefficients indicate measured radiation in the CABO weather files (see Section 4.4).
- Initialization of soil moisture content by running the water balance before emergence. The introduction of the variable ISDAY (start date water balance) in the timer file (WCCTI.TIM) (see Section 4.5.1).

1.6 Set up of this user's guide

This guide consists of six chapters:

- Chapter 1, the present chapter, provides a general introduction and information on this user's guide.
- Chapter 2 provides information on the hard- and software requirements, on the installation of WOFOST and the source code of WOFOST.
- In Chapter 3, the working of the WCC is described. Each different cluster of input and output data (tab) is presented and discussed. Running WOFOST from a command box (e.g. "terminal mode") is also explained. This chapter gives the user an impression of how the WCC and WOFOST should be used.
- Chapter 4 describes the data files on crops, soils, weather and how additional data defining specific site conditions and crop calendar are grouped into clusters. The output files and log files are also discussed.

2 Installation of WOFOST Control Centre

2.1 System requirements and installation

The WOFOST Control Centre can be installed on computers running Windows XP, Windows Vista, Windows 7, 8 and 10. Note that the *Borland Database Engine is not required anymore* to install WCC.

To install WCC, run the installation program which will ask you to accept the EURL license and will ask for an installation directory. WCC MUST be installed in a directory where the user has read and write access!

The good side of this approach is that the installation of WCC does not need any administrative rights. Moreover, the WCC has no dependencies and makes no entries in the Windows Registry. The installation folder of WCC can therefore be copied or moved to another location and can even run from a USB device. The downside of this approach is that the installer of WCC will not make an entry in the Start Menu for starting WCC and the user will need to start the "WOFOST Control Centre.exe" from the installation folder (although the Start Menu entry can be created manually).

2.2 Source code of WOFOST

The source code of WOFOST version 7.1.7 is written in FORTRAN-77 and can be downloaded from <http://www.wageningenur.nl> as a separate package. This source code is described in Annex F. Annex F also presents a diagram of the model structure, most of the different subroutines and how they are related to each other.

The WOFOST related subroutines make use of standard subroutines (e.g. for opening and reading files) from the TTUTIL library v4 (Rappoldt and van Kraalingen, 1990). The TTUTIL library is included with the WOFOST source distribution and has been slightly adapted to allow longer path names.

To modify the source code, WOFOST must be recompiled and linked using a FORTRAN compiler. When changes made to the source code influence the input and output, the WOFOST Control Centre cannot be used anymore and WOFOST should be run from the Command Line (e.g. "terminal mode"). In this specific situation, the temporary input files (see Section 4.5), which the WCC generates on the sub directory 'RUNIO', can be used to edit input data.

WOFOST is known to run on Windows, Linux and Mac OSX computers without any problems. Information on how to compile and link WOFOST 7.1.7 on different platforms using the GNU FORTRAN compiler can be obtained from the README files included with the WOFOST source distribution.

3 Description of WOFOST Control Centre (WCC)

3.1 Introduction

Chapter 3 describes the WOFOST Control Centre (WCC) version 2.1. The WCC is a Graphical User Interface on top of WOFOST (version 7.1.7). With the WCC, you can edit and view the input data for WOFOST, run WOFOST, and view and analyze the output data in table or in graphical form. This chapter provides the description of the various functions and features in the WCC and serves as a reference for these details. When you encounter problems please read the appropriate sections in Chapter 3 and 4 and also check Annex C (troubleshooting).

In this chapter, illustrations for each different window and for each different tab within a window of the WCC are shown. The example provided is a run for potential and water limited production of winter wheat in the Netherlands, with fixed emergence on a coarse soil using daily weather data. The input and output files for this run are described in Chapter 4.

The choices you can make in the WCC are described in this chapter and are marked bold. This makes it easier to find a certain topic you are interested in.

This chapter consists of technical information on how to handle the WCC (Section 3.2) and the description of the following functions and features of WOFOST:

- general, controlling features: the menu and button bar (Section 3.3);
- editing input data of WOFOST (Section 3.4);
- viewing and analyzing detailed output data of WOFOST (Section 3.5);
- viewing and analyzing summary output data of WOFOST (Section 3.6);
- running WOFOST in terminal mode (Section 3.7).

3.2 Technical information on handling the WCC

The WOFOST Control Centre can be started by clicking on the file "Wofost Control Centre.exe" in the installation directory. The WCC log-on screen will appear followed by the main window of the WCC session. Technically the WCC has the following elements (see Figure 1):

- menu bar (options: File, Result, Help);
- button bar (options: Exit, Reset, Run, Result detailed, Result summary, Help);
- tabs (options: General, Crop, Weather, Soil, Nutrients, Reruns).

The button bar represents the most regularly used options of the menu bar so, all the options in the button bar are also available in the menu bar. You may activate the options in the WCC using the mouse or by using the 'hot' keys. The hot keys are activated by simultaneously pressing the 'alt' key and an underlined letter in the WCC. For example, the combination 'alt' with the letter 'f' will activate the File option (see Figure 1). Within a menu, you can choose an option by pressing on the keyboard the underlined letter of that option. Options within a

tab can also be operated using the 'tab' and up/down arrow keys. You can move from one tab to another by pressing the left/right arrow key.

In certain cases, choosing options or editing values is disabled. You will notice this by the grey colour of options or values instead of a white or black colour. Whether options or values are disabled depends on choices that were made earlier by the user. Finally, values changed by the user are checked whether they are between physically possible limits. This control takes place after you leave the field where you enter the value. In the rerun tab (Section 3.4.7), this control takes place when you activate the run function in the WCC or when you select a new variable.

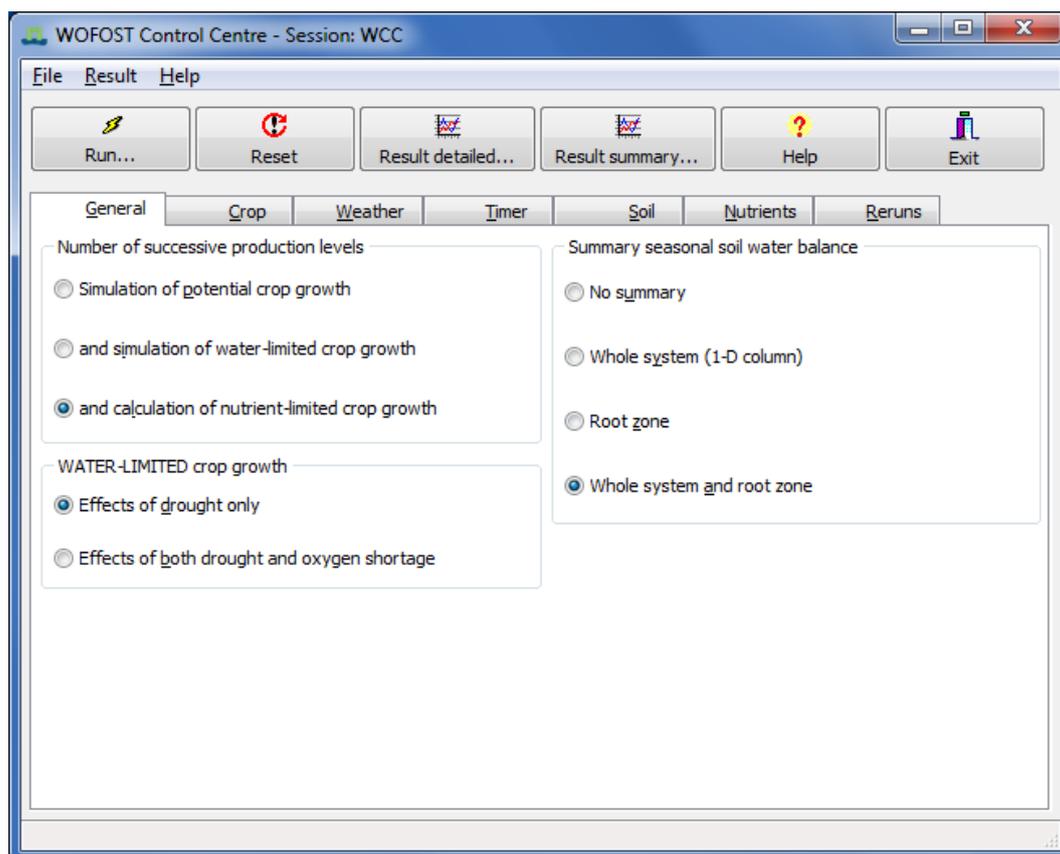


Figure 1. Example of the tab 'General' of the WOFOST Control Centre.

3.3 General, controlling features (menu and button bar)

The following features are relevant to control and work with the WCC:

- open and save (as) a session (menu bar) (Section 3.3.1);
- reset data (menu and button bar) (Section 3.3.2);
- run WOFOST 7.1.7 (menu and button bar) (Section 3.3.3);
- view and edit (log) files (menu bar) (Section 3.3.4);
- exit the WCC (menu and button bar) (Section 3.3.5);
- viewing and analyzing the detailed and summary results (menu and button bar) (section 3.3.6);
- help function (menu and button bar) (Section 3.3.7);

- about the WCC (menu bar) (Section 3.3.8);
- editing and viewing input data (tabs and additional windows) (Section 3.4).

In this section, all above listed items are described except for the different input tabs (Section 3.4) and the special windows for viewing and analyzing the results (Section 3.5 and 3.6).

3.3.1 Open and save (as) a session (menu bar)

When you start the WCC, it will read a set of input and output files with default names (Table 1). The content and format of these files are shown in Chapter 4. The contents of these files are always equal to the settings of the latest run.

Changes you make while working with the WCC are only saved:

- The moment you run WOFOST (see Section 3.3.3). The settings of the run are saved in the default files (Table 1);
- When you explicitly save the settings using the 'save (as)' option in the WCC (see below).

WCC gives you the possibility to save changes done in the input and output files under a different name. Choose 'File/Save session as' from the menu bar. In the 'Save file as' window under the directory ..\RUNIO, supply a filename for the session. The name 'WCC' is not allowed. This name is used inside the program as a work name. The name of the session you provide has a maximum of 6 characters. An extension is not permitted. Choosing 'File/Save session' from the menu bar saves your set of input and output (files).

One setting, the rerun checkbox is not saved when you use the save (as) functionality. So each time you want WOFOST to make reruns you have to enable the rerun function by clicking on the rerun checkbox.

It is also possible to open a specific set of files that has been saved in an earlier session. To open a session (set of input and output files), choose 'File/Open session' from the menu bar. Select in the 'File open' window the session you would like to open. The information of the input and output files is loaded in the WCC and if output files are available, they can be viewed and analyzed.

When you use the 'Save session (as)' option, the WCC copies all the default files as shown in Table 1 to files under the name supplied by the user. When you use the open session functionality, the WCC copies the files with the user defined name to the default files as shown in Table 1.

Table 1 The input and output files of one session

| The input and output files | Description |
|----------------------------|---|
| WCC.WCC | File with run options |
| WCCTI.TIM | Timer file: time related data (weather, crop calendar) |
| WCCSI.SIT | Site file: concerns the default soil characteristics |
| WCCRR.RER | Rerun file: for series of consecutive runs |
| WCC.OUT | File with detailed output |
| WCC.PPS | File with summary results about the potential crop production |
| WCC.WPS | File with summary results about the water-limited crop production |
| WCC.SUM | File with summary results of both potential and water- |

3.3.2 *Reset data (menu and button bar)*

A handy feature in the WCC is the reset option in the different tab pages. When you choose **'File/reset'** from the menu bar or the **'Reset'** button on the button bar, WCC loads the default values of variables into the WCC session. These values are implemented in the source code of the program and cannot be changed by the user.

3.3.3 *Run WOFOST 7.1.7 (menu and button bar)*

Choose 'File/run' from the menu bar or the 'Run' button on the button bar. WCC will automatically save the input settings to the default files (Table 1). These files will be used as input by WOFOST version 7.1.7 when WCC executes WOFOST.

When you run WOFOST version 7.1.7, a Command-box window appears with the message *'Running the simulation. Please wait...'*. After this message, three things can happen:

- The message *'Press any key to continue'* appears. Press any key and close the Command-box. A window with the message 'Simulation successful' appears. You can now look at the results.
- The message *'Press any key to continue'* appears. Press any key and close the Command-box. A window with the message 'Runtime error while running the simulation. Show log-file?' appears. In this case, you can have a look at the WCC.LOG that contains information on the simulation run. The log-file should lead you to the cause of the runtime error. Sometimes you may get a runtime error message in the Command-box.
- No message appears and the simulation seems to be taking longer than expected. Stop the simulation by pressing 'Enter'. The message *'Press any key to continue'* appears. Press any key and close the Command-box. A window with the message 'Runtime error while running the simulation. Show log-file?' appears. Have a look at the WCC.LOG that contains information on the simulation run. The log-file should lead you to the cause of the runtime error.

3.3.4 *View and edit (log) files (menu bar)*

The internal file viewer and editor can open/edit files of less than or equal to 32 Kbytes.

- A log file (plain ASCII) is created every time you run WOFOST. You can view this log file by choosing **'File/View log-File'** from the menu bar.
- The function **'File/View File'** from the menu bar enables you to view any plain ASCII file on your system. Choose the desired directory and file in the 'File/Open file' window.
- The **'File/Edit File'** option in the menu bar lets you edit any plain ASCII file on your system. Select the desired directory and file in the **'File/Open file'** window. However, for serious editing of files, you are better off installing a good text editor on your system

3.3.5 Exit the WCC (menu and button bar)

To leave WCC choose **'File/Exit'** from the menu bar or the **'Exit'** button on the button bar. You may also click on the **'x'** button at the upper right hand corner of the main window.

3.3.6 Viewing and analyzing the detailed and summary results (menu and button bar)

Choose **'Result/Detailed...'** from the menu bar or the **'Result detailed...'** button on the button bar to view and analyze the detailed results of a run with WOFOST. The detailed results are shown in a table format and can also be viewed in graphical form (see Section 3.5).

Choose **'Result/Summary...'** from the menu bar or the **'Result summary...'** button on the button bar to view and analyze the summarized results of a run with WOFOST. Special output windows will show the results of the run in the form of tables only (see Section 3.6). Summary results are only available when WOFOST has been run for two or more years.

3.3.7 Help function (menu and button bar)

Choose **'Help/Contents'** from the menu bar or the **'Help'** button on the button bar to display the user manual. The help function can also be activated by pressing 'F1'-key.

3.3.8 About the WCC (menu bar)

The **'Help/About'** option in the menu bar provides information on exact WCC and WOFOST version and.

3.4 Input data for WOFOST

The input data for WOFOST is described in several tabs (General, Crop, Weather, Timer, Soil, Nutrients, Reruns). In these tabs you can choose options, edit values, and choose crop, weather, and soil files. In the Reruns tab you can change the values of variables in the crop and soil files for a series of WOFOST runs (see Section 3.4.7). The contents of the weather file can only be changed by editing the weather file outside the WCC. If you would like to edit or change crop, soil and weather files you should work very carefully and follow the guidelines in Chapter 5 how to format these input files.

3.4.1 General data

The tab 'General' pertains to the selection of the production level(s) (Figure 1). In WOFOST, it is possible to choose 'Simulation of potential crop growth' only, or simulation of potential crop growth 'and simulation of water-limited crop growth', or simulation of potential and water-limited crop growth 'and calculation of nutrient-limited crop growth'.

Each of the three hierarchical levels of crop *growth* that are distinguished in the model (potential growth, water limited growth and nutrient limited growth) corresponds to a level of crop *production*: potential, water limited and nutrient limited production.

When you select 'Simulation of potential crop growth' or 'and simulation of water-limited crop growth', there is no need to enter data about nutrients so the 'Nutrients' tab is not shown. Furthermore in the water limited crop growth, you can choose between simulating the 'Effects of drought only' or 'Effects of both drought and oxygen shortage' (i.e. oxygen shortage in the root zone).

You can also choose to have or not to have a 'Summary seasonal soil water balance'. The summary can be for the whole soil system and/or for the root zone only (this zone extends as roots grow). The water balance is simulated for the period from emergence until the last day of simulation.

3.4.2 Crop data

In this tab (Figure 2), select the file with specified data about a certain crop or variety you want to simulate. The list of '**Available crops**' shows the crop name and a description, including an indication of the region where the variety is grown. The filename for each crop appears on the bottom bar when you click on the description. The crop file contains a large number of crop model parameters. The right pane shows the contents of the crop parameter files and allows you to scroll through the parameter file to have a look at the parameter values.

Crop parameter values can be changed by editing the parameter file, but often a more convenient way of assessing the impact of a variable is by running the model several times with different parameter values. This can be accomplished using the '**Rerun**' tab (Section 3.4.7).

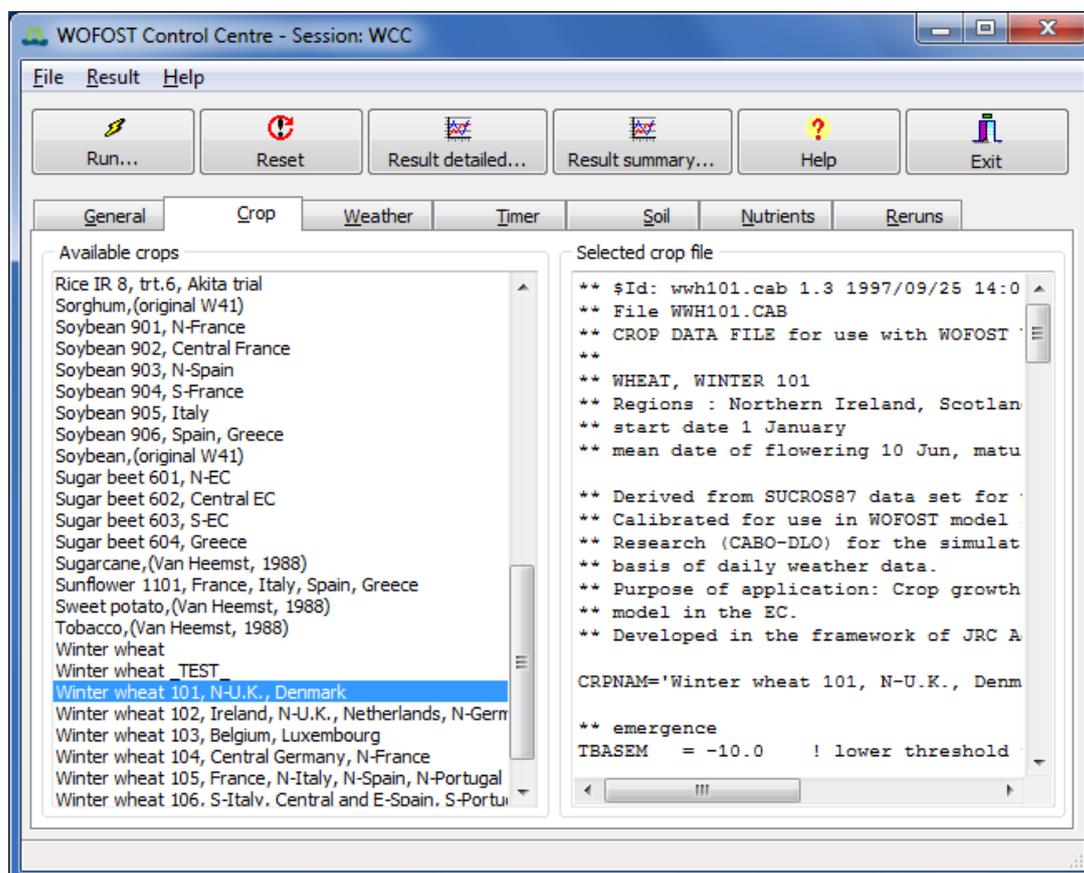


Figure 2. Example of WCC tab 'Crop'.

3.4.3 Weather data

In the tab '**Weather**' (Figure 3) you first have to choose the weather format. Previous versions of WOFOST supported the use of monthly or decadal weather data. However, this option has been abandoned because the use of monthly weather data is strongly discouraged. Therefore, the only supported weather format is the CABO format which stores daily values of several weather variables (<http://edepot.wur.nl/43010>).

Next you can select data from a weather station or a location for which CABO weather files are available. The first and last year available are also shown on the right of the window.

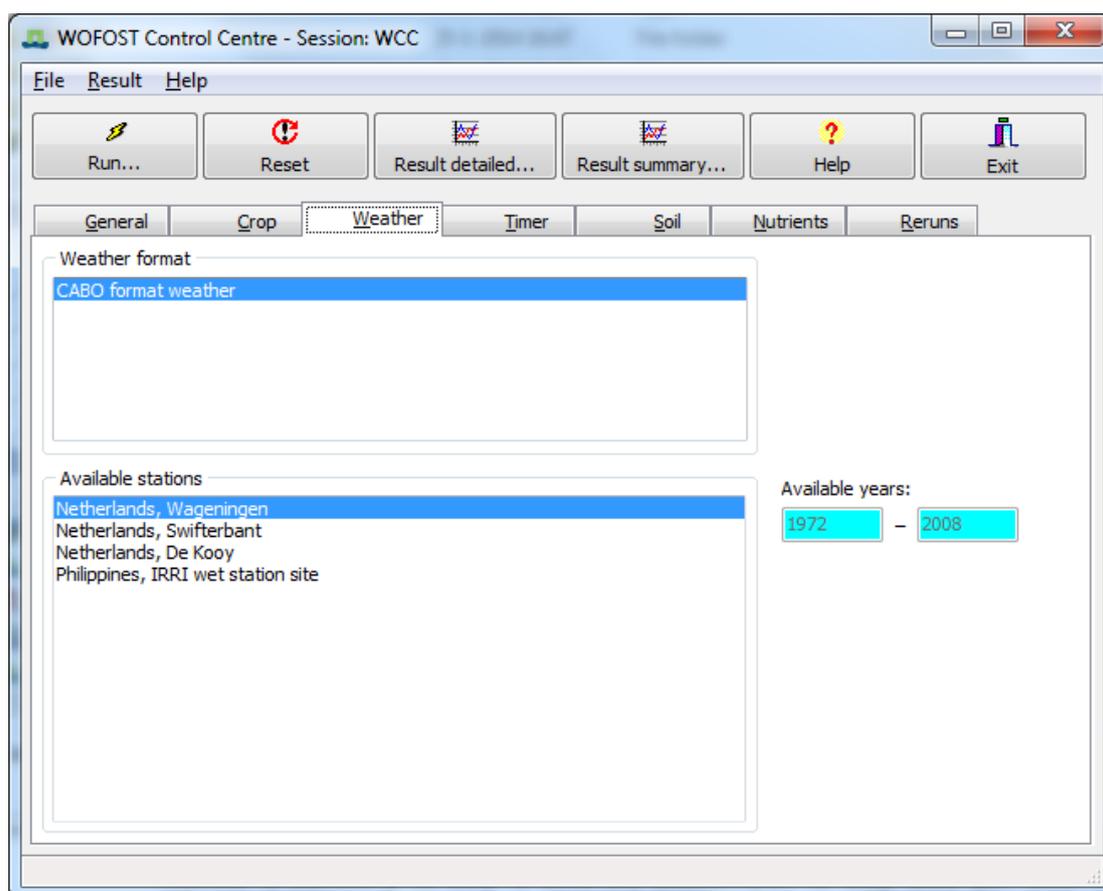


Figure 3. Example of the WCC tab 'Weather'.

3.4.4 Timer data

Under the 'Timer' tab all settings are arranged that deal with the timer, the start of the simulation, the number of years to simulate and the options for starting and ending the crop (Figure 4).

The date is always expressed as *day number of the year (doy)*, hence 1 January is doy 1 and 31 December is doy 365 (or 366 in leap years). The WCC checks the specified doy and duration and corrects the doy and duration for values smaller than 1 (WCC sets value on 1) and greater than 366 (WCC sets value on 366). See Annex D for a table with calendar dates and their corresponding doy.

First of all, the general timer options must be selected: 1) the output interval which is usually one day and 2) the start day of the water balance. The interpretation of the start day of the water balance depends on the start day of the crop simulation. If the start day of the water balance is after the start of the water balance, it is assumed to lie in the year preceding the start day of the crop simulation.

Next, the start 'Start year' must be provided in which the crop simulation must start. The default value is the first year for which meteorological data is available. The start year can be the only year you are interested in or the first year of a series of years for which you want to simulate crop growth. Specify the number of 'Consecutive years' (seasons) for which crop growth should be simulated, starting from the year indicated in the start year. This value, however, should not exceed the number of available years after the start year.

Finally, the options for starting and ending the crop simulation must be specified. First the user must specify the crop calendar day when the simulated growing period should start. When a 'Fixed emergence date' is selected, simulation starts at the day you indicate. When 'Fixed sowing date' is selected, simulation starts on the day of emergence, calculated on the basis of the thermal time needed for emergence. When you select 'Variable sowing date', the 'best moment' for sowing is determined by the physical conditions of the soil (humidity, workability), which depend on soil characteristics and the weather before and during the potential sowing season. To determine this best moment, the calculations start 10 days prior to the first possible sowing day. The user must specify the earliest and latest possible sowing day.

For the end day option, select 'Fixed end date' when the end of the growing period is not determined by physiological maturity. Indicating a fixed end date means the simulation has to stop, irrespective of the development stage of the crop. This can be the case with, for example, sugar beet, which is harvested, in the vegetative stage.

Select the option 'Maturity (\leq max. duration)' if you want the simulation to stop at crop maturity. If you select this option, you will also be asked to provide the maximum duration, i.e. the maximum number of days the crop can be in the field. Provide the maximum number of days the crop can grow in one growing season. This option is added to prevent errors like a crop that continues growth for an unrealistically long time because the thermal time needed to reach maturity is not attained due to low temperatures in fall. Maximum duration refers to the number of days after emergence, not to the day of the year!

When you choose the option 'Earliest of both dates', simulation will stop when the crop is mature, unless the fixed end day or the maximum duration is reached before maturity.

Note that the YEAR in the various screens, dropdown lists, charts and output windows of WCC will always refer to the 'Start year', despite the fact that the simulation can start in the previous year (for example in case of early water balance start) or end in the next year (crop crossing the year boundary).

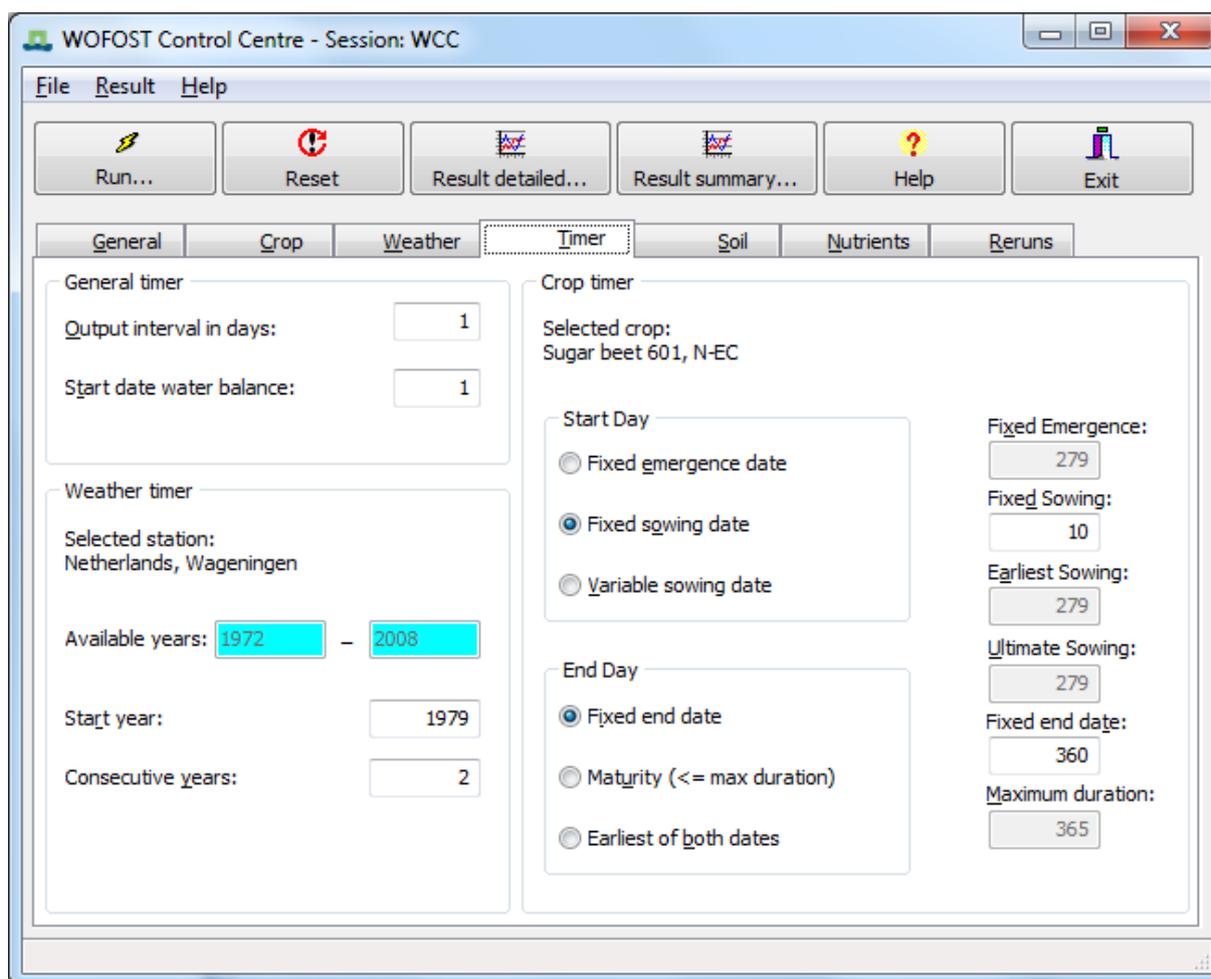


Figure 4. Example of the WCC tab "Timer".

3.4.5 Soil data

In the tab 'Soil' (Figure 5) you can choose the soil type and specify the hydrological characteristics of the field. The water supply to the crop depends, in addition to rainfall, on the hydrological characteristics of the crop field.

The user is expected to provide the values to characterize field conditions. Select a soil type in the menu 'Available soil types'. Each soil type is described in a separate soil file. Clicking on the soil type will show its filename at the bottom bar. The soil types delivered with WOFOST consist of two groups: EC (European Community)/SR ('Staringreeks')-group and the texture/AWC (available water capacity per meter soil depth)-group.

The files starting with 'EC' have been developed in connection to the soil map of the EC (CEC, 1985; Reinds et al., 1992). Files starting with 'SR' are connected to the 'Staringreeks' (Wösten et al., 1994). Soil types starting with EC and SR can be used in simulation of water-limited crop growth with free drainage as well as with groundwater influence. Soil types indicated by AWC values can only be used for simulation with free drainage, as information on hydraulic conductivity is not available. When you simulate potential crop growth, you also need to indicate a soil type because it may be used to determine the optimum sowing date.

Besides the soil type you have to supply other variables related to the hydrology. 'Initial surface storage' enables you to give an initial value for the surface storage at emergence (e.g. for transplanting rice). 'Maximum surface storage' capacity depends on slope and furrow depth of the surface (relief and micro-relief).

The 'Initial available soil water' is the quantity of soil water available for crop growth in the potential root zone at the beginning of the simulation. The potential root zone is given in the crop file (maximum root depth of mature crop) and the field 'Maximum rooting depth of soil'. WOFOST selects the minimum of both rooting depth values. Available soil water means the actual amount of water in the soil in excess of the amount at permanent wilting point. The maximum available water is the amount of water between saturation and permanent wilting point.

It is possible to set a maximum soil moisture content for the given initial rooting depth ('Maximum initial moisture content in the initial rooting depth'). This way you can start the simulation with dry conditions in the topsoil (maximum) and wet conditions in the sub soil (by supplying a high initial available soil water content). The value for the 'Maximum initial moisture content in the initial rooting depth' is checked for values lower than moisture content at wilting point and values higher than moisture content at saturation for the chosen soil type. If you like to have the maximum at the level of wilting point just type a '0'; for saturation just type a '1'. The WCC will automatically adjust the values into the right values for wilting point and saturation.

When you provide a higher 'Initial available soil water' value than the potential root zone can contain, the model assumes the soil water content to be at saturation in the potential root zone. The surplus of the initial water is supposed to have percolated to greater depth.

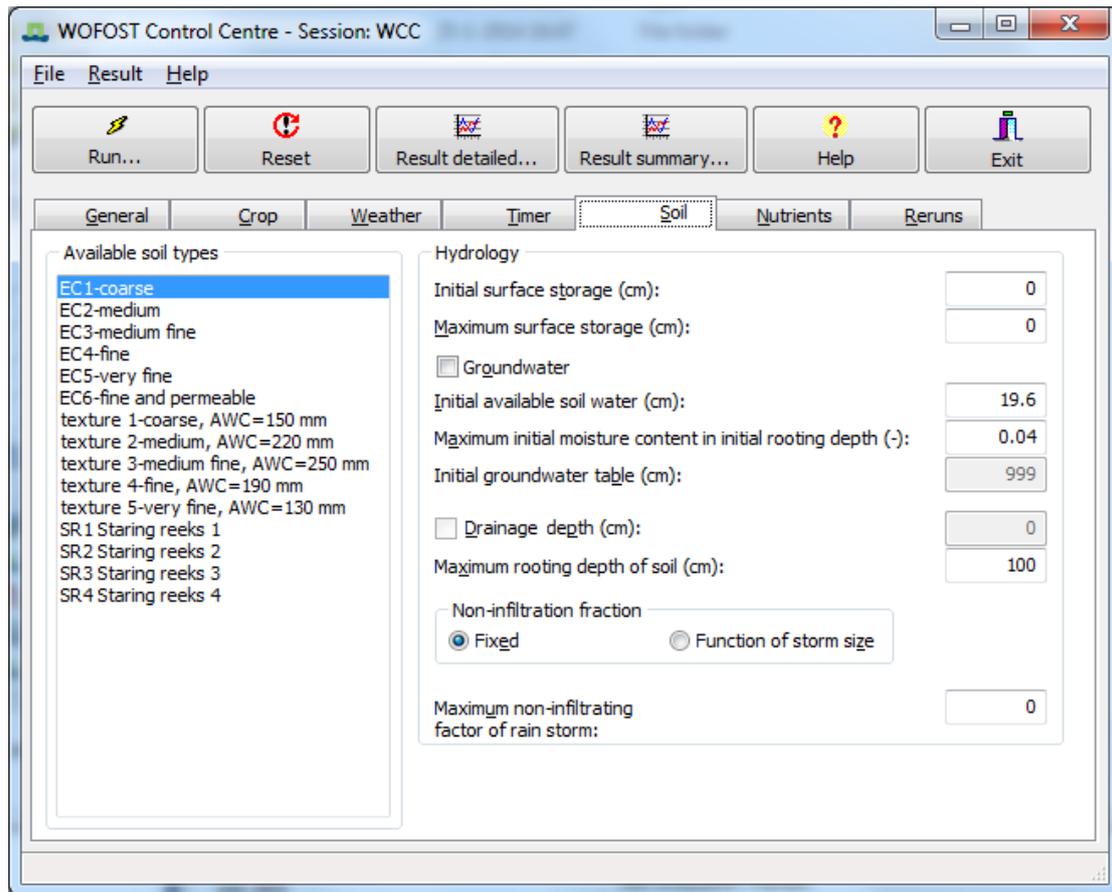


Figure 5. Example of tab 'Soil'.

When you provide a smaller 'Initial available soil water'-value than the potential root zone can contain, WOFOST first allocates this water to the initial rooting depth (usually 10 cm) until this layer is at the maximum moisture content ('Maximum initial moisture content in the initial rooting depth'). Excess water is evenly distributed over the remainder of the potential root zone.

You can choose to have 'Groundwater influence' on crop growth or not. Without groundwater influence, the water supply to the crop depends on:

- the water storage capacity of the soil (available water capacity, AWC);
- the initial available soil water content ('Initial available soil water' corrected for the maximum moisture content in the initial rooting depth);
- rainfall during the growing period only.

With groundwater influence, the water supply to the crop will be provided by capillary rise of water from the ground water to the rooting zone. When this option is selected, 'Initial available soil water' and 'Maximum initial moisture content in the initial rooting depth' are not relevant anymore and are disabled. Provide the value for 'Initial groundwater table'. Simulation results for soils with groundwater influence are not yet very reliable.

With ground water influence, you may activate the use of a drainage system by clicking on 'Drainage depth'. Activating the drainage system can lead to a decrease in the soil water content above the drains. Because of the time needed

for the water to enter the drains, the ground water table can temporarily be located above the drains.

The 'Maximum rooting depth of soil' is dictated by soil characteristics (profile depth, presence of ground water, etc.). A maximum rooting depth is also given in the crop file. WOFOST selects the smaller value of rooting depth for simulation.

The 'Non-infiltrating fraction' of rainfall can be fixed (constant) or can depend on the rainfall intensity. The infiltrating fraction of the rain is directly added to the soil water. The non-infiltrating fraction is stored on the soil surface first and may subsequently infiltrate while it may be subject to evaporation and/or run-off. If you selected 'Fixed', the amount of rain that does not infiltrate is the amount of rain (cm d-1) times NOTINF (the 'Maximum non-infiltrating fraction' which is in the range 0-1). If you select 'Function of storm size', the maximum non-infiltrating fraction (NOTINF) is multiplied by a fraction NINFTB (range 0 - 1) that depends on the amount of rain. Up to 0.5 cm d-1, NINFTB = 0 and all rain infiltrates; above 1.5 cm d-1, NINFTB = 1 and the fraction non-infiltrating rain equals its maximum NOTINF; between 0.5 and 1.5 cm d-1, NINFTB increases linearly.

3.4.6 *Nutrient data*

In the tab 'Nutrients' (Figure 6), specify data on the fertility of the soil. Calculations for nutrient-limited crop growth are based on the 'Basic soil supply' of the macro nutrients 'Nitrogen (N)', 'Phosphorus (P)' and 'Potassium (K)'. Calculations of the nutrient requirements for potential and water limited production are based on the 'Basic soil supply' of the nutrients and the 'Apparent recovery fraction' of extra fertilizer applied to the crop needed to reach the potential and water limited production level.

The basic soil supply of a nutrient is the amount of nutrient in the unfertilized soil that is potentially available for uptake by a standard crop in one growing season of 120 days. This module has been developed originally for maize in Kenya. The default values of the maximum basic soil supplies characterize a moderate inherent soil fertility leading to unfertilized maize crop yields of around 2500 kg ha-1 dry matter. Since soil supply is assumed to be for a crop with a growing cycle of 120 days, the values for basic supply of nutrients in the detailed output file are not necessarily the same as the ones you provide here. If the growing cycle exceeds 120 days the basic supply is higher and vice versa.

The apparent recovery fraction is the ratio of the additional nutrient uptake by the crop due to fertilizer application and the quantity of the nutrient applied. In reality the values for basic nutrient supply from the soil and fertilizer recovery fraction are dependent on soil, climate and past and current land use. The standard settings of the nutrient tab allow to estimate the possible contribution of soil nutrients to yield formation or inversely to quantify the required amount of fertilizer to reach potential and water limited yields. Depending on the choice of input values different kinds of information can be obtained from the model. For example, if you assume a soil with a basic supply of 0 kg ha⁻¹ for each element, and a fertilizer recovery fraction of 1.0, the model calculates the balanced nutrient uptakes needed for reaching the potential and water-limited yields.

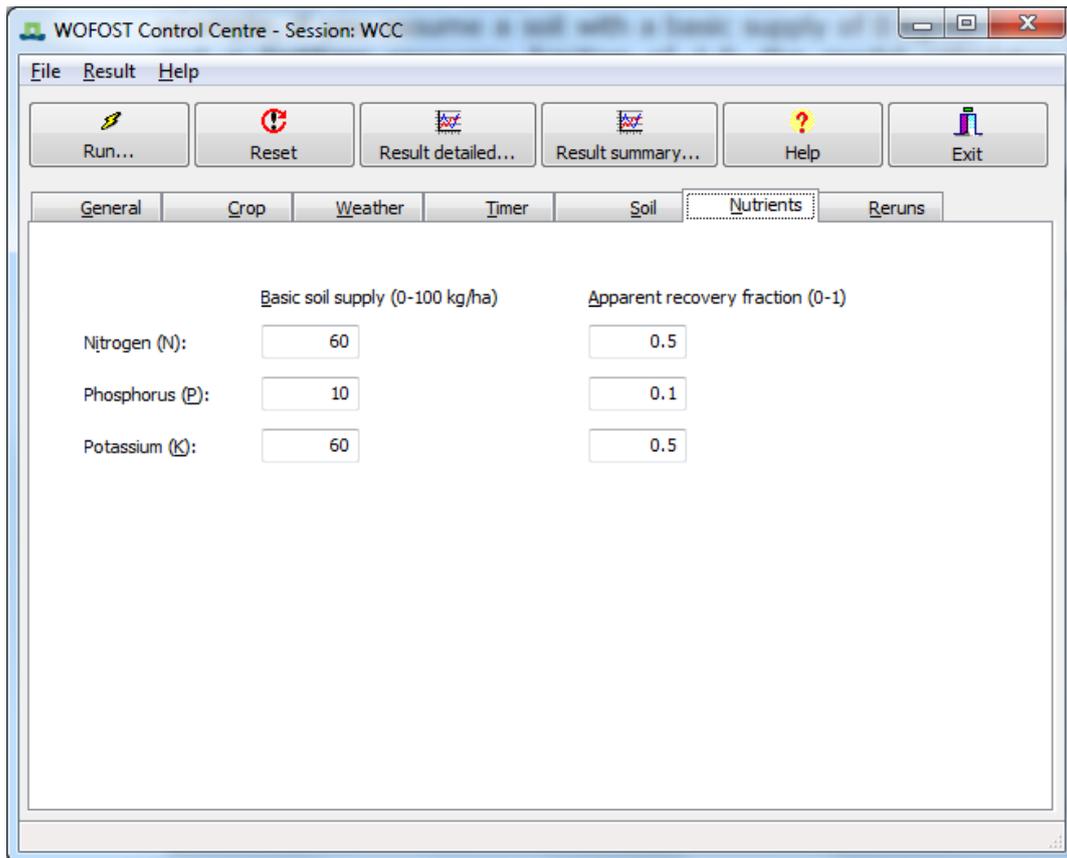


Figure 6. Example of tab 'Nutrients'.

3.4.7 Rerun data

In the tab 'Rerun' (Figure 7), click on the 'Use reruns' box to have several consecutive WOFOST-runs wherein you may vary values of input variables. Define additional runs by clicking on the 'Add rerun' button. Select variables with the 'Select variables' button. Values of the variables are edited in the matrix shown on the rerun tab page.

To remove a rerun, click on the specified run and activate the button 'Remove rerun'. The last rerun cannot be removed. The name of the run is the name of the session (WCC or the name you supplied with the save (as) session function on the menu bar) combined with a number. This name will be used in the output windows to select results for the different runs with WOFOST.

You can select one or more variables ('Select variables...') for which you would like to vary the value in the different runs. A new window will appear that will guide you through the selection of variables (Figure 8). The 'Select group' lets you choose between different groups of variables ('Crop', 'Soil', 'Timer', 'Site'). This differentiation is based on the contents of different input files of WOFOST (crop (Section 4.2), soil (Section 4.3), timer (Section 4.5.1) and site (Section 4.5.2)). It is not possible to select variables related to weather. If you would like to change values of weather variables, you have to edit the specified weather file.

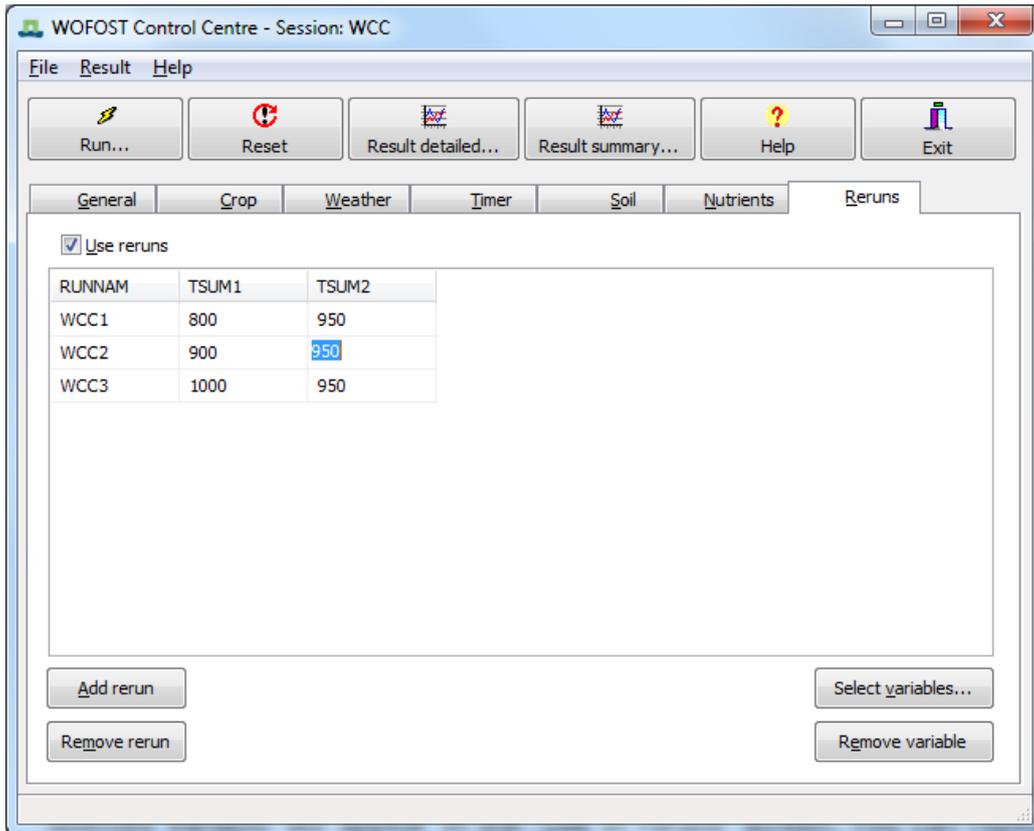


Figure 7. Example of tab 'Reruns'.

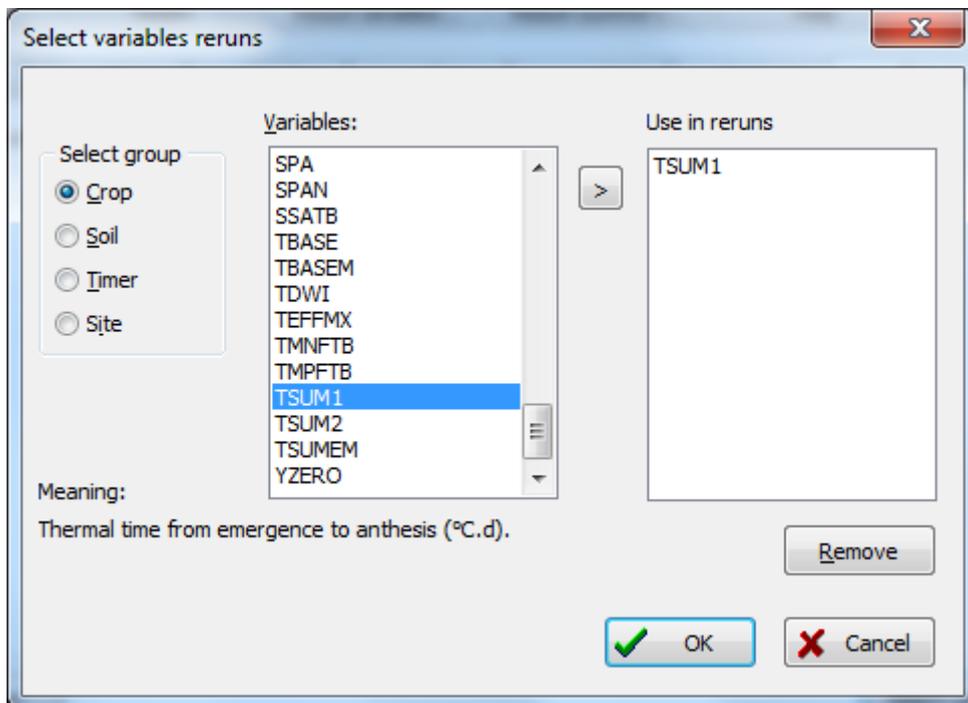


Figure 8. Example of tab 'Select variables'.

Choose the desired variable in the 'Variables' list and click on the '>' button. The selected variable will appear in the 'Use in reruns' screen. You can repeat the selection for more variables. The 'Meaning' of each variable is explained in the

lower left part of the window. You can also remove variables by clicking on the variable in the 'Use in reruns' screen and pressing the 'Remove' button. Choose the 'OK' or 'Cancel' button to return to the 'Reruns' tab.

To remove variables in the 'Reruns' tab (Figure 7), click on one of the fields of the variable and activate the 'Remove variable' button. You can change the values of the variables by entering the fields in the matrix. Two-dimensional variables (arrays) can be edited by clicking on the right mouse button. A new window appears ('Edit Rerun variable') with the name and the description of the variable and a matrix that can be edited. The matrix contains the value of the variable and the index (could be: development stage, temperature or soil moisture tension) for which the value is given. You can edit both the index and the value of the variable.

Variables that are not included in the reruns keep their values as defined in the other input tabs (general, crop, weather, soil, nutrients) and as defined in the selected crop, weather and soil files.

When the user wants to fill in relatively low or high values for a certain variable (e.g. because of sensitivity analysis) it is possible that the WCC replies with the message 'INVALID INPUT' together with the allowed range of values for this variable. It is possible to change these upper and lower limits. Therefore you have to exit the WCC and edit the file WCC_VAR.csv on the main WCC directory. Annex E shows the lower and upper limits of the variables used in WOFOST.

3.5 Detailed results of WOFOST

To view results of a WOFOST run, click 'Result detailed...' on the button bar of the WCC. The 'Detailed output' window is activated (). This window consists of:

- Pull down menus to choose a run ('RUNNAM') and a simulation year ('YEAR'). The rainfall year ('RAIN') is related to monthly weather data which is not supported anymore and has been disabled. The selection in these pull down menus determines the results that are shown in the different tabs;
- Buttons to open other output files ('Open'), to create graphs ('Graph'), to leave the detailed output window ('Close') and to export the results of a selection (run, simulation year, rainfall year) to Excel ('Excel');
- Several tabs to view tables with results for potential crop growth (Section 3.5.1), water-limited crop growth (Section 3.5.2), the simulated water balance (Section 3.5.3) and the nutrient limited crop growth (Section 3.5.4).

3.5.1 Potential results

The ('Potential') result tab (Figure 9) shows general information on:

- 'WEATHER:' description and file name of chosen weather;
- 'RAIN:' (rainfall option used) (see Section 3.4.3): this will always state 'belonging to weather station' because only daily weather data from CABOWE files is supported.
- 'CROP:' description and file name of chosen crop;
- 'SOIL:' description and file name of chosen soil;

- 'START:' data on the start conditions: sowing date and emergence data. A value of '-99' for sowing date indicates a fixed emergence option.

Results for 'POTENTIAL CROP PRODUCTION' in table format are shown for different time steps ('DAY') according to the value you specified in the 'Output interval in days' in the input tab 'General'. The column headings and their description are provided in Table 2. A 'SUMMARY' of results is also given for the potential production results (

Table 3).

Table 2. Description of the output of Potential Crop Production table window.

| Column | Description |
|--------|--|
| YEAR | year of the simulation time step |
| DAY | day of year of the simulation time step (1-366) |
| IDSEM | number of days since emergence (d) |
| DVS | development stage of crop (-) |
| TSUM | thermal time since emergence ($^{\circ}\text{C d}$) |
| WLV | dry weight of living leaves (kg ha^{-1}) |
| WST | dry weight of living stems (kg ha^{-1}) |
| WSO | dry weight of living storage organs (kg ha) |
| TAGP | total above ground production (dead and living plant organs) (kg ha^{-1}) |
| LAI | leaf area index (leaf area)/(soil area) (ha ha^{-1}) |
| TRA | transpiration rate (mm d^{-1}) |
| GASS | gross assimilation rate ($\text{kg (CH}_2\text{O) ha}^{-1} \text{d}^{-1}$) |
| MRES | maintenance respiration rate ($\text{kg (CH}_2\text{O) ha}^{-1} \text{d}^{-1}$) |
| DMI | rate of dry matter increase ($\text{kg ha}^{-1} \text{d}^{-1}$). |

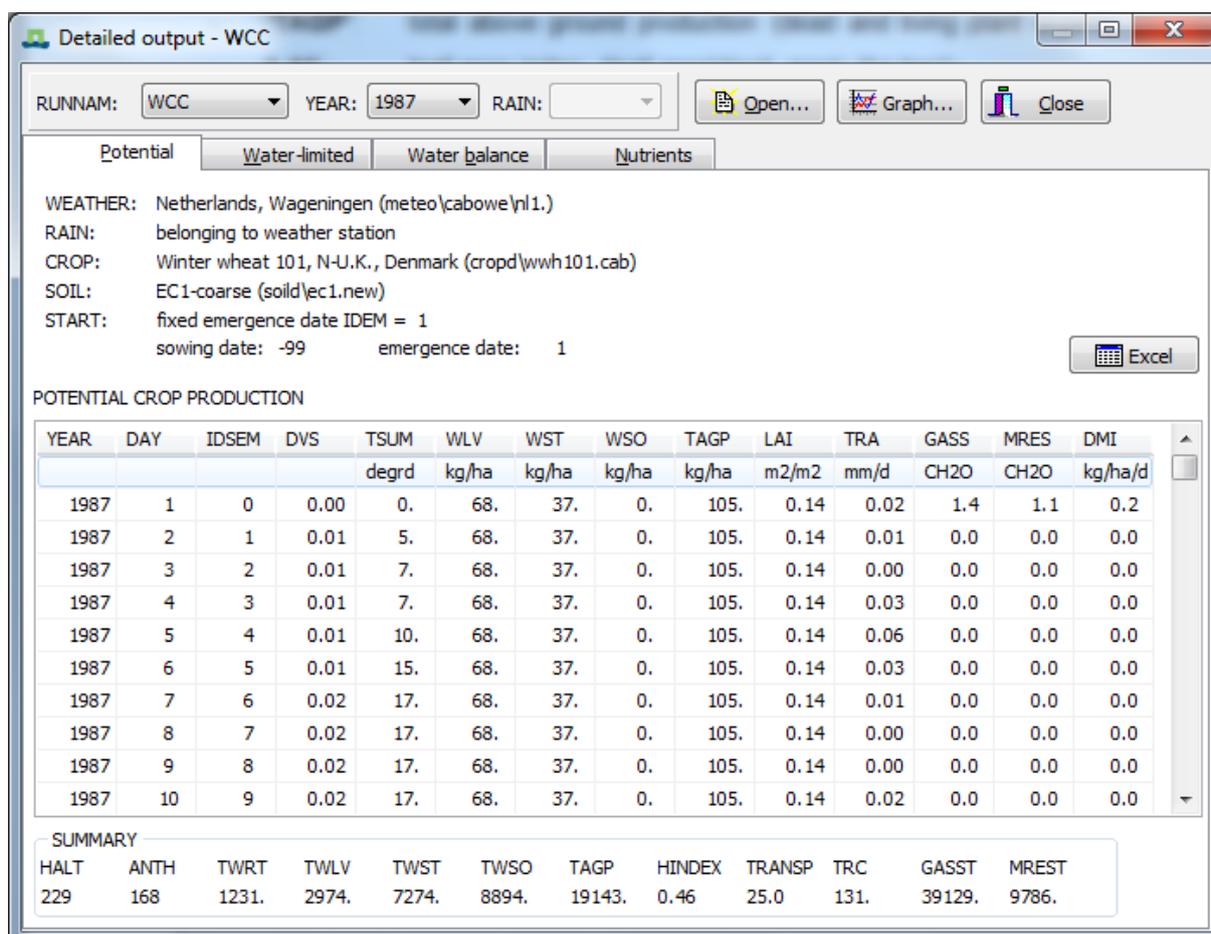


Figure 9. Example of window 'Detailed output' – tab 'Potential'.

Table 3. Description of the summary results for the potential crop production run.

| Column | Description |
|--------|---|
| HALT | day number at harvest (day of the year) |
| ANTH | duration of pre-anthesis phase (d) |
| TWRT | total dry weight of roots (dead and living) (kg ha ⁻¹) |
| TWLV | total dry weight of leaves (dead and living) (kg ha ⁻¹) |
| TWST | total dry weight of stems (dead and living) (kg ha ⁻¹) |
| TWSO | total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| TAGP | total above ground production (dead + living) (kg ha ⁻¹) |
| HINDEX | harvest index: weight of storage organs / weight of total above ground crop (-) |
| TRANSP | total transpiration (cm water) |
| TRC | transpiration coefficient rate (kg (water) / kg (dry matter)) |
| GASST | total gross assimilation (kg (CH ₂ O) ha ⁻¹) |
| MREST | total maintenance respiration (kg (CH ₂ O) ha ⁻¹). |

The 'Graph' button enables you to draw graphs of specified output data of the potential crop growth (Figure 10). These are the same output data as shown in the table of the result tab 'Potential'. There is also an option to present one graph showing the total above ground production (dry weight of living and dead plant organs) and its components: dry weight of living stems, dry weight of living stems and dry weight of living storage organs. The 'Graph' window offers you to load another output file ('Output file 2...'). With the buttons 'Y-axis 1' and 'Y-axis 2' you can control the position of the y-axis (left and right).

Finally, the graph window allows you to control how the simulation results from different years are synchronized on the chart. Results from different simulation years are synchronized by plotting them as day number since the 1st of January. However, this can cause problems for simulations crossing the year boundary. Therefore, you can choose for synchronizing the results for different years on the 1st of January of the harvest year (Figure 11) or the year of sowing/emergence (Figure 12). The former option will cause days before the 1st of January of the year of the harvest to be plotted as negative numbers.

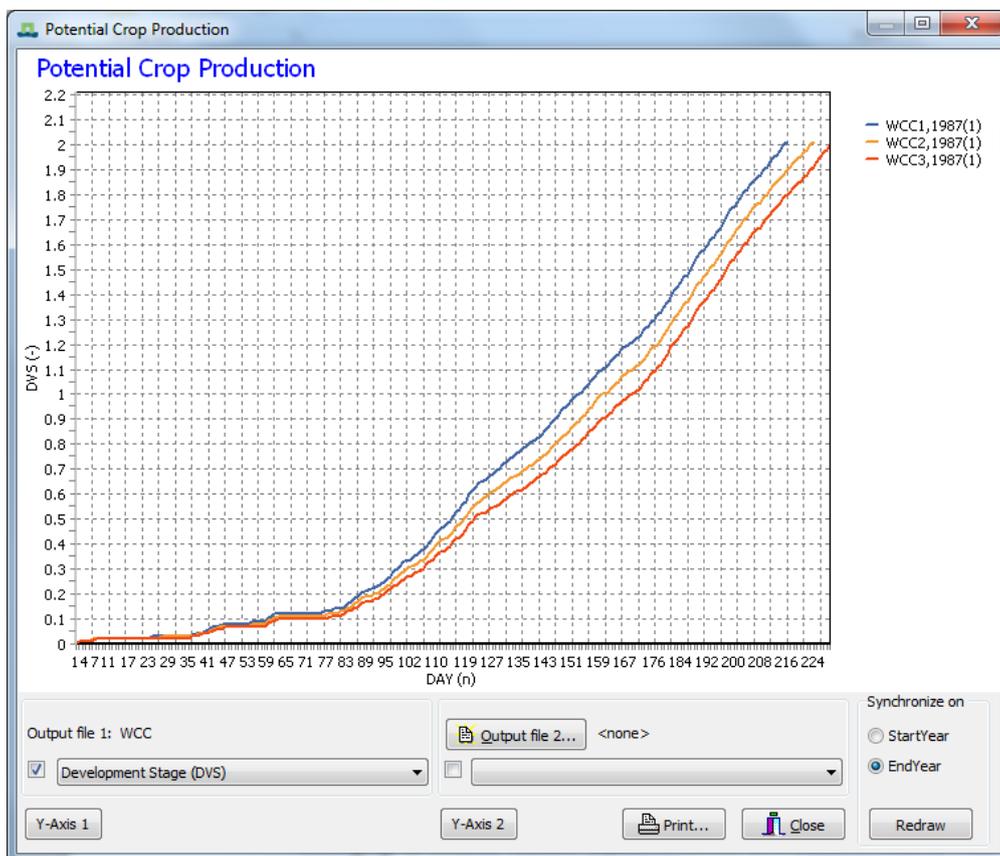


Figure 10. Example of 'Graph' window for potential production for three different reruns.

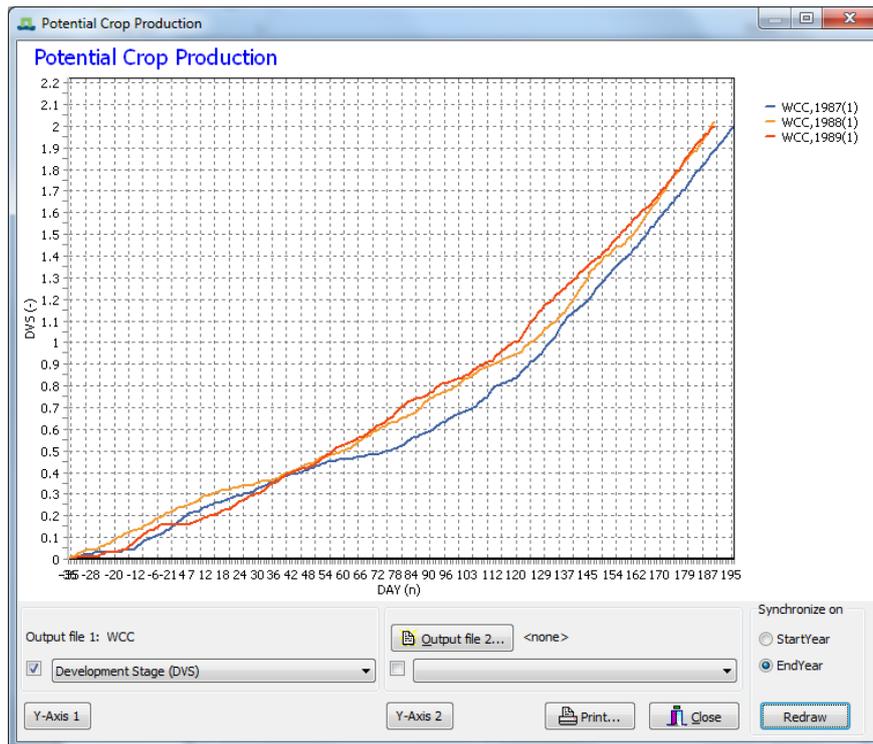


Figure 11. Chart window showing the simulation results for the years 1987, 1988, 1989 synchronized on the year of harvest (EndYear). Simulation time-steps before January 1 are shown as negative numbers.

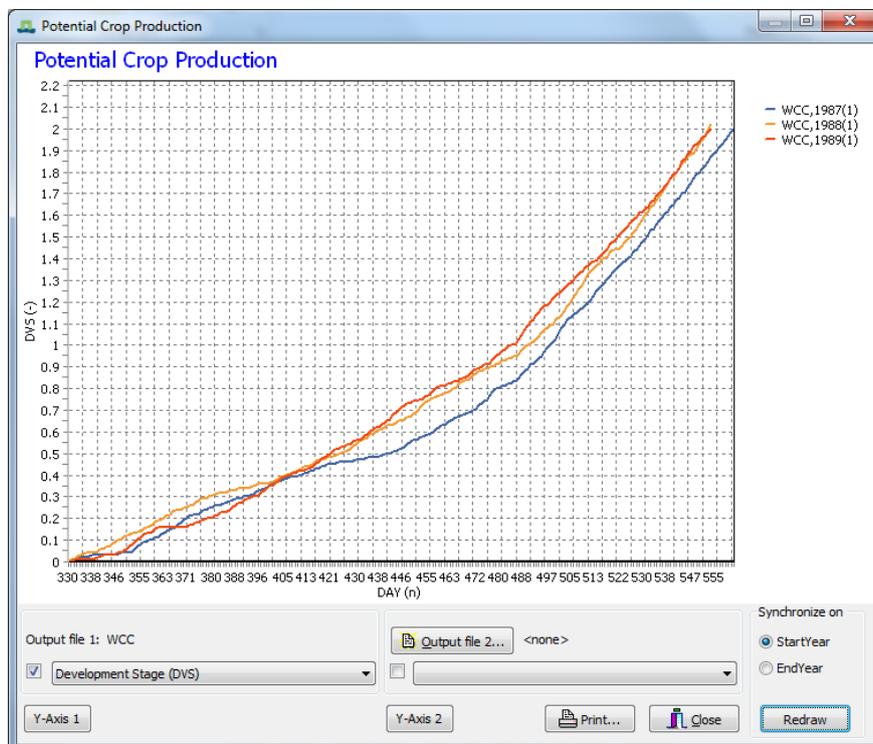


Figure 12. Chart window showing the simulation results for the years 1987, 1988, 1989 synchronized on the year of sowing (StartYear). Simulation time-steps after 31 December of the year of sowing/emergence are shown as numbers > 365.

3.5.2 Water-limited results

The 'Water-limited' result tab (Figure 13) gives results only when simulation of water-limited crop growth is chosen. The following general information is presented:

- 'WEATHER:' description and file name of chosen weather;
- 'RAIN:' rainfall option used (see Section 3.4.3): This will always read 'belonging to weather station' because the use of monthly weather data is not supported anymore.
- 'CROP:' description and file name of chosen crop;
- 'SOIL:' description and file name of chosen soil;
- 'START:' data on the start conditions: sowing date and emergence data. A value of '-99' for sowing date indicates a fixed emergence option.
- a title 'WATER (AND O₂) LIMITED CROP PRODUCTION WITH(OUT) GROUNDWATER' that indicates whether WOFOST has been executed with or without groundwater influence and with or without the effect of oxygen shortage (see input tab 'Soil');
- soil related data (a summary of the options chosen in the input tab 'Soil');
- indication how amount of infiltrated rainfall is determined. It can be a 'fixed fraction' or 'variable fraction';
- 'RDMso': maximum rooting depth allowed by soil (cm) (see input tab 'Soil');
- 'NOTinf': maximum fraction of rain not-infiltrating into soil (-) (see input tab 'Soil');
- 'SM0': soil moisture content of saturated soil ($\text{cm}^{-3}(\text{water}) / (\text{cm}^{-3}(\text{soil}))$);
- 'SMFC': soil moisture content at field capacity ($\text{cm}^{-3}(\text{water}) / (\text{cm}^{-3}(\text{soil}))$);
- 'SMW': soil moisture content at wilting point ($\text{cm}^{-3}(\text{water}) / (\text{cm}^{-3}(\text{soil}))$);
- 'SMLIM': maximum initial soil moisture content of the initial rooting depth ($\text{cm}^{-3}(\text{water}) / (\text{cm}^{-3}(\text{soil}))$) (see input tab 'Soil');
- 'RDM': maximum rooting depth used in simulation (determined by crop and soil) (cm);
- 'WAV': initial amount of available water in total rootable zone (soil moisture content above wilting point (cm water) (same as 'Initial available soil water' in input tab 'Soil');
- 'SSmax': maximum surface storage capacity (cm water) (see input tab 'Soil').

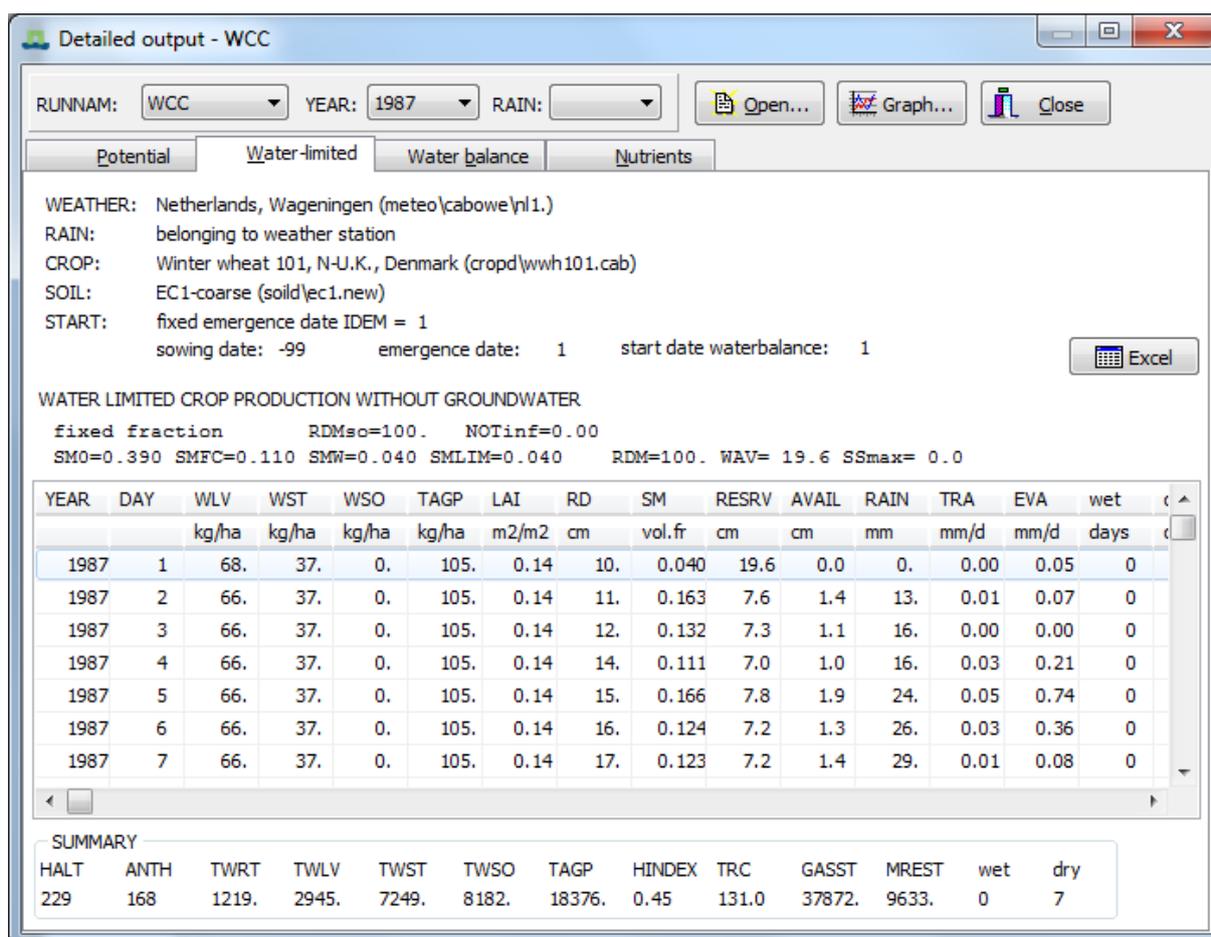


Figure 13. Example of window 'Detailed output' – tab 'Water-limited'.

Results in table format are shown for different time steps ('DAY') according to the value you gave in the 'Output interval in days' in the input tab 'General'. The matrix is filled only when WOFOST has been run for water limited production (Table 4), moreover summary results are provided at the bottom of the window (Table 5).

Table 4. Description of the output of Water-Limited Crop Production table window.

| Column | Description |
|--------|--|
| YEAR | year of the simulation time step |
| DAY | day of year of the simulation time step (1-366) |
| WLW | dry weight of living leaves (kg ha ⁻¹) |
| WST | dry weight of living stems (kg ha ⁻¹) |
| WSO | dry weight of living storage organs (kg ha ⁻¹) |
| TAGP | total above ground production (dead and living plant organs) (kg ha ⁻¹) (only given when simulated without groundwater influence) |
| LAI | leaf area index (leaf area)/(soil area) (ha ha ⁻¹) |
| RD | depth of actual root zone (cm) |
| SM | soil moisture content in actual root zone (cm ⁻³ (water) / (cm ⁻³ (soil))) |
| RESRV | available soil water in potential root zone (in and below actual root zone) (cm water) (only given when simulated without groundwater influence) |

| | |
|--------|--|
| AVAIL | amount of water available in actual root zone (cm water) (only given when simulated without groundwater influence) |
| RAIN | total rainfall in the simulation period (mm) |
| TRA | transpiration rate (mm d ⁻¹) |
| EVA(P) | evaporation rate from soil or from water stored on soil surface (mm d ⁻¹) |
| SS | surface storage (cm water) |
| ZT | depth of groundwater table (cm below soil surface) |
| wet | days characterized by reduced crop growth due to oxygen shortage (d) |
| dry | days characterized by reduced crop growth due to water shortage (d). |

Table 5. Summary results provided for the Water-Limited Crop Production simulation.

| Column | Description |
|---------------|--|
| HALT | day number at harvest (day of the year) |
| ANTH | duration of pre-anthesis phase (d) |
| TWRT | total dry weight of roots (dead and living) (kg ha ⁻¹) |
| TWL | total dry weight of leaves (dead and living) (kg ha ⁻¹) |
| TWST | total dry weight of stems (dead and living) (kg ha ⁻¹) |
| TWSO | total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| TAGP | total above ground production (dead and living plant organs) (kg ha ⁻¹) |
| HINDEX | harvest index weight of storage organs / weight of total above ground crop (-) |
| TRC | transpiration coefficient rate (kg (water) / kg (dry matter)) |
| GASST | total gross assimilation (kg (CH ₂ O) ha ⁻¹) |
| MREST | total maintenance respiration (kg (CH ₂ O) ha ⁻¹) |
| wet | total number of days characterized by reduced crop growth due to oxygen shortage (d) |
| dry | total number of days characterized by reduced crop growth due to water shortage (d). |

The 'Graph' button enables you to draw graphs of specified output data of the water-limited crop growth (Figure 10). These are the same output data as shown in the table of the result tab 'Water-limited'. There is also an option to present one graph showing available soil water in potential root zone (in and below actual root zone) together with the amount of water available in actual root zone. The 'Graph' window offers you to load another output file ('Output file 2...'). With the buttons 'Y-axis 1' and 'Y-axis 2' you can control the position of the y-axis (left and right).

3.5.3 Water balance results

The ('Water balance') result tab (Figure 14) shows water balances of the whole system ('WATER BALANCE WHOLE SYSTEM') and the root zone ('WATER BALANCE ROOT ZONE'). The water balance for the whole system provides information on:

- initial and the final water content and their difference, either for the maximum rooting zone or, when ground water influence is assumed, for the first 10 m;
- initial and final surface storage of water and their difference;
- irrigation (always 0, since there is no option for irrigation in WOFOST);
- rainfall;
- evaporation (from the soil or surface water) and transpiration (by the crop) together: water loss to atmosphere);
- runoff, percolation to the ground water, and, the water loss through the drains (when groundwater is present).

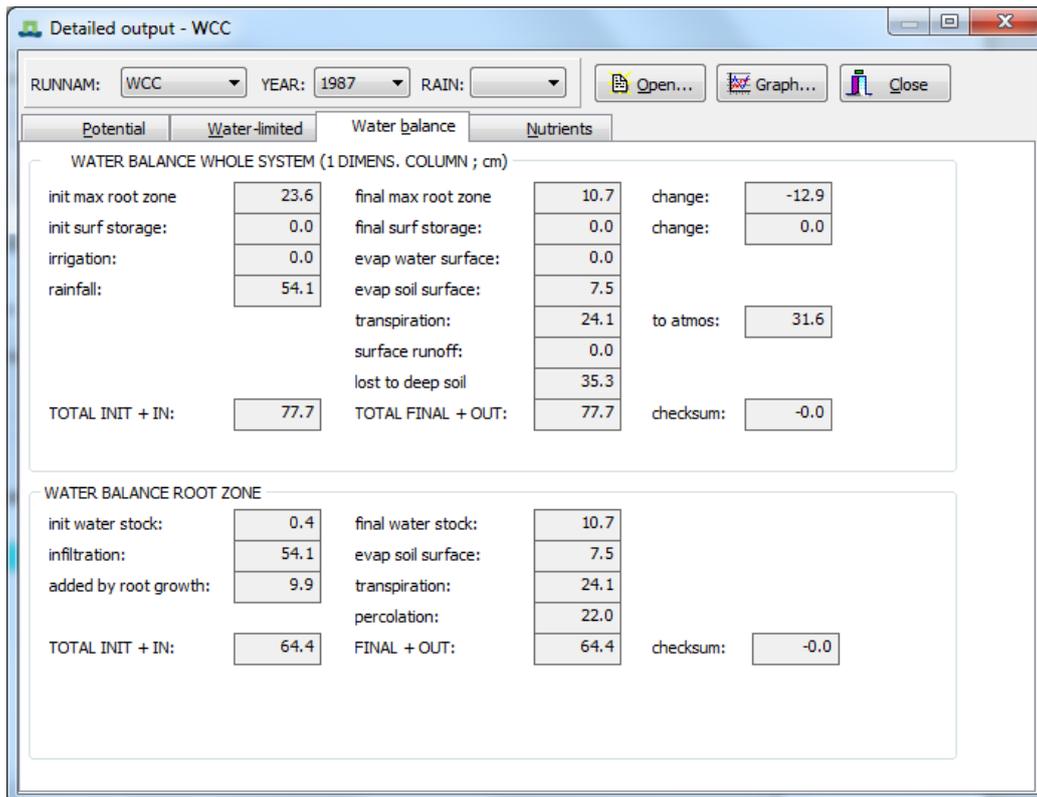


Figure 14. Example of window 'Detailed output' – tab 'Water balance'.

The checksum is used to check the water balance by subtracting the final water content and the water lost (TOTAL FINAL + OUT) from the initial water content and the water that entered the system (TOTAL INIT + IN). Checksum should be 0.0 or, due to rounding errors, close to 0.0. The water balance for the root zone provides information on:

- initial and final water content in the root zone;
- infiltration into the root zone (i.e. rainfall minus runoff);
- evaporation (from the soil) and transpiration (by the crop);
- increase in available water due to root growth;
- percolation to the ground water;
- capillary rise (when groundwater is present).

The checksum ((TOTAL INIT + IN) - (FINAL + OUT)) should be 0.0 or, due to rounding errors, close to 0.0.

The 'Graph' button enables you to draw bar diagrams of the water balances for the whole system and/or root zone (Figure 15). The bar diagram consists of two columns:

- on the left: initial water content and the water that entered the system ('INIT + IN');
- on the right: the final water content and the water lost ('FINAL + OUT').

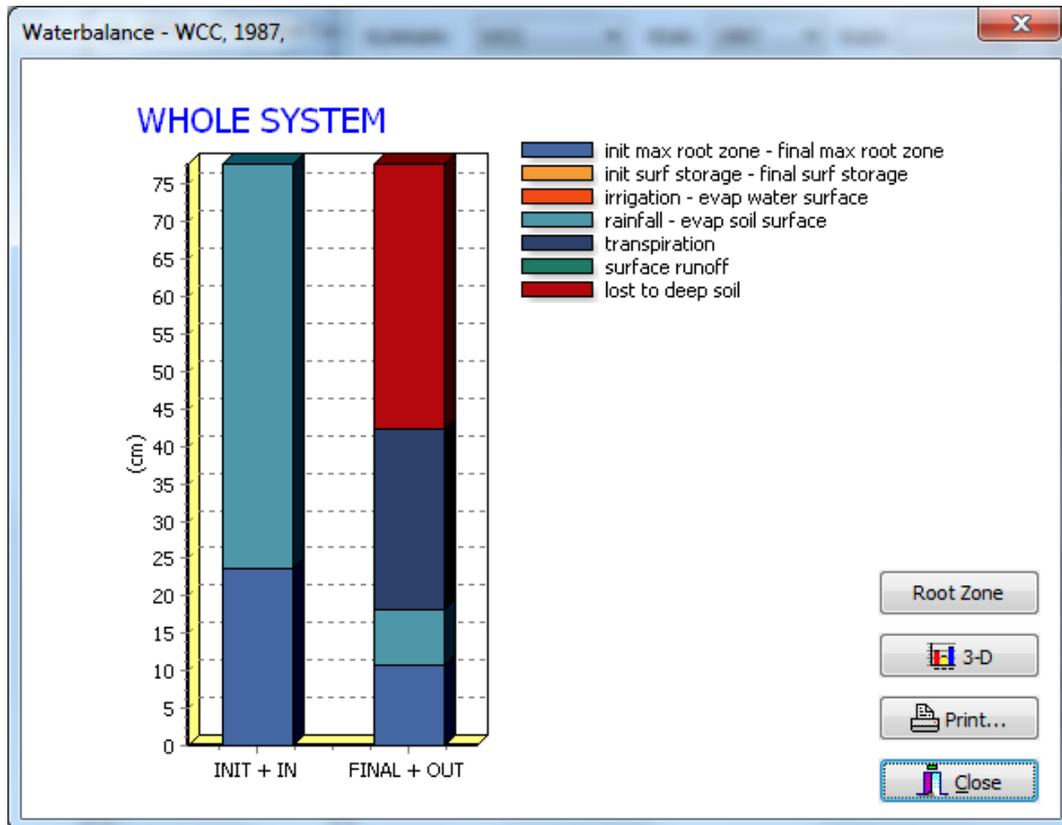


Figure 15. Example of 'Graph' window for water balances.

The different components of the column are explained in the legend. If a component appears in both columns (initial value (left) and final value (right)) this component has one colour. If a water balance was simulated for both the whole system and root zone (see input tab 'General'), a button appears to switch from both options ('Root zone' or 'Whole system').

3.5.4 Nutrient results

The ('Nutrients') result tab (Figure 16) is only available when 'and calculation of nutrient-limited crop growth' is chosen in the input tab 'General'. This tab first provides calculated values for the basic soil supply of nutrients and the recovery fractions for additional fertilizers, followed by the results for potential, nutrient limited, and water-limited production. The simulated yield of leaves, stems and storage organs (dry weight (kg ha^{-1})), the ratio (storage organ / (leaves + stems)) and the harvest index (storage organs / total above ground biomass) is provided. Subsequently, the amount of fertilizer that would be needed to obtain potential and water-limited production is given in element form (kg ha^{-1}). The fertilizer requirements are calculated on the basis of balanced nutrient supply

assuming that the element concentrations in the biomass are the average of minimum and maximum.

The nutrient limited yield is calculated according to a much more complicated scheme, taking into account an optimum balance between the three nutrients. The nutrient limited yield is therefore sometimes relatively higher than the water limited yield. This becomes visible when the nutrient and water limited production levels are of the same order of magnitude. Moreover, the nutrient limited yield and water limited yield are estimated independently so the nutrient limited yield can exceed the calculated water limited yield, even in terms of total biomass. According to the hierarchical approach this should not be possible. The correct interpretation is that without supplementary irrigation the nutrient limited yield cannot be obtained.

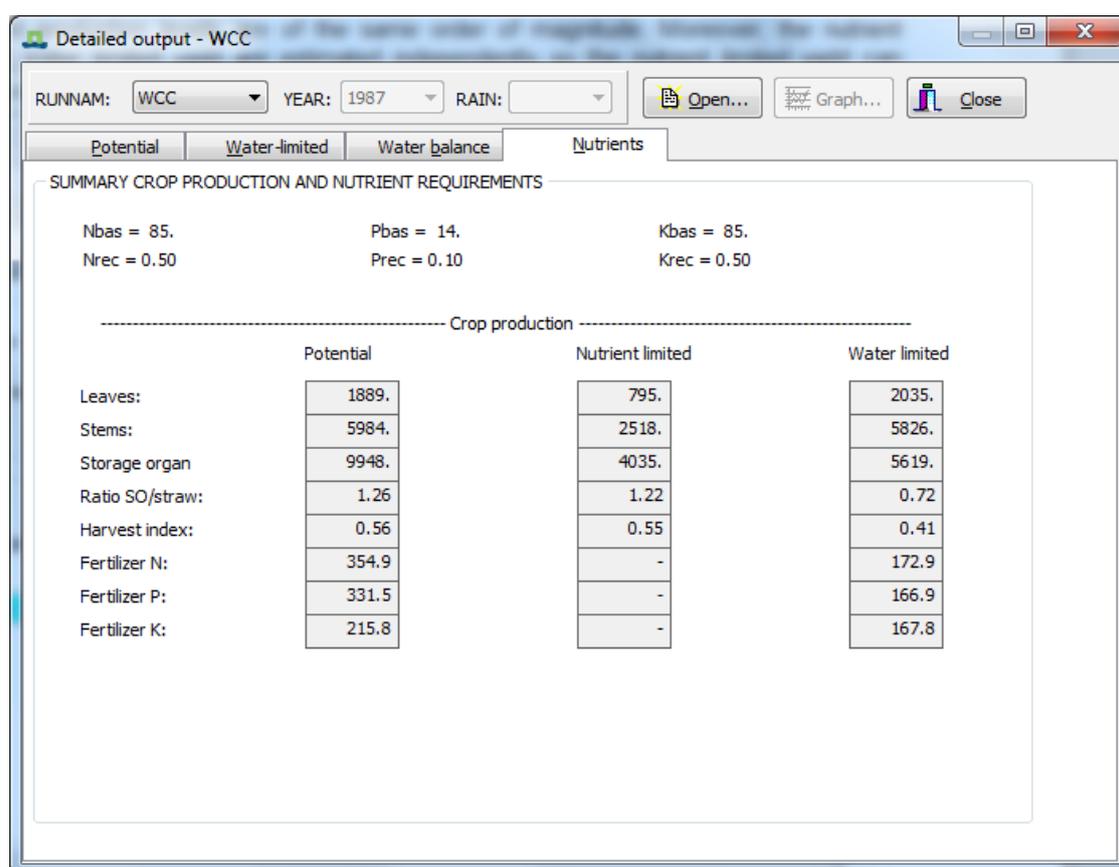


Figure 16. Example of window 'Detailed output' – tab 'Nutrients'.

The example (Figure 16) shows an apparent anomaly: the amount of leaf biomass in the water limited production exceeds the potential leaf biomass. The reason is that the potential yield is given for the latest of three years, while the water limited yield is given as the average over three years.

3.6 Summary results of WOFOST

To view the summary of results of a WOFOST run, click on 'Result summary...' on the button bar in the main window. A message 'No Summary results available' will appear if only one weather year was simulated. The 'Summary output'

consists of three tabs: Potential, Water-limited and Summary which will be described in the following sections.

3.6.1 Potential results

The ('Potential') result tab (Figure 17) shows general information on:

- 'WEATHER:' description and file name of chosen weather;
- 'CROP:' description and file name of chosen crop;
- 'SOIL:' description and file name of chosen soil.

The 'Excel' button exports the results of a selected run to Excel. This button is only valid for the first table and not for the statistical table.

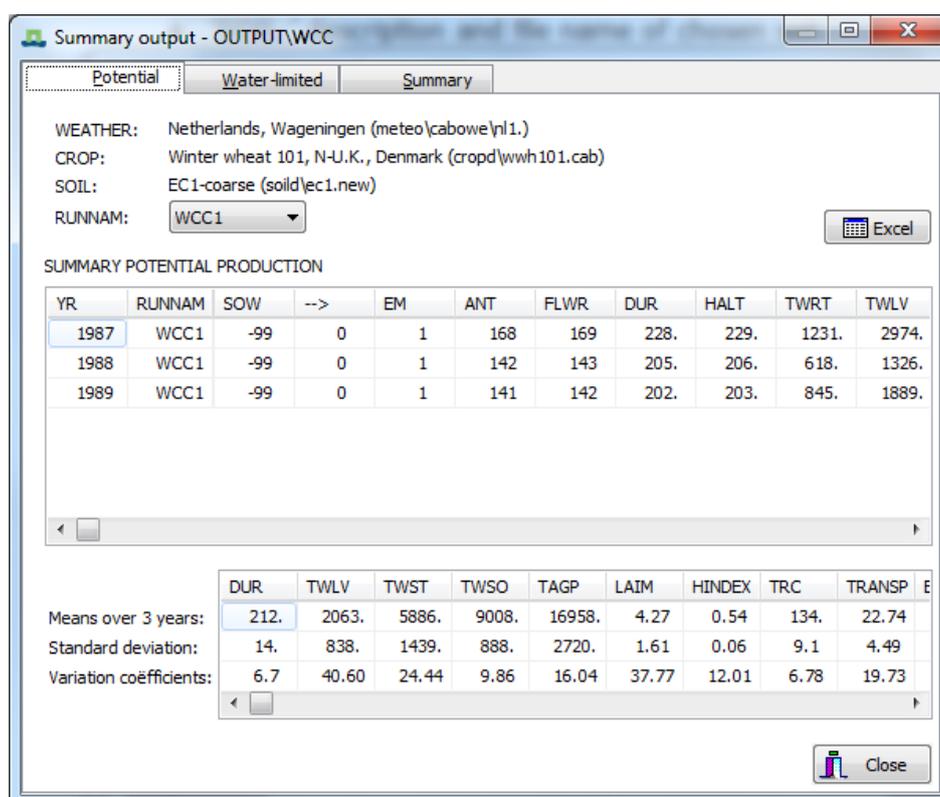


Figure 17. Example of window 'Summary output' – tab 'Potential'.

Summary results for potential production ('SUMMARY POTENTIAL PRODUCTION') are given in table format. One line is given for each growing season and run (Table 6). Moreover, a table is filled with means ('Means over x years'), standard deviation ('Standard deviation'), and variation coefficients ('Variation coefficients') when a run for two or more weather years is made (Table 7).

Table 6. Description of the WOFOST summary output table for potential crop production.

| Column | Description |
|--------|---|
| YR | simulation year, which always refers to the year when the simulation has started (e.g. sowing or emergence) |
| RUNNAM | name of the simulation run |
| SOW | sowing date (day in year) (in case of fixed emergence value is -99) days between sowing and emergence (d) (in case of fixed emergence value is 0) |

| | |
|--------|---|
| EM | emergence date (day in year) |
| ANT | duration of pre-anthesis phase (d) |
| FLWR | day of flowering (day in year) |
| DUR | duration of simulation period (d) |
| HALT | day number at harvest (day in year) |
| TWRT | total dry weight of roots (dead and living) (kg ha ⁻¹) |
| TWLV | total dry weight of leaves (dead and living) (kg ha ⁻¹) |
| TWST | total dry weight of stems (dead and living) (kg ha ⁻¹) |
| TWSO | total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| TAGP | total above ground production (dead and living plant organs) (kg ha ⁻¹) |
| LAIM | maximum leaf area index (ha ha ⁻¹) |
| HINDEX | harvest index weight of storage organs / weight of total above ground crop (-) |
| TRC | transpiration coefficient rate (kg (water) / kg (dry matter)) |
| GASST | total gross assimilation (kg (CH ₂ O) ha ⁻¹) |
| MREST | total maintenance respiration (kg (CH ₂ O) ha ⁻¹) |
| TRANSP | total transpiration (cm water) |
| EVSOL | total evaporation from soil surface (cm water). |

Table 7. Description of the WOFOST summary statistics table for potential crop production.

| Column | Description |
|---------------|---|
| DUR | duration of simulation period (d) |
| TWLV | total dry weight of leaves (dead and living) (kg ha ⁻¹) |
| TWST | total dry weight of stems (dead and living) (kg ha ⁻¹) |
| TWSO | total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| TAGP | total above ground production (dead and living plant organs) (kg ha ⁻¹) |
| LAIM | maximum leaf area index (ha ha ⁻¹) |
| HINDEX | harvest index as weight of storage organs / weight of total above ground crop biomass (-) |
| TRC | transpiration coefficient rate (kg (water) / kg (dry matter)) |
| TRANSP | total transpiration (cm water) |
| EVSOL | total evaporation from soil surface (cm water). |

3.6.2 Water-limited results

The ('Water-limited') result tab (Figure 18) shows general information on:

- 'WEATHER:' description and file name of chosen weather;
- 'CROP:' description and file name of chosen crop;
- 'SOIL:' description and file name of chosen soil;
- 'RAIN:' indication which rainfall option is used. This will always read 'belonging to weather station' because the use of monthly or dekadal weather data has been abandoned.
- '(NO) GROUNDWATER' indication whether there is groundwater influence.

The general information is valid only for the first default run and not for additional runs, which you can choose in 'RUNNAM'. Therefore the general information has a grey colour (disabled) in case an additional run is chosen.

The 'Excel' button exports the results of a selected run to Excel. It is only valid for the first table and not for the statistical table.

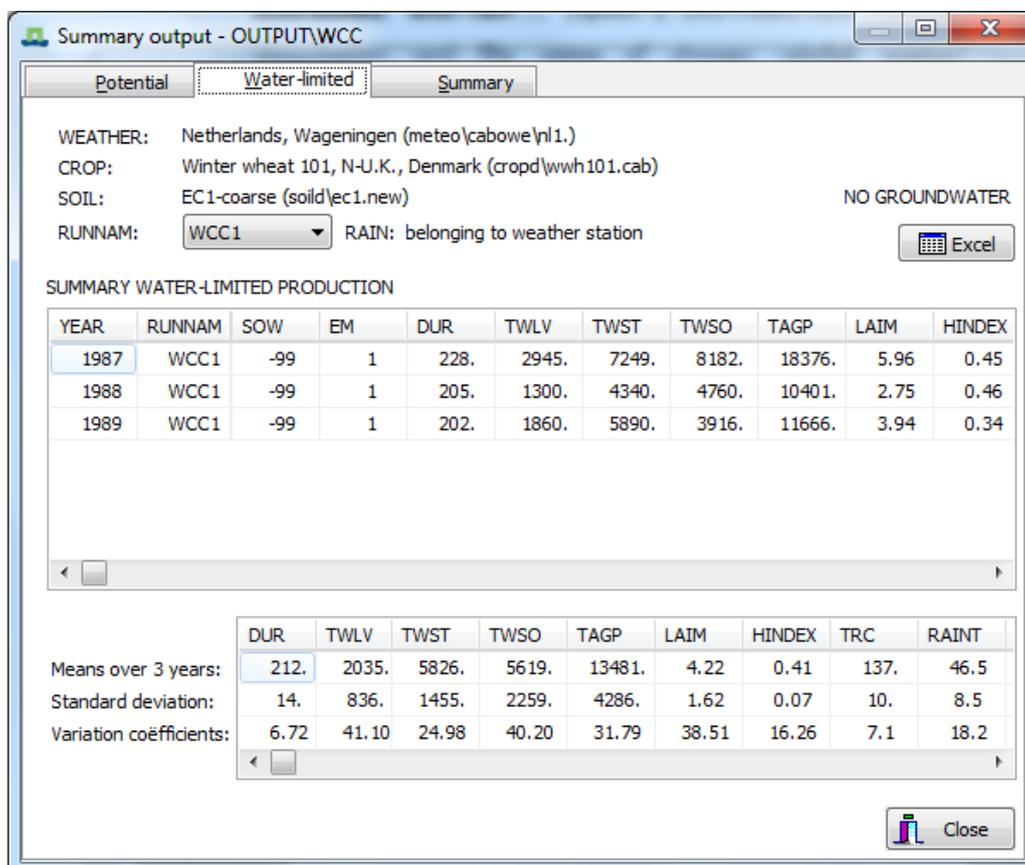


Figure 18. Example of window 'Summary output' – tab 'Water-limited'.

Summary results for water-limited production ('SUMMARY WATER-LIMITED PRODUCTION') are given in table format (Table 8). One line is given for each simulation year (weather year) and RUNNAM. Furthermore, a table is filled with means ('Means over x years'), standard deviation ('Standard deviation') and variation coefficients ('Variation coefficients') when a run for two or more years is made (Table 9).

Table 8. Description of the WOFOST summary output table for water-limited crop production.

| Column | Description |
|--------|---|
| YEAR | simulation year |
| RUNNAM | name of the simulation run |
| SOW | sowing date (day in year) (in case of fixed emergence value is -99) |
| EM | emergence date (day in year) |
| DUR | duration of simulation period (d) |
| TWLV | total dry weight of leaves (dead and living) (kg ha ⁻¹) |
| TWST | total dry weight of stems (dead and living) (kg ha ⁻¹) |

| | |
|--------|--|
| TWSO | total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| TAGP | total above ground production (dead and living plant organs) (kg ha ⁻¹) |
| LAIM | maximum leaf area index (ha ha ⁻¹) |
| HINDEX | harvest index weight of storage organs / weight of total above ground crop (-) |
| TRC | transpiration coefficient rate (kg (water) / kg (dry matter)) |
| RAINT | total rainfall in the simulation period (cm water) |
| DELWAT | difference between final and initial available water in the root zone (cm water) |
| TRAT | total transpiration (cm water) |
| EVSOL | total evaporation from soil surface (cm water) |
| LOSST | total water percolated to deep soil, not available for plant growth (cm water) |
| TSR | total surface runoff during simulation period (cm water) |
| RYLD | relative yield water-limited yield / potential yield (%) |
| RAGP | relative total above ground production water-limited production / potential production (%) |

Table 9. Description of the WOFOST summary statistics table for water-limited crop production.

| Column | Description |
|---------------|--|
| DUR | duration of simulation period (d) |
| TWLV | total dry weight of leaves (dead and living) (kg ha ⁻¹) |
| TWST | total dry weight of stems (dead and living) (kg ha ⁻¹) |
| TWSO | total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| TAGP | total above ground production (dead and living plant organs) (kg ha ⁻¹) |
| LAIM | maximum leaf area index (ha ha ⁻¹) |
| HINDEX | harvest index weight of storage organs / weight of total above ground crop (-) |
| TRC | transpiration coefficient rate (kg (water) / kg (dry matter)) |
| RAINT | total rainfall in the simulation period (cm water) |
| DELWAT | difference between final and initial available water in the root zone (cm water) |
| TRAT | total transpiration (cm water) |
| EVSOL | total evaporation from soil surface (cm water) |
| LOSST | total water percolated to deep soil, not available for plant growth (cm water) |
| RYLD | relative yield water-limited yield / potential yield (%) |
| RAGP | relative total above ground production water-limited production / potential production (%) |

3.6.3 Summary results

The ('Summary') result tab (Figure 19) shows means of variables over simulated weather (and rainfall) years) for:

- different runs with WOFOST;
- for potential and optionally water-limited crop growth.

This is a repetition of the information given the 'Potential' and 'Water limited' result tabs but now ordered in one clear overview (Table 10).

Note: This 'Summary' tab on the 'Summary output' window is filled only when WOFOST is run for more than two weather years and more than one run is used in the 'Rerun' tab.

| PS | RUNNAM | IZT | SOW | EM | DUR | TWLV | TWST | TWSO | var% | TAGP | var% |
|----|--------|-----|------|----|------|-------|-------|-------|-------|--------|------|
| PP | WCC1 | 0 | -99. | 1. | 212. | 2063. | 5886. | 9008. | 9.86 | 16958. | 16.0 |
| WP | WCC1 | 0 | -99. | 1. | 212. | 2035. | 5826. | 5619. | 40.20 | 13481. | 31.7 |
| PP | WCC2 | 0 | -99. | 1. | 206. | 1547. | 4597. | 8660. | 17.96 | 14804. | 24.2 |
| WP | WCC2 | 0 | -99. | 1. | 206. | 1521. | 4546. | 6547. | 35.33 | 12615. | 34.5 |

| PS | RUNNAM | IZT | SOW | EM | LAIM | HINDEX | RYLD | RAGP | TRC | RDMSOL |
|----|--------|-----|------|----|------|--------|-------|-------|------|--------|
| PP | WCC1 | 0 | -99. | 1. | 212. | 2063. | | | | |
| WP | WCC1 | 0 | -99. | 1. | 212. | 2035. | 63.18 | 78.74 | 137. | 100. |
| PP | WCC2 | 0 | -99. | 1. | 206. | 1547. | | | | |
| WP | WCC2 | 0 | -99. | 1. | 206. | 1521. | 75.45 | 84.45 | 133. | 100. |

Figure 19. Example of window 'Summary output' – tab 'Summary'.

Table 10. Description of the different fields in the window 'Summary output' – tab 'Summary'.

| Column | Description |
|--------|--|
| PS | production level (PP = potential WP = water-limited) |
| RUNNAM | name of the simulation run |
| IZT | influence of ground water (0 = no influence 1 = influence) |
| SOW | sowing date (day in year) (in case of fixed emergence value is -99) |
| EM | emergence date (day in year) |
| DUR | duration of simulation period (d) |
| TWLV | total dry weight of leaves (dead and living) (kg ha ⁻¹) |
| TWST | total dry weight of stems (dead and living) (kg ha ⁻¹) |
| TWSO | total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| var% | variation coefficient of total dry weight of storage organs (dead and living) (kg ha ⁻¹) |
| TAGP | total above ground production (dead and living plant organs) (kg ha ⁻¹) |

| | |
|--------|--|
| var% | variation coefficient of total above ground production (dead and living plant organs) (kg ha ⁻¹) |
| LAIM | maximum leaf area index (ha ha ⁻¹) |
| HINDEX | harvest index weight of storage organs / weight of total above ground crop (-) |
| RYLD | relative yield water-limited yield / potential yield (%) |
| RAGP | relative total above ground production water-limited production / potential production (%) |
| TRC | transpiration coefficient rate (kg (water) / kg (dry matter)) |
| RDMSOL | maximum rooting depth allowed by soil (cm). |

3.7 Running WOFOST from the Command Prompt

WOFOST can be run from a command prompt or a terminal (linux, Mac OSX) by executing the wofost executable ("*wofost.exe*" on windows systems) within the main directory. This option becomes important when you want to change the source code of WOFOST and these changes influence the input and/or output of WOFOST. In that case, the graphical user interface WCC cannot be used anymore and WOFOST should be run as stand-alone. Moreover, the WCC is not available on computers running Linux or Mac OSX so for these systems running WOFOST from a terminal is the only available option.

When WOFOST is run from the command prompt, input of WOFOST can be edited through the different run files described in Section 4.5. Crop, soil, and weather files should not be edited. These files are chosen in the run files. If changes have to be made in the crop, soil, or weather files, new crop, soil, or weather files should be created. Results can be viewed and analyzed in the output files described in Section 4.6.

4 Input and output files of WOFOST

4.1 Introduction

In principle, WOFOST can simulate the growth of any annual crop growing at any location. To facilitate this, the specific crop, soil and weather parameters have been put in separate data files. This makes it relatively easy to add a new file with e.g. the parameters of a specific crop you work with, or data from a nearby weather station. Additional information is given in run files named WCCTI.TIM (weather and crop calendar related data), WCCSI.SIT (default values for soils that are not given in the soil file), WCCRR.RER (to define series of consecutive WOFOST-runs) and WCC.WCC (general information on names of files etc.).

This chapter describes the structure of:

- crop files (Section 4.2);
- soil files (Section 4.3);
- weather files (Section 4.4);
- run files (Section 4.5);
- output files (Section 4.6);
- log-files (Section 4.7).

The variables used in the data files are explained in Annex B. For a complete description of the variables and their function in WOFOST, you are referred to Supit et al. (1994).

The WCC does not check the values of parameters given in the crop, soil and weather files. Only when the user selects those parameters in the rerun tab (Section 3.4.7) the WCC does such tests. Also WOFOST does not carry out a full control of lower and upper limits of given input. So it is important to fill in right values in the crop, soil and weather files without mistakes. For example it is possible to fill in a negative number for TSUM1 in the crop file. WCC and WOFOST will execute the run with this erroneous value without any problem. However, the simulation results are wrong (negative development stage). Another example can be given for the CABO-weather files (Section 4.4.2). If you make mistakes in the day number (e.g. day 77 is followed by day 79) WOFOST does not signal any problem but the results are wrong. So the advice is to work very careful when editing and building new crop, soil and weather files.

The collection of basic data is treated in Van Keulen and Wolf (1986) and in Penning de Vries et al. (1989).

4.2 Crop files

For each crop (or cultivar) you want to simulate, you have to provide WOFOST with a specific set of parameters. These parameters refer to, amongst other things, phenology, assimilation and respiration characteristics, and partitioning of assimilates to plant organs. These parameters are specified in a crop file that is stored in the directory \Wofost Control Centre\CROPD\. In the WCC you can

choose the file in the tab 'Crop' (see Section 3.4.2); when running WOFOST in the terminal mode you supply the file name in the timer file (see Section 4.5). The file extension of the crop files is divers and does not have meaning.

See Annex B for the meaning of the variable names. The syntax of the crop files is presented in Figure 20. There are no specific rules for the file names. An example of a crop file is presented in Table 11.

- The file consists of names and values of variables, separated by an equal => sign.
- The name of a variable cannot exceed six characters.
- Each variable may appear only once.
- Variables may appear in the file in any order.
- More than one variable and value can be written on one line as long as they are separated by a semi-colon <;>.
- With the exception of array variables, the variable and its value have to be on the same line.
- Only the first 80 characters of each line are read.
- Comment lines start with an asterisk <*> in the first column or an exclamation mark <!> in any column.
- Blank lines are allowed.
- No tabs or other control and extended ASCII characters are allowed.
- In case of array variables, more than one numerical value may follow the equal sign, separated by commas <, >.
- Identical values in an array may be given as <n*numerical value>, e.g. <5 * 10> instead of <10, 10, 10, 10, 10>
- Arrays may be written on successive lines, as long as the continuation character <, > is used (e.g. AMAXTB in Fig. 29).
- Somewhere (advisable just after the header) the WCC variable CRPNAM (for crops) or SOLNAM (for soils) has to be given. To this variable a description (character string) of the crop or soil is assigned that is enclosed with obligated quotes <'>

Figure 20. Syntax rules of the crop and soil files (Van Kraalingen, 1991).

Most of the crop files included in WOFOST have been developed for simulation of crop growth in the EC (Boons-Prins et al., 1993). The differences among the different files of one species are usually very small. The regions of the EC to which the data sets pertain are indicated in the comment in the files.

The crop files are ready for use, but you may want to change them or use completely new files. For instance when you want to simulate a specific variety or a crop not included. Because a large number of data is needed (), creating new crop files can be cumbersome. Some values can be retrieved from the literature (e.g. Van Heemst, 1988; Penning de Vries et al., 1989) but you may need to obtain others by experimentation. Consult e.g. Van Keulen (1986) on the collection of plant data.

While the measurement of some plant-parameters requires a lot of work, others are more easy to obtain, e.g. the thermal time needed to reach a certain phenological stage (TSUM1, TSUM2) can be easily observed. If you want to change such parameters, the use of rerun files can be very helpful (Section 4.5).

Table 11. Example of a crop file (WWH101.CAB).

```
** $Id: wwh101.cab 1.3 1997/09/25 14:07:03 LEM release $
** File WWH101.CAB
** CROP DATA FILE for use with WOFOST, June 1992
**
** WHEAT, WINTER 101
```

```

** Regions : Northern Ireland, Scotland, northern UK (R71), Denmark
** start date 1 January
** mean date of flowering 10 Jun, mature 15 Aug

** Derived from SUCROS87 data set for wheat.
** Calibrated for use in WOFOST model at the Centre for Agrobiological
** Research (CABO-DLO) for the simulation of crop growth and yield on the
** basis of daily weather data.
** Purpose of application: Crop growth monitoring with agrometeorological
** model in the EC.
** Developed in the framework of JRC Agriculture Project Action 3.

CRPNAM='Winter wheat 101, N-U.K., Denmark'

** emergence
TBASEM = -10.0    ! lower threshold temp. for emergence [cel]
TEFFMX = 30.0    ! max. eff. temp. for emergence [cel]
TSUMEM = 0.      ! temperature sum from sowing to emergence [cel d]

** phenology
IDSL   = 0       ! indicates whether pre-anthesis development depends
                ! on temp. (=0), daylength (=1) , or both (=2)
DLO    = -99.0   ! optimum daylength for development [hr]
DLC    = -99.0   ! critical daylength (lower threshold) [hr]
TSUM1  =1000.    ! temperature sum from emergence to anthesis [cel d]
TSUM2  = 950.    ! temperature sum from anthesis to maturity [cel d]
DTSMTB = 0.00, 0.00,    ! daily increase in temp. sum
                30.00, 30.00,    ! as function of av. temp. [cel; cel d]
                45.00, 30.00
DVSI   = 0.      ! initial DVS
DVSEND = 2.00    ! development stage at harvest (= 2.0 at maturity [-])

** initial
TDWI   = 210.00  ! initial total crop dry weight [kg ha-1]
LAIEM  = 0.1365  ! leaf area index at emergence [ha ha-1]
RGR LAI = 0.00817 ! maximum relative increase in LAI [ha ha-1 d-1]

** green area
SLATB  = 0.00, 0.00212, ! specific leaf area
                0.50, 0.00212, ! as a function of DVS [-; ha kg-1]
                2.00, 0.00212
SPA    = 0.000   ! specific pod area [ha kg-1]
SSATB  = 0.0, 0.0,    ! specific stem area [ha kg-1]
                2.0, 0.0    ! as function of DVS
SPAN   = 31.3    ! life span of leaves growing at 35 Celsius [d]
TBASE  = 0.0     ! lower threshold temp. for aging of leaves [cel]

** assimilation
KDIFTB = 0.0, 0.60,    ! extinction coefficient for diffuse visible
                2.0, 0.60    ! light [-] as function of DVS
EFFTB  = 0.0, 0.45,    ! light-use effic. single leaf [kg ha-1 hr-1]
                40.0, 0.45   ! j-1 m2 s] as function of daily mean temp.
AMAXTB = 0.00, 35.83,  ! maximum leaf CO2 assimilation as function
                1.00, 35.83, ! of DVS
                1.30, 35.83,
                2.00, 4.48
TMPFTB = 0.00, 0.01,   ! reduction factor of AMAX
                10.00, 0.60, ! as function of av. temp. [cel; -]
                15.00, 1.00,
                25.00, 1.00,
                35.00, 0.00
TMNFTB = 0.00, 0.00,   ! red. factor of gross assim. rate
                3.00, 1.00  ! as function of low min. temp. [cel; -]

** conversion of assimilates into biomass
CVL    = 0.685   ! efficiency of conversion into leaves [kg kg-1]
CVO    = 0.709   ! efficiency of conversion into storage org. [kg kg-1]
CVR    = 0.694   ! efficiency of conversion into roots [kg kg-1]
CVS    = 0.662   ! efficiency of conversion into stems [kg kg-1]

```

```

** maintenance respiration
Q10      = 2.0    ! rel. incr. in resp. rate per 10 Cel temp. incr. [-]
RML      = 0.0300 ! rel. maint. resp. rate leaves [kg CH2O kg-1 d-1]
RMO      = 0.0100 ! rel. maint. resp. rate stor.org. [kg CH2O kg-1 d-1]
RMR      = 0.0150 ! rel. maint. resp. rate roots [kg CH2O kg-1 d-1]
RMS      = 0.0150 ! rel. maint. resp. rate stems [kg CH2O kg-1 d-1]
RFSETB   = 0.00, 1.00, ! red. factor for senescence
          2.00, 1.00    ! as function of DVS [-; -]

** partitioning
FRTB     = 0.00, 0.50, ! fraction of total dry matter to roots
          0.10, 0.50, ! as a function of DVS [-; kg kg-1]
          0.20, 0.40,
          0.35, 0.22,
          0.40, 0.17,
          0.50, 0.13,
          0.70, 0.07,
          0.90, 0.03,
          1.20, 0.00,
          2.00, 0.00
FLTB     = 0.00, 0.65, ! fraction of above-gr. DM to leaves
          0.10, 0.65, ! as a function of DVS [-; kg kg-1]
          0.25, 0.70,
          0.50, 0.50,
          0.646, 0.30,
          0.95, 0.00,
          2.00, 0.00
FSTB     = 0.00, 0.35, ! fraction of above-gr. DM to stems
          0.10, 0.35, ! as a function of DVS [-; kg kg-1]
          0.25, 0.30,
          0.50, 0.50,
          0.646, 0.70,
          0.95, 1.00,
          1.00, 0.00,
          2.00, 0.00
FOTB     = 0.00, 0.00, ! fraction of above-gr. DM to stor. org.
          0.95, 0.00, ! as a function of DVS [-; kg kg-1]
          1.00, 1.00,
          2.00, 1.00

** death rates
PERDL    = 0.030 ! max. rel. death rate of leaves due to water stress
RDRRTB   = 0.00, 0.000, ! rel. death rate of roots
          1.50, 0.000, ! as a function of DVS [-; kg kg-1 d-1]
          1.5001, 0.020,
          2.00, 0.020
RDRSTB   = 0.00, 0.000, ! rel. death rate of stems
          1.50, 0.000, ! as a function of DVS [-; kg kg-1 d-1]
          1.5001, 0.020,
          2.00, 0.020

** water use
CFET     = 1.00 ! correction factor transpiration rate [-]
DEPNR    = 4.5 ! crop group number for soil water depletion [-]
IAIRDU   = 0 ! air ducts in roots present (=1) or not (=0)

** rooting
RDI      = 10. ! initial rooting depth [cm]
RRI      = 1.2 ! maximum daily increase in rooting depth [cm d-1]
RDMCR    = 125. ! maximum rooting depth [cm]

** nutrients
** maximum and minimum concentrations of N, P, and K
** in storage organs in vegetative organs [kg kg-1]
NMINSO   = 0.0110 ; NMINVE = 0.0030
NMAXSO   = 0.0310 ; NMAXVE = 0.0105
PMINSO   = 0.0016 ; PMINVE = 0.0004
PMAXSO   = 0.0060 ; PMAXVE = 0.0020
KMINSO   = 0.0030 ; KMINVE = 0.0070
KMAXSO   = 0.0080 ; KMAXVE = 0.0280

```

| | | |
|-------|--------|--|
| YZERO | = 200. | ! max. amount veg. organs at zero yield [kg ha-1] |
| NFIX | = 0.00 | ! fraction of N-uptake from biol. fixation [kg kg-1] |

After collecting crop data and comparing model results with the observations, calibration may be necessary to improve model performance. This may improve the results for the specific area, but will reduce general applicability of the model (Penning de Vries and Spitters, 1991).

4.3 Soil files

A soil file contains information on physical soil characteristics. This comprises data on water retention, hydraulic conductivity and workability. These soil data are used in the calculation of the daily water balance of the soil needed to simulate water-limited growth, and to determine the optimal sowing date. Chemical soil properties are not included in this file. The default values of chemical properties are included in the site file (Section 4.5.2).

Table 12. Example of a soil file (EC1.NEW).

```

** $Id: ec1.new 1.2 1997/09/18 17:33:54 LEM release $
**
** SOIL DATA FILE for use with WOFOST, June 1990
**
** EC1-coarse

SOLNAM='EC1-coarse'

** physical soil characteristics

** soil water retention
SMTAB  = -1.000,  0.390,  ! vol. soil moisture content
          1.000,  0.380,  ! as function of pF [log (cm); cm3 cm-3]
          1.300,  0.360,
          1.491,  0.332,
          2.000,  0.185,
          2.400,  0.086,
          2.700,  0.056,
          3.400,  0.040,
          4.204,  0.040,
          6.000,  0.040
SMW    = 0.040 ! soil moisture content at wilting point [cm3/cm3]
SMFCF  = 0.110 ! soil moisture content at field capacity [cm3/cm3]
SM0    = 0.390 ! soil moisture content at saturation [cm3/cm3]
CRAIRC = 0.090 ! critical soil air content for aeration [cm3/cm3]

** hydraulic conductivity
CONTAB = 0.000,  1.999,  ! 10-log hydraulic conductivity
          1.000,  1.381,  ! as function of pF [log (cm); log (cm/day)]
          1.300,  1.004,
          1.491,  0.708,
          1.700,  0.100,
          2.000, -1.125,
          2.400, -3.060,
          2.700, -3.959,

```

```

3.000, -4.620,
3.400, -5.328,
3.700, -6.000,
4.000, -6.585,
4.204, -7.201

K0      = 99.770 ! hydraulic conductivity of saturated soil [cm day-1]
SOPE    = 12.47  ! maximum percolation rate root zone[cm day-1]
KSUB    = 24.03  ! maximum percolation rate subsoil [cm day-1]

** soil workability parameters
SPADS   = 0.800 ! 1st topsoil seepage parameter deep seedbed
SPODS   = 0.040 ! 2nd topsoil seepage parameter deep seedbed
SPASS   = 0.900 ! 1st topsoil seepage parameter shallow seedbed
SPOSS   = 0.070 ! 2nd topsoil seepage parameter shallow seedbed
DEFLIM  = 0.000 ! required moisture deficit deep seedbed

```

The soil files are stored in \Wofost Control Centre\SOILD. In the WCC, you can choose the file in the tab 'Soil' (see Section 3.4.5); when running WOFOST in the TERMINAL mode you supply the file name in the site file (see Section 4.5).

The soil types delivered with WOFOST consist of two groups: EC (European Community) / SR('Staringreeks')-group and the texture/AWC(available water capacity per meter soil depth)-group. Soil types starting with EC and SR (files with extension *.NEW) can be used in simulation of water-limited crop growth with free drainage as well as with groundwater influence. Soil types indicated by AWC values (files with the extension *.AWC) can only be used for simulation with free drainage, as information on hydraulic conductivity is not available.

The files starting with 'EC' have been developed in connection to the soil map of the EC (CEC, 1985; Reinds et al., 1992). The files starting with 'SR' are connected to the 'Staringreeks' (Wösten et al., 1994).

The collection of soil data is described in Driessen (1986c). Table 12 provides an example of a soil file. The syntax is identical to that of the crop files.

4.4 Weather files

Weather files contain the meteorological data used in the simulation model. This concerns radiation (sunshine), air temperature, rainfall (precipitation), air humidity and wind speed. As with all data, you should always check the weather data you use. Using your common sense may help you find typing errors, errors due to instrument failure, etc. Van Keulen and Van Heemst (1986) describe the meteorological data needed.

In previous version of WOFOST, two different types of weather files could be used: the WOFOST-format containing monthly weather data and the CABO-format for daily weather data (<http://edepot.wur.nl/43010>). However, the option to use monthly weather data has been removed from the WOFOST Control Centre, for two reasons:

- The use of monthly weather data is strongly discouraged and is not necessary given that daily weather data is generally available.
- The use of monthly weather data lead to strange results in WOFOST and given the point above we decide not to spend time fixing this problem.

For completeness the description of the WOFOST weather format for monthly data has been retained, but it is not supported anymore.

4.4.1 WOFOST-format

Note: Monthly weather data in WOFOST format is no longer supported!

The WOFOST-format files contain either long-term monthly averages (WOFOST-climate) or time-series of monthly averages (WOFOST-weather) of the relevant meteorological variables. Their syntax is presented in Table 13 with examples in

Table 14 and Table 15. The first three lines in the files are comments with variables that are important for the WCC to recognize the weather station and present characteristics of this station in the WCC. The files are located in the directory ../WCC/METEO/CLIMD. In the WCC, you can choose the file in the tab 'Weather' (see Section 3.4.3); when running WOFOST in the TERMINAL mode you supply the file name in the timer file (see Section 4.5). There are no special rules for the names of the WOFOST-format weather files.

Table 13. Syntax of WOFOST-format files.

| | |
|--|---|
| line 1: | the WCC-variable 'WCCDESCRIPTION' with the description of the weather station. |
| line 2: | the WCC-variable 'WCCFORMAT' with an indication for the weather format. WCCFORMAT=1 indicates long-term monthly averages (WOFOST-climate). WCCFORMAT=0 indicates time-series of monthly averages (WOFOST-weather). |
| line 3: | the WCC-variable 'WCCYEARS' that gives the years. WOFOST-climate: WCCYEARS = 1000. WOFOST-weather: WCCYEARS will be one or a row of years. Missing years are not allowed. In case there are missing years you have to split the data into different files. |
| (lines 1 to 3 are proceeded with <*> indicating these are comment lines. Note the double asterisks that are obligated). Also keep in mind that no extraneous tabs/spaces should be placed after the WCCDESCRIPTION, WCCFORMAT and WCCYEARS lines. | |
| line 4: | information of the weather station. |
| line 5: | year, latitude, altitude, the coefficients A and B for the Ångström formula (Supit et al. (1994)). |
| lines 6-17: | average monthly weather data; one line per month, from January to December: |
| | <p style="padding-left: 40px;">Column 1: minimum temperature (°C) 2: maximum temperature (°C) 3: irradiation (MJ m⁻² d⁻¹) 4: vapor pressure (hPa) 5: wind speed (m s⁻¹) 6: precipitation (mm month⁻¹) 7: number of days with rain (d)</p> |
| The values should be separated by at least one space character. In case of WOFOST climate files (with long term average weather), the year should be set at 1000. Missing values are not allowed. The last line of the file should be followed by a hard return . | |

Table 14. Excerpt from a WOFOST-weather file (S08536.WOF).

```

** WCCDESCRIPTION=Portugal, Lisboa/Portela
** WCCFORMAT=0
** WCCYEARS=1961-1981
  8536 LISBOA/PORTELA
1961 38.7 95. 0.18 0.55
  5.9 14.4 7.609 10.4 4.1 35. 15.
  8.6 17.8 10.943 12.9 4.1 22. 12.
 11.6 20.4 13.752 12.5 4.2 66. 14.
 10.4 20.0 19.201 13.8 4.3 43. 10.
 15.1 23.9 22.000 15.6 4.2 48. 10.
 16.4 25.6 24.477 17.1 4.5 17. 5.
 17.9 28.0 25.992 17.3 4.8 0. 2.
 19.4 29.8 23.678 16.4 4.4 0. 0.
 15.7 25.9 18.194 18.2 4.0 20. 6.
 12.2 22.2 12.974 15.5 3.6 39. 9.
 9.2 18.1 8.738 11.9 3.8 217. 13.
 8.6 16.9 6.969 12.9 3.9 109. 15.
(...)
8536 LISBOA/PORTELA
1981 38.7 95. 0.18 0.55
 7.6 16.1 9.108 8.9 4.1 12. 1.
 7.0 16.2 10.943 10.6 4.1 76. 12.
 9.2 18.0 13.752 10.5 4.2 109. 14.
 10.8 20.4 19.201 11.1 4.3 54. 10.
 12.8 21.6 22.000 12.5 4.2 44. 10.
 15.5 24.7 24.477 14.6 4.5 16. 5.
 18.8 28.9 25.198 13.6 4.8 4. 1.
 17.5 27.9 23.678 17.3 4.4 0. 0.
 16.2 26.3 18.194 16.4 4.0 33. 6.
 14.1 24.1 13.995 13.3 3.6 30. 4.
 9.9 18.9 8.738 11.9 3.8 93. 13.
 10.1 18.4 5.734 12.5 3.9 257. 18.

```

Table 15. Example of a WOFOST-climate file (M296.WOF).

```

** WCCDESCRIPTION=Spain, Santander
** WCCFORMAT=1
** WCCYEARS=1000
  296 SANTANDER
1000 43.5 68. 0.18 0.55
 6.7 11.9 4.496 8.8 4.5 119. 16.
 6.5 11.9 6.785 8.8 2.5 89. 14.
 8.4 14.7 10.136 10.0 4.2 74. 13.
 9.4 15.2 13.670 11.0 3.6 82. 14.
 11.4 17.0 15.925 13.0 3.4 88. 15.
 14.1 19.7 17.381 15.6 3.4 66. 13.
 16.1 21.5 17.365 17.4 3.1 59. 12.
 16.4 22.2 15.421 18.1 2.8 84. 14.
 14.9 21.6 11.822 16.7 2.8 114. 14.
 12.4 18.3 8.390 13.6 3.4 134. 14.
 9.6 14.9 5.346 10.8 4.2 134. 16.
 7.4 12.3 3.840 9.3 4.5 155. 18.

```

4.4.2 CABO-format

Files with CABO-format contain daily weather data. Each file contains the weather data for one station and one year. Their syntax is presented in Table 16 with an excerpt of a CABO-format file presented in

Table 17. The CABO file naming convention defines the filename as:

<location name><station number>.<last 3 numbers of the year>

Where the <location name> is a string, the <station number> is a number between 1 and 999 (at least 1 character) and the extension consists of the last three numbers of the year. For example, NL3.987 stands for the Netherlands, station 3 (De Kooy), year 1987. The entire length of the CABO name plus the full path cannot be longer than 250 characters.

WOFOST comes with data from three stations in the Netherlands: Wageningen, Swifterbant and De Kooy. CABO-format weather files have been developed at CABO (Van Kraalingen et al., 1991). The files are stored in the directory \METEO\CABOWE. In the WCC, you can choose the file in the tab 'Weather' (see Section 3.4.3); when running WOFOST in the TERMINAL mode you supply the file name in the timer file (see Section 4.5).

Table 16. Syntax of CABO-weather files (Van Kraalingen et al., 1991).

| | | | | | | | | | | | | | | | | | | |
|---|---|-------------------|--|---------|--|---------------|--|--|--|---|--|---|--|---------------------------------------|--|---|--|--|
| <p>File header: a continuous block of lines that start with a <*> in the first column. The file header contains general information about the data and their origin.</p> <p>The file header ends with three WCC-variables preceded with <*> as comment leader (note that double asterisks are obligated):</p> <ul style="list-style-type: none">- the WCC-variable 'WCCDESCRIPTION' with the description of the weather station (this description must be exactly the same (including spaces) for different files of the same weather station, otherwise WCC will not recognize these files as belonging to the same station).- the WCC-variable 'WCCFORMAT' with an indication for the weather format. WCCFORMAT=2 indicates daily weather data (CABO-format).- the WCC-variable 'WCCYEARNR' that gives the year. <p>Keep in mind that no extraneous tabs/spaces should be placed after the WCCDESCRIPTION, WCCFORMAT and WCCYEARS lines.</p> <p>Lines that follow the header:</p> <p>line 1: the longitude, latitude, altitude and coefficients A and B for the Ångström formula (Supit et al. (1994). The last two parameters serve also as indicator if global radiation is derived from sunshine hours or has been measured. If global radiation has been measured, the Ångström coefficients are preceded with a minus sign. The values do not have to be written in a strict format but should be separated by at least one space character.</p> <p>line 2 - 368: daily weather data. One line relates to one day.</p> <table><tr><td>Column</td><td>1: station number</td></tr><tr><td></td><td>2: year</td></tr><tr><td></td><td>3: day number</td></tr><tr><td></td><td>4: irradiation ($\text{kJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$)</td></tr><tr><td></td><td>5: minimum temperature ($^{\circ}\text{C}$)</td></tr><tr><td></td><td>6: maximum temperature ($^{\circ}\text{C}$)</td></tr><tr><td></td><td>7: early morning vapor pressure (kPa)</td></tr><tr><td></td><td>8: mean wind speed at 2 m above ground ($\text{m}\cdot\text{s}^{-1}$)</td></tr><tr><td></td><td>9: precipitation ($\text{mm}\cdot\text{d}^{-1}$)</td></tr></table> <p>Day numbers range from 1 to 365 (366 in leap years). The values should be separated by at least one space character. For missing values see Figs. 36 and 37. The last line of the file should be followed by a hard return. It is not allowed to add comments after the last line.</p> | Column | 1: station number | | 2: year | | 3: day number | | 4: irradiation ($\text{kJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) | | 5: minimum temperature ($^{\circ}\text{C}$) | | 6: maximum temperature ($^{\circ}\text{C}$) | | 7: early morning vapor pressure (kPa) | | 8: mean wind speed at 2 m above ground ($\text{m}\cdot\text{s}^{-1}$) | | 9: precipitation ($\text{mm}\cdot\text{d}^{-1}$) |
| Column | 1: station number | | | | | | | | | | | | | | | | | |
| | 2: year | | | | | | | | | | | | | | | | | |
| | 3: day number | | | | | | | | | | | | | | | | | |
| | 4: irradiation ($\text{kJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) | | | | | | | | | | | | | | | | | |
| | 5: minimum temperature ($^{\circ}\text{C}$) | | | | | | | | | | | | | | | | | |
| | 6: maximum temperature ($^{\circ}\text{C}$) | | | | | | | | | | | | | | | | | |
| | 7: early morning vapor pressure (kPa) | | | | | | | | | | | | | | | | | |
| | 8: mean wind speed at 2 m above ground ($\text{m}\cdot\text{s}^{-1}$) | | | | | | | | | | | | | | | | | |
| | 9: precipitation ($\text{mm}\cdot\text{d}^{-1}$) | | | | | | | | | | | | | | | | | |

Table 17. Excerpt of a CABO-weather file (NL1.987).

```

-----*
* Station name: Wageningen (Haarweg), Netherlands
* Year: 1987
* Author: Willem Stol en Vitale Nuzzo
* Source: Natuur- en Weerkunde - data invoer: Hennie de Ruiter
(...)
*
** WCCDESCRIPTION=Netherlands, Wageningen
** WCCFORMAT=2
** WCCYEARNR=1987
-----*
  5.67  51.97    7.  -0.18 -0.55
1 1987  1   470.   3.0  7.9  0.770  2.8  13.0
1 1987  2   620.  -3.9  7.3  0.660  5.4  2.7
1 1987  3  2420.  -6.4  4.0  0.500  1.9  0.1
(...)
1 1987 168 12750.  5.3 13.6  1.060  3.0  3.5
1 1987 169 18130.  6.9 15.9  1.020  3.2  0.0
1 1987 170  7950.  6.9 14.4  1.260  2.1  7.0
(...)
1 1987 363   710.  8.3 11.9  1.010  5.2  2.9
1 1987 364  1400.  7.8 11.3  1.100  3.5  5.0
1 1987 365  2000.  7.4 10.0  0.980  3.8  0.0

```

Daily weather data are often incomplete. There are several ways to handle this problem when using the CABO-format (Table 18). Missing data can be estimated automatically, by linear interpolation between the available data. There are, however, some exceptions. Because precipitation is too erratic, it is not interpolated but set at zero when missing. Automatic interpolation is impossible when there are no data on either side e.g. at the beginning and the end of the year. It is sometimes possible to derive the missing values in a different way. For instance, data from a weather station in the vicinity or the long term daily averages from the same station can be used. An example of a part of a CABO-format file with missing data is presented in Table 19.

Table 18. The treatment of missing values in CABO-format weather files (Van Kraalingen et al., 1991).

Missing data in a CABO weather file can be treated in three different ways:

1. Put -99 in place of the missing value; the value will then be calculated by linear interpolation between the available data (except for precipitation).
2. If all data are missing for a particular day, you can leave the complete day (line) out. All data will then be calculated by linear interpolation between the available data (except for precipitation).
3. The missing data can be estimated with data from e.g. other weather stations or with long-term averages from the same station.

If you replace missing values yourself, this should be marked in the data file by inserting a status line beginning with -999 and followed by eight values (see Fig. 37). The first two are dummy values for year and station; the remaining six are attributes for the weather variables. These attributes can have values between one and four:

- 1 - measured (i.e. not missing)
- 2 - interpolated
- 3 - estimated from e.g. another meteorological station
- 4 - not available (no interpolation or estimation possible)

The status line refers to all the following lines, until a new status line replaces it.

Table 19. Excerpt from a CABO-format weather file (NL2.989) with missing values.

| | | | | | | | | |
|-------|------|----|--------|------|------|-------|-----|------|
| (...) | | | | | | | | |
| 2 | 1989 | 63 | 6540. | 5.1 | 10.8 | 0.940 | 4.2 | 0.6 |
| 2 | 1989 | 64 | 4860. | 7.5 | 13.9 | 1.130 | 3.1 | 0.0 |
| -999 | 1989 | 65 | 1 | 1 | 1 | 1 | 3 | 1 |
| 2 | 1989 | 65 | 7440. | 6.5 | 17.6 | 0.510 | 3.5 | 0.0 |
| 2 | 1989 | 66 | 2360. | 6.0 | 11.0 | 0.810 | 3.5 | 19.3 |
| -999 | 1989 | 67 | 1 | 1 | 1 | 3 | 3 | 1 |
| 2 | 1989 | 67 | 4340. | 0.0 | 7.4 | 0.730 | 4.5 | 5.9 |
| -999 | 1989 | 68 | 1 | 1 | 1 | 1 | 3 | 1 |
| 2 | 1989 | 68 | 13000. | -0.3 | 10.3 | 0.360 | 4.0 | 6.0 |
| -999 | 1989 | 69 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1989 | 69 | 10030. | 5.0 | 13.8 | 0.940 | 4.5 | 0.0 |
| 2 | 1989 | 70 | 7110. | 3.7 | 10.9 | 0.970 | 2.7 | 0.6 |
| (...) | | | | | | | | |

4.4.3 Rainfall files

Note: The use of rainfall files is no longer supported!

Rainfall files contain daily rainfall data only. Rainfall data must be used in combination with a complete data set (either daily or monthly) of any available weather station.

The option to use separate rainfall files is of much practical value. Rainfall generally has more spatial variation than the other weather variables. Rainfall data are also usually available at much higher density than any of the other weather variables (Van Keulen and van Heemst, 1986). Rainfall can also be used to simulate the effect of irrigation.

The rainfall files are stored in subdirectory \Wofost Control Centre\METEO\CLIMD. In the WCC you can choose the file by activating the button 'Rainfall data options' on the 'Weather' tab (see Section 3.4.3). When running WOFOST in the TERMINAL mode, supply the file name in the timer file (see Section 4.5). Syntax rules are given in Table 20. The filename is free; files that come with WOFOST have the name *.RRD. An example is provided in Table 21.

Table 20. Syntax of a rainfall file.

line 1: the WCC-variable 'WCCDESCRIPTION' with the description of the rainfall station.
line 2: the WCC-variable 'WCCFORMAT' with an indication for the weather format.
WCCFORMAT=99 indicates rainfall station.
line 3: the WCC-variable 'WCCYEARS' that gives the years.
WCCYEARS will be one or series of years.
(lines 1 to 3 are preceded with <**> indicating these are comment lines. Note the double asterisks that are obligated).
The header ends with lines that start with a <*>; these lines may contain any information.
First line after the header:
line 1: number of years, available years.
line 2-367: day of the year, daily precipitation (mm) for each year. When the year is not a leap year, the precipitation on day 366 is zero.
The values should be separated by at least one space character. Missing values are not allowed.

Table 21. Excerpt from a rainfall file (NIAMEY.RRD).

```
** WCCDESCRIPTION=Niamey
** WCCFORMAT=99
** WCCYEARS=1950-1952
*
* Weather station: Niamey.
*
3 1950 1951 1952
1 0.0 0.0 0.0
2 0.0 0.0 0.0
3 0.0 0.0 0.0
(...)
238 1.8 0.0 0.0
239 2.3 33.4 0.0
240 21.0 0.0 36.2
(...)
364 0.0 0.0 0.0
365 0.0 0.0 0.0
366 0.0 0.0 0.0
```

4.5 Run files

For running WOFOST, so-called run files are used. There are four types of run files:

- the timer file (WCCTI.TIM) on weather and crop calendar related data (Section 4.5.1);
- the site file (WCCSI.SIT) on default values for soil (Section 4.5.2);
- the rerun file (WCCR.RER) on defining series of consecutive WOFOST-runs (Section 4.5.3)
- the run option file (WCC.WCC) on general information like file names etc. (Section 4.5.4).

These files are stored in subdirectory \Wofost Control Centre\RUNIO. Syntax rules for the run files are similar to those of the crop and soil files (Table 11). When running WCC, the variables in these run files are changed through the

interface on the different tab pages. When running WOFOST in TERMINAL mode, all the variables can be changed in the specific run files.

4.5.1 Timer file

The timer file especially concerns those variables with a time-related unit (weather, crop calendar). The file WCCTI.TIM is presented (Table 22). A figure with some explanation on the variables is shown in

Table 23. Variables that occur in the timer file are discussed in more detail in the description of the WCC (Chapter 3).

Table 22. An example of the timer file (WCCTI.TIM).

```

** File      : ..\RUNIO\WCCTI.TIM
** Generated by: C:\Program files\Wofost Control Centre\EXEC\WCC.EXE
** Date     : 3/22/98 4:41:10 PM
RUNNAM  = 'WCC'
IWEATH  = 2
CLFILE  = 'NL1.'
ISYR    = 1987
INYEAR  = 3
IRNDAT  = 3
RAFILE  = '<none>'
ISYRR   = -999
INYRG   = 1
CRFILE  = 'WWH101.CAB'
ISTCHO  = 0
IDEM    = 1
IDSOW   = 1
IDESOW  = 100
IDLSOW  = 140
IENCHO  = 2
IDAYEN  = 270
IDURMX  = 260
IBAL    = 1
PRDEL   = 50.000000
CRPNAM  = 'Winter wheat 101, N-U.K., Denmark'
SOLNAM  = 'EC1-coarse'
CLMNAM  = 'Netherlands, Wageningen'
RAINAM  = '<none>'
ISDAY   = 1

```

Table 23. Variables in the timer file: type (C = character string enclosed with '<'>; I = integer; R = real), their meaning and some additional information (see Fig. 40 and Annex B).

| parameter | type | meaning and possible values |
|------------------|-------------|--|
| RUNNAM | C | Run name (max. 6 characters, between quotes). |
| IWEATH | I | Format of weather: 0 (WOFOST-monthly), 1 (WOFOST-climate), or 2 (CABO). |
| CLFILE | C | File name of weather station. |
| ISYR | I | First year for which crop growth is simulated. |
| INYEAR | I | Number of years to simulate crop growth. |
| IRNDAT | I | Option for the use/selection of rainfall data: 0 (generates statistics with varying total monthly rainfall and number of rainy days), 1 (distributes monthly rainfall over given number of days), 2 (reads rainfall data out of separate file) or 3 (rainfall as it occurs in weather file). See Chapter 4 about the input of rainfall to learn more about this option). |
| RAFILE | C | Name of rainfall station. |
| ISYRR | I | (First) Year of rainfall data to be used (if IRNDAT = 2). If IRNDAT ≠ 2, then ISYRR = - |

| | | |
|--------|---|---|
| | | 999. |
| INYRG | I | Number of runs for which rainfall has to be generated (IRNDAT = 0), or distributed (IRNDAT = 1). If IRNDAT ≠ 0 or 1, then INYRG = 1 (WOFOST does not accept 0!). This variable is also used for the number of rainfall years (IRNDAT = 2). |
| CRFILE | C | Name of crop file. |
| ISTCHO | I | Options for start simulation: 0 (fixed emergence day), 1 (fixed sowing day) and 2 (variable sowing day). |
| IDEM | I | Day of emergence (day of year). Used if ISTCHO = 0. |
| IDSOW | I | Day of sowing (day of year). Used if ISTCHO = 1. |
| IDESOW | I | Earliest possible day of sowing (day of year). Used if ISTCHO = 2. |
| IDLSOW | I | Ultimate sowing day (day of year). Used if ISTCHO = 2. |
| IENCHO | I | Option to determine end of simulation: 1 (fixed end day), 2 (maturity, but not to exceed maximum duration), or 3 (earliest of both days). |
| IDAYEN | I | Ultimate day of harvest (day of year). Used if IENCHO = 1 or 3. |
| IDURMX | I | Maximum number of days from emergence to end of simulation used if IENCHO = 2 or 3. |
| IBAL | I | Option for output summary water balance: 0 (no summary), 1 (for whole system), 2 (for root zone), or 3 (for whole system and root zone). |
| PRDEL | R | Output interval: one output line per time interval. Output lines for day of emergence, anthesis and the last day are always provided. If the output interval is longer than the growing period, the detailed output will be reduced to these three lines. No detailed output will be produced, if the interval is set at zero days. |
| CRPNAM | C | Description of crop. |
| SOLNAM | C | Description of soil. |
| CLMNAM | C | Description of weather station. |
| RAINAM | C | Description of rainfall station. |
| ISAY | I | Start date of the water balance (day of year). |

4.5.2 Site file

Site file concerns the default values for soil characteristics that are not given in the soil file. The file WCCSI.SIT is presented in Table 24. In

Table 25 some explanation is provided. Variables that occur in the site file are discussed in more detail in the description of the WCC (Chapter 3).

Table 24. An example of the site file (WCCSI.SIT).

```

** File      : ..\RUNIO\WCCSI.SIT
** Generated by: C:\Program files\Wofost Control Centre\EXEC\WCC.EXE
** Date     : 3/22/98 4:41:10 PM
SOFIL = 'EC1.NEW'
IZT    = 0
IFUNRN = 0
IDRAIN = 0
SSMAX  = 0.000000
WAV    = 20.000000
ZTI    = 999.000000
DD     = 20.000000
RDMSOL = 120.000000
NOTINF = 0.000000
NBASE  = 60.000000
NREC   = 0.500000
PBASE  = 10.000000
PREC   = 0.100000
KBASE  = 60.000000
KREC   = 0.500000
SSI    = 0.000000
SMLIM  = 0.040000

```

Table 25. The variables in the site file: type (C = character string enclosed with <'>; I = integer; R = real), their meaning and some additional information (Annex B).

| variable | type | meaning and possible values |
|----------|------|--|
| SOFILE | C | Name of soil file. |
| IZT | I | Ground water influence: 0 (no) or 1 (yes). |
| IFUNRN | I | Non-infiltrating fraction of rain is function of storm size (1) or not (0). |
| IDRAIN | I | Presence (1) or absence (0) of drains. |
| SSMAX | R | Maximum surface storage capacity (cm water). |
| WAV | R | Initial amount of available soil water in the rootable soil (moisture content above permanent wilting point) (cm water). |
| ZTI | R | Initial depth of the ground water table (cm). The value 999 is maximum initial depth of the ground water table. |
| DD | R | Drainage depth (cm). |
| RDMSOL | R | Maximum rooting depth allowed by soil (cm). This is dictated by soil characteristics like profile depth and presence of ground water. |
| NOTINF | R | (Maximum) non-infiltrating fraction of rainfall. Range: 0 - 1. |
| NBASE | R | Basic supply of nitrogen by the unfertilized soil (N, kg•ha ⁻¹). Range: 0 - 100. |
| NREC | R | Apparent nitrogen recovery. Increase in uptake of N as fraction of applied N. Range: 0 - 1. |
| PBASE | R | Basic supply of phosphorus by the unfertilized soil (P, kg•ha ⁻¹). Range: 0 - 10. |
| PREC | R | Apparent phosphorus recovery. Increase in uptake of P as fraction of applied P. Range: 0 - 1. |
| KBASE | R | Basic supply of potassium by the unfertilized soil (K, kg•ha ⁻¹). Range: 0 - 100. |
| KREC | R | Apparent potassium recovery. Increase in uptake of K as fraction of applied K. Range: 0 - 1. |
| SSI | R | Initial surface storage (cm water). |
| SMLIM | R | Maximum moisture content in topsoil (cm water). This value should be between moisture content at wilting point and moisture content at saturation. |

4.5.3 Rerun file

With the rerun file, a series of consecutive WOFOST-runs can be defined by providing a set of new values for one or more variables for each consecutive run. The variables that are not included in such a set keep their values as defined in the different input files.

In each set (run) within one rerun file, the same variables must appear, even if their values are identical to those in the previous set (run). The order of the variables should be the same in each set (run). A new set (run) starts when the first variable is repeated. Further the syntax rules for the timer, site, crop and soil file apply. An example of a rerun file is given in Table 26.

Table 26. An example of the rerun file (WCCR.RER).

```

** File      : ..\RUNIO\WCCR.RER
** Generated by: C:\Program files\Wofost Control Centre\EXEC\WCC.EXE
** Date     : 3/22/98 4:41:10 PM
RUNNAM='WCC1';
TSUM1=1000.
RUNNAM='WCC2';
TSUM1=1050.

```

4.5.4 Run option file

The run option file stores all required run options. The file is stored in the directory "RUNIO". The file WCC.WCC is presented in Table 27 ; Table 28 shows some explanation on the variables. Before running WOFOST, the program WCC automatically copies WCC.WCC to the file RUNOPT.DAT. This is because WOFOST

expects the filename RUNOPT.DAT. If WOFOST is to be run in TERMINAL mode, be sure to copy the file WCC.WCC to RUNOPT.DAT before executing WOFOST.

Table 27. An example of the run option file (WCC.WCC).

```

** File      : ..\RUNIO\RUNOPT.DAT
** Generated by: C:\Program files\Wofost Control Centre\EXEC\WCC.EXE
** Date      : 3/22/98 4:41:10 PM
IOPT2 = 4      ! Start/Stop options
IPRODL = 3     ! Production levels
IOXWL = 0     ! Type of water-limited crop growth
TIMFIL = 'WCCTI.TIM' ! Timer filename
SITFIL = 'WCCSI.SIT' ! Site filename
WOFRER = 'WCCRR.RER' ! Rerun filename
WOFOUT = 'WCC.OUT' ! Filename detailed output
SERIES = 1    ! Final results for series of years
REPORT = 1    ! Report: one line per year and statist
FIXNAM = 'WCC' ! Output filename (max 8, no ext.)
RQUIRD = 1    ! Long term means results

```

Table 28. The variables in the run option file: type (C = character string enclosed with <'>; I = integer; R = real), their meaning and some additional information (see Table 27 and Annex B).

| variable | type | meaning and possible values |
|----------|------|---|
| IOPT2 | I | Start/Stop option: 2 (run WOFOST with default input from data files), 4 (run WOFOST from reruns file without default run) and 5 (run FSEOPT for calibration of WOFOST; only possible in TERMINAL mode and not available in WCC). |
| IPRODL | I | Production levels: 1 (simulation of potential crop growth), 2 (simulation of water limited crop growth), 3 (calculation of nutrient limited crop growth). |
| IOXWL | I | Type of water-limited crop growth: 0 (effects of drought only), 1 (effects of both drought and oxygen shortage). |
| TIMFIL | C | Timer filename. |
| SITFIL | C | Site filename. |
| WOFRER | C | Rerun filename. |
| WOFOUT | C | Filename detailed output. |
| SERIES | I | Final results for series of years: 0 (no), 1 (yes). This option has meaning only when running WOFOST in TERMINAL mode. The WCC gives always output when the run covers more than 1 year. |
| REPORT | I | Report: 1 (one line per year and statistics). This is the only valid option also for running WOFOST in TERMINAL mode. |
| FIXNAM | C | Output filename for summary output of potential and water limited production (max 8 characters; no extension because WOFOST uses *.WPS and *.PPS as extension). This is only used when running WOFOST in TERMINAL mode; WCC uses its own filename. |
| RQUIRD | I | Long term means results. This is a summary file of the summary files of potential and water limited production: 0 (no), 1 (yes). In WCC, the summary is only shown when there are more than two years (because of calculating statistics) and the rerun option is used. File name of this summary file is FIXNAM and the extension *.SUM. |

4.6 Output files

This section discusses the way WOFOST presents the simulation results. Simulation results are stored in output files. There are four different output file types (Table 29).

Table 29. The output files.

| <u>File name</u> | <u>Contents</u> | <u>Section</u> |
|------------------|---|----------------|
| *.OUT | detailed output of simulation | 5.6.1 |
| *.PPS | summary output for potential growth | 5.6.2 |
| *.WPS | summary output for water limited growth | 5.6.3 |
| *.SUM | summary output | 5.6.4 |

The detailed output of each simulation is always created (each run in WCC and TERMINAL mode).

The summary output for potential (*.PPS) and water limited growth (*.WPS) is only shown when WCC has been run for more than one year. Statistics are given for runs of three or more weather years (in case of water-limited also for more than two rainfall years). When running WOFOST in TERMINAL mode, you can choose, by editing the WCC.WCC file, for a summary output of potential and water limited growth even if it is only for one year. Statistics will only be given for runs of more than two years.

The summary output (one line per type of growth) is created in the WCC only when simulation is made for more than two weather years (in case of water-limited also for more than two rainfall years) and more than one run is used in the reruns. A summary output can always be chosen in the TERMINAL mode by editing the WCC.WCC file. However, no output will be shown (only a header) for runs with less than three years.

The simulation results are discussed briefly. See Annex B for explanation of the variable names. Van Keulen and Wolf (1986) provide an extensive discussion of most output variables. See Janssen et al. (1990) and Section 3.5.4 for the output on nutrient-limited production.

4.6.1 Detailed output

An example of a detailed output file for each production level is provided. Potential growth is presented in Table 30, water-limited growth in Table 31, the water balance in Table 32, and the nutrient requirements in Table 33. The default name of a detailed output file is WCC.OUT. In the WCC, you can change the name by using the session options (see Section 3.3.1). When running WOFOST in the TERMINAL mode, supply the filename in the run option file (see Section 4.5).

The first lines in a detailed output file provide general information on the simulation (Table 30). The run name (RUNNAM), the name of the output file (OUTPUT), and the name of the rerun file used, if any (RERUN) are given. WEATHER provides information on the weather format and the start year of the simulation. If CABO format (one file per year) is used, the name of the weather file does not change when simulation is done for a series of years. The indicated start year, however, changes and provides the correct information. The rain option (RAIN), crop (file) (CROP), and soil type (SOIL) used for simulation are specified. START provides information on the start date of the water balance, the day of sowing, and emergence.

Table 30. Detailed output, potential growth

```

**WOFOST version 7.1.7, release February 2011
RUNNAM -> WCC
OUTPUT -> file: ..\output\wcc.out
RERUNS -> no reruns
WEATHER-> name: Netherlands, Wageningen
           file: ..\meteo\cabowe\nl1.   start year: 1987
RAIN    -> belonging to weather station
CROP    -> name: Winter wheat 101, N-U.K., Denmark
           file: ..\cropd\wwh101.cab
SOIL    -> name: EC1-coarse
           file: ..\soild\ec1.new
START   -> fixed emergence date IDEM = 1
           start waterbalance = -99      sowing date = -99      emergence date = 1
POTENTIAL CROP PRODUCTION
=====
DAY IDSEM DVS  TSUM   WLW   WST   WSO   TAGP  LAI  TRA  GASS  MRES  DMI
           degrd kg/ha  kg/ha  kg/ha  kg/ha m2/m2  mm/d CH2O CH2O  kg/ha/d
  1  0  0.00   0.   68.   37.   0.   105.  0.14 0.02   1.4   1.1   0.2
 51 50  0.07   67.   70.   38.   0.   108.  0.15 0.04   0.0   0.0   0.0
101 100 0.27  268.  173.   85.   0.   258.  0.37 0.32  39.4   2.7  25.1
151 150 0.78  781. 2755. 4391.   0.  7170.  5.84 1.08 220.1  63.7 104.3
169 168 1.00 1004. 2774. 7274.  532. 10780.  5.88 2.77 495.6  84.0 291.7
201 200 1.56 1538. 2316. 6846. 7446. 17695.  4.91 2.23 357.0 147.5 148.6
229 228 2.00 1957.  112. 3889. 8894. 19143.  0.24 0.27  10.1  10.1   0.0
SUMMARY:
HALT  ANTH  TWRT   TWLV   TWST   TWSO   TAGP  HINDEX  TRANSP  TRC  GASST  MREST
229 168  1231.  2974.  7274.  8894.  19143.  0.46  25.0 131. 39129.  9786.

```

The results of the simulation are provided under POTENTIAL CROP PRODUCTION. A line with variable names is given (DAY, IDSEM, DVS, etc. See Annex B and Section 3.5.1 for explanation). After a blank line follows a line with the units of the variables. The model output is provided with each line representing a specific day. The number of lines depends on the length of the simulation and on the requested output interval. In this example, the interval was 50 days. The day of anthesis (development stage, DVS = 1) and the last day of simulation are always included. The last three lines provide a summary of the simulation results.

If water-limited growth is simulated as well, the next part of the file provides the relevant output, as shown in the example in Table 31. The structure of this output is similar to the output for potential production. Additional variables (RESERV, AVAIL, RAIN etc.), describing hydrological and other field conditions are provided; other variables are left out like GASS, MRES (see Annex B and Section 3.5.2 for explanation).

The general information on the run name etc. is followed by a line with WATER (AND O2) LIMITED CROP PRODUCTION WITH/WITHOUT GROUNDWATER. Oxygen limitation refers to excessive supply of water in the rooting zone. With or without groundwater refers to the selected soil conditions. This line is followed by the variables defining field conditions. Finally, the daily model output and the summary are provided.

Table 31. Detailed output, water-limited growth.

```

**WOFOST version 7.1.7, release February 2011
RUNNAM -> WCC
OUTPUT -> file: ..\output\wcc.out
RERUNS -> no reruns
WEATHER-> name: Netherlands, Wageningen
           file: ..\meteo\cabowe\nl1.   start year: 1987
RAIN    -> belonging to weather station
CROP    -> name: Winter wheat 101, N-U.K., Denmark
           file: ..\cropd\whl101.cab
SOIL    -> name: EC1-coarse
           file: ..\soild\ec1.new
START   -> fixed emergence date IDEM = 1
           start waterbalance = 1 (1987)  sowing date = -99  emergence date = 1
WATER LIMITED CROP PRODUCTION WITHOUT GROUNDWATER
=====
fixed fraction      RDMso= 60.   NOTinf=0.00
SM0=0.390 SMFC=0.110 SMW=0.040 SMLIM=0.104   RDM= 60. WAV= 20.0 SSmax= 0.0
DAY  WLW  WST  WSO  TAGP  LAI  RD   SM  RESRV  AVAIL  RAIN  TRA  EVA  wet  dry
      kg/ha kg/ha kg/ha kg/ha m2/m2 cm vol.fr cm   cm   mm mm/d mm/d days
  1   68.  37.   0.  105.  0.14 10. 0.104 18.1  0.6   0.  0.02 0.09  0  0
 51   70.  38.   0.  108.  0.15 60. 0.110  4.2  4.2  51.  0.04 0.14  0  0
101  173.  85.   0.  258.  0.37 60. 0.112  4.3  4.3 174.  0.32 1.81  0  0
151 2755. 4391.   0. 7170.  5.84 60. 0.105  3.9  3.9 279.  1.08 0.09  0  0
169 2774. 7274.  532. 10780.  5.88 60. 0.096  3.3  3.3 346.  2.77 0.23  0  0
201 2069. 6846. 5112. 15360.  4.39 60. 0.123  5.0  5.0 433.  2.16 0.37  0 12
229  112. 3889. 6695. 16944.  0.24 60. 0.106  3.9  3.9 541.  0.27 0.69  0  0
SUMMARY :
                                stress days
HALT ANTH TWRT  TWLV  TWST  TWSO  TAGP HINDEX TRC  GASST  MREST wet dry
229 168 1231.  2974.  7274.  6695. 16944.  0.40 129.5 34966.  8725.  0 12

```

The lines on water-limited crop growth are followed by the water balance(s) (Table 32). The water balance can be for the whole soil system and/or for the root zone only (this zone extends as roots grow). The water balance covers the period between emergence and the last day of simulation. The different components of the water balance are explained in Section 3.5.3.

Table 32. Detailed output, water balance

| WATER BALANCE WHOLE SYSTEM (1 DIMENS. COLUMN ; cm) | | | | |
|--|------|---------------------|------|---------------------|
| init max root zone | 20.5 | final max root zone | 6.3 | change: -14.2 |
| init surf storage | 0.0 | final surf storage | 0.0 | change: 0.0 |
| irrigation | 0.0 | evap water surface | 0.0 | |
| rainfall | 54.1 | evap soil surface | 7.6 | |
| | | transpiration | 21.9 | to atmos: 29.5 |
| | | surface runoff | 0.0 | |
| | | lost to deep soil | 38.7 | |
| TOTAL INIT + IN | 74.6 | TOTAL FINAL + OUT | 74.6 | checksum: -0.0 init |

Following the water balance or the output on potential crop growth if water-limited crop growth is not simulated, the results of the subsequent years are provided and so on. If nutrient-limited production is simulated, the output on plant nutrients is given following the output for all years (Table 33). It first provides the calculated values for the basic supply of nutrients and their recoveries, followed by the results for potential, nutrient-limited, and water-limited production. The simulated yield of leaves, stems and storage organs (dry weight, $\text{kg}\cdot\text{ha}^{-1}$), the ratio (storage organ / (leaves + stems)) and the harvest index (storage organ / total above ground biomass) is provided. Subsequently, the amount of fertilizer that would be needed to obtain potential and water-limited production is given in element form ($\text{kg}\cdot\text{ha}^{-1}$).

Table 33. Detailed output, nutrient requirements.

| SUMMARY CROP PRODUCTION AND NUTRIENT REQUIREMENTS | | | | |
|---|-----------------|------------------|-----------------|--|
| Nbas = 85., Pbas = 14., Kbas = 85. | | | | |
| Nrec = 0.50, Prec = 0.10, Krec = 0.50 | | | | |
| ===== | | | | |
| | Potential | Nutrient limited | Water limited | |
| | Crop production | Crop production | Crop production | |
| ----- | | | | |
| Leaves | 1889. | 795. | 2035. | |
| Stems | 5984. | 2518. | 5841. | |
| Storage organ | 9948. | 4035. | 6462. | |
| Ratio SO/straw | 1.26 | 1.22 | 0.84 | |
| Harvest index | 0.56 | 0.55 | 0.45 | |
| Fertilizer N | 354.9 | - | 208.5 | |
| Fertilizer P | 331.5 | - | 199.1 | |
| Fertilizer K | 215.8 | - | 177.5 | |

When reruns are defined (Section 4.5.3) the detailed output for potential, water-limited including water balances and nutrient requirements are repeated for each rerun.

4.6.2 Summary output

In the output files *.PPS (potential growth, Table 34) and *.WPS (water-limited growth, Table 35), the detailed output (Section 4.6.1) is summarized. One line is given for each growing season, similar to the summary lines in the file with detailed output.

Additional variables provided in *.PPS are FLWR (flowering date), LAIM (maximum leaf area index) and EVSOL (total evaporation soil surface) (see Annex B and Section 3.6.1 for explanation).

In the *.WPS file, some additional variables pertaining to the water balance are provided (LAIM, DELWAT, TRAT, EVSOL, LOSST, TSR, RYLD, RAGP) (see Annex B and Section 3.6.2 for explanation).

When the simulations cover three weather years or more (in case of water-limited production also three rainfall years or more), the mean, standard deviation and the coefficient of variation of some output variables over these years are given.

The default name of a *.PPS, a *.WPS file is WCC.* (WCC.PPS, etc.). This can be changed in the session functionality of the WCC (see Section 3.3.1). When running WOFOST in TERMINAL mode, the name can be changed in the run option file (see Section 4.5).

The output file *.SUM (Table 36), provides a summary of the *.PPS and *.WPS files. It gives the long-term average of some variables at one location. There is one line for potential production (PS=PP) and one line for water-limited production (PS=WP). *.SUM is only filled when WOFOST is run for more than two weather years (in case of water-limited crop growth also more than two rainfall years) and reruns is used. When running WOFOST in TERMINAL mode, the run option file can be edited to create this file (see Section 4.5).

Table 34. An example of a *.PPS file.

```

**WOFOST version 7.1.7, release February 2011
OUTPUT -> file: ..\output\wcc.pps
**
**
** RESULTS OF CROP GROWTH SIMULATION MODEL WOFOST: SUMMARY POTENTIAL PRODUCTION
WEATHER-> name: Netherlands, Wageningen
           file: ..\meteo\cabowe\n11.   start year: 1987
RAIN  -> belonging to weather station
CROP  -> name: Winter wheat 101, N-U.K., Denmark
           file: ..\cropld\wwh101.cab
SOIL  -> name: EC1-coarse
           file: ..\soild\ec1.new
**
**
** SUMMARY POTENTIAL PRODUCTION
** YR RUNNAM SET SOW --> EM ANT FLWR DUR HALT  TWRT  TWLV  TWST  TWSO  TAGP  LAIM HINDEX TRC    GASST  MREST TRANSP EVSOL
1987 WCC      0 -99 0   1 168 169 228. 229.  1231.  2974.  7274.  8894. 19143.  6.01  0.46 131.  39129.  9786.  25.0  3.6
1988 WCC      0 -99 0   1 142 143 205. 206.   618.  1326.  4401.  8183. 13911.  2.81  0.59 126.  26543.  5832.  17.6  4.7
1989 WCC      0 -99 0   1 141 142 202. 203.   845.  1889.  5984.  9948. 17820.  4.00  0.56 144.  34944.  8207.  25.6  3.9
**
**
** MEANS over 3 years :                212.                2063.  5886.  9008. 16958.  4.27  0.54 134.                22.74  4.1
** STANDARD DEVIATIONS :                14.                838.  1439.  888.  2720.  1.61  0.06  9.1                4.49  0.6
** VARIATION COEFFICIENTS :                6.7                40.60  24.44  9.86  16.04 37.77 12.01  6.78                19.73 14.11
** VARIATION COEFFICIENTS :                6.5                37.39  18.36  13.26  13.43 32.22 12.69  6.87                18.07 13.46

```

Table 35. An example of a *.WPS file.

```

**WOFOST version 7.1.7, release February 2011
OUTPUT -> file: ..\output\wcc.wps
**
**
** RESULTS OF CROP GROWTH SIMULATION MODEL WOFOST: SUMMARY WATER-LIMITED PRODUCTION
WEATHER-> name: Netherlands, Wageningen
           file: ..\meteo\cabowe\n11.   start year: 1987
RAIN  -> belonging to weather station
CROP  -> name: Winter wheat 101, N-U.K., Denmark
           file: ..\cropld\wwh101.cab
SOIL  -> name: EC1-coarse
           file: ..\soild\ec1.new

NO GROUNDWATER
**
**
** SUMMARY WATER-LIMITED PRODUCTION
** YEAR RUNNAM SET SOW EM  DUR  TWLV  TWST  TWSO  TAGP  LAIM HINDEX  TRC RAIN  DELWAT  TRAT  EVSOL  LOSST  TSR  RYLD  RAGP
1987 WCC      0 -99  1  228.  2974.  7274.  6695.  16944.  6.01  0.40  130.  54.1 -14.2  21.9  7.6  38.7  0.0  75.3  88.5
1988 WCC      0 -99  1  205.  1319.  4000.  2477.  7795.  2.77  0.32  135.  48.0 -13.4  10.5  10.2  40.7  0.0  30.3  56.0
1989 WCC      0 -99  1  202.  1879.  5211.  3181.  10271.  3.95  0.31  142.  37.3 -16.2  14.6  7.3  31.6  0.0  32.0  57.6
MEANS over 3 years :      212.  2057.  5495.  4118.  11670.  4.24  0.34  136.  46.5 -14.6  15.7  8.3  37.0      45.8  67.4
STANDARD DEVIATIONS      :  14.  842.  1656.  2260.  4732.  1.64  0.05  6.  8.5  1.4  5.8  1.6  4.8      25.51  18.31
VARIATION COEFFICIENTS :  6.72  40.93  30.13  54.89  40.55 38.57 13.84  4.7  18.2  9.8  36.9  19.5  12.8

```

Table 36. An example of a *.SUM file.

```

** FILE: ..\output\wcc.sum
** WITH SUMMARY OF LONG TERM SIMULATED YIELD STATISTICS, POTENTIAL AND WATER-LIMITED PRODUCTION
** CALCULATED WITH **WOFOST version 7.1.7, release February 2011
**
**PS RUNNAM IZT SOW EM DUR TWLV TWST TWSO var% TAGP var% LAIM HINDEX RYLD RAGP TRC RDMSOL
PP WCC1 0 -99. 1. 212. 2063. 5886. 9008. 9.86 16958. 16.04 4.27 0.54
WP WCC1 0 -99. 1. 212. 2035. 5841. 6462. 30.94 14338. 27.98 4.22 0.45 72.59 84.01 136. 120.
PP WCC2 0 -99. 1. 215. 2340. 6598. 8928. 13.26 17866. 13.43 4.76 0.50
WP WCC2 0 -99. 1. 215. 2311. 6492. 5954. 32.41 14756. 26.82 4.70 0.40 68.20 82.16 138. 120.

```

4.7 Log-files

Different log-files are produced every time WOFOST is run. Log-files are output files that contain information on the last run(s) executed. There are three different log files:

- WCC.LOG (always produced);
- WOFOST.LOG (only produced when errors occur);
- WEATHER.LOG (only produced when CABO weather is used).

The WCC.LOG contains valuable information on the simulation run when a runtime error occurs. In most cases this will lead you to the cause (and solution) of the runtime error (see Section 3.3.3). It is put in the directory "RUNIO".

WOFOST.LOG contains information on the data and run files that have been used when a runtime error occurs. It is put in the directory "RUNIO".

WEATHER.LOG contains the file header and the warnings and errors that occurs, if any, during the processing of CABO-format weather. WEATHER.LOG is put in directory "RUNIO". The error messages in WEATHER.LOG also appear in WCC.LOG.

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Annex A Abbreviations

| | |
|----------|--|
| AB-DLO | DLO - Research Institute for Agrobiolology and Soil fertility. |
| CABO-DLO | DLO - Centre for Agro-Biological Research (currently AB-DLO). |
| CEC | Commission of the European Communities. |
| CGMS | Crop Growth Monitoring System. |
| CWFS | Centre for World Food Studies. |
| DLO | Agricultural Research Department. |
| EC | European Community(ies). |
| FAO | Food and Agriculture Organization of the United Nations. |
| FSE | FORTRAN Simulation Environment (Van Kraalingen, 1991). |
| GIS | Geographic Information System. |
| IRRI | International Rice Research Institute, Los Baños, Philippines. |
| ISRIC | International Soil Reference and Information Centre. |
| JRC | Joint Research Centre of the Commission of the European Communities. |
| MARS | Monitoring Agro-ecological resources with Remote sensing and Simulation; Monitoring Agriculture with Remote Sensing. |
| NASREC | National Soil Reference Collection and Database. |
| QUEFTS | QUantitative Evaluation of the Fertility of Tropical Soils (Janssen et al., 1990). |
| SC-DLO | DLO Winand Staring Centre for Integrated Land, Soil and Water Research. |
| SYSNET | Systems Research Network for Eco-regional Land Use Planning in Tropical Asia. |
| WAU | Wageningen Agricultural University. |
| WAU-TPE | Wageningen Agricultural University, Department of Theoretical Production-Ecology. |

Annex B Description of variables and parameters in WOFOST

Legend to Table 37:

variable type: C = character
 I = integer
 R = real

Input from or output to file:

iOF = input from run option file
 iRF = input from rerun file
 iTD = input from timer file
 iSD = input from site file
 iCF = input from crop data file
 iSF = input from soil data file
 oDR = output to file with detailed results per growing season
 oSY = output to file with results for series of years
 oLT = output to file with long term mean results

Table 37. Description of variables and parameters in WOFOST

| <i>Variable or parameter</i> | <i>Type and I/O</i> | <i>Description</i> |
|------------------------------|---------------------|--|
| AMAXTB | R iCF | Maximum leaf CO ₂ assimilation rate as a function of development stage of the crop (kg•ha ⁻¹ •hr ⁻¹ ; -). |
| ANT(H) | I oDR, oSY | Duration of pre-anthesis phase (d). |
| AVAIL | R oDR | Amount of water available in actual root zone (cm water). |
| AWC | R oDR, oSY, oLT | Available water capacity of soil (mm water per m soil depth). |
| CFET | R iCF | Correction factor for evapotranspiration in relation to the reference crop. |
| CONTAB | R iSF | 10-log hydraulic conductivity as a function of pF (log(cm•d ⁻¹); log(cm)). |
| CLFFILE | C iTD | Filename of weather station. |
| CLMNAM | C iTD | Description of weather station. |
| CRAIRC | R iSF | Critical soil air content for aeration (cm ⁻³ •cm ⁻³). |
| CRFIL | C iTD | Filename of crop file. |
| CRPNAM | C iCF | Crop name. |
| CVL | R iCF | Conversion efficiency of assimilates into leaf (kg•kg ⁻¹). |
| CVO | R iCF | Conversion efficiency of assimilates into storage organ |

| | | | |
|--------|---|----------|--|
| | | | (kg•kg ⁻¹). |
| CVR | R | iCF | Conversion efficiency of assimilates into root (kg•kg ⁻¹). |
| CVS | R | iCF | Conversion efficiency of assimilates into stem (kg•kg ⁻¹). |
| DAY | I | oDR | Day number of calendar year. |
| DD | R | iSD | Depth of drainage (cm). |
| DEFLIM | R | iSF | Required moisture deficit for a deep seedbed (cm) (soil workability parameter). |
| DELWAT | R | oSY | Difference between final and initial available water in the root zone of (cm water). |
| DEPNR | R | iCF | Crop group number for soil water depletion. |
| DLC | R | iCF | Critical day length (photoperiod) (hr). |
| DLO | R | iCF | Optimum day length (photoperiod) (hr). |
| DMI | R | oDR | Rate of dry matter increase (kg•ha ⁻¹ •d ⁻¹). |
| DTSMTB | R | iCF | Daily increase in thermal time as function of average temperature (°C•d ⁻¹). |
| DUR | I | oSY, oLT | Duration of simulation period (d). |
| DVS | R | oDR | Development stage of crop (-). |
| DVSEND | R | iCF | Development stage at harvest. |
| DVSI | R | iCF | Initial development stage. |
| EFFTB | R | iCF | Initial light-use efficiency of CO ₂ assimilation of single leaves as function of daily temperature ((kg•ha ⁻¹ •hr ⁻¹)/(J•m ⁻² •s ⁻¹); °C). |
| EM | I | oSY, oLT | Emergence date, (day of the year). |
| EVA | R | oDR | Evaporation rate from soil or from water stored on soil surface (mm•d ⁻¹). |
| EVSOL | R | oSY | Total evaporation from soil surface (cm water). |
| FIXNAM | C | iOF | Output filename for summary output of potential and water limited production (max 8 characters, no extension). This is only used when running WOFOST in TERMINAL mode; WCC uses its own filename. |
| FLTB | R | iCF | Fraction of above ground dry matter increase partitioned to leaves as a function of development stage (kg•kg ⁻¹ ; -). |
| FLWR | I | oSY | Day of flowering (day in year). |
| FOTB | R | iCF | Fraction of above ground dry matter increase partitioned to storage organs as a function of development stage (kg•kg ⁻¹ ; -). |
| FRTB | R | iCF | Fraction of total dry matter increase partitioned to roots as a function of development stage (kg•kg ⁻¹ ; -). |
| FSTB | R | iCF | Fraction of above ground dry matter increase partitioned |

| | | | |
|--------|---|---------------|--|
| | | | to stems as a function of development stage (kg•kg ⁻¹ ; -). |
| GASS | R | oDR | Gross assimilation rate (kg (CH ₂ O)•ha ⁻¹ •d ⁻¹). |
| GASST | R | oDR, oSY | Total gross assimilation (kg (CH ₂ O)•ha ⁻¹). |
| HALT | I | oDR, oSY | Day number at harvest (day of the year). |
| HINDEX | R | oDR, oSY, oLT | Harvest index: weight of storage organs / weight of total above ground crop. |
| IAIRDU | I | iCF | Presence of air ducts in roots (e.g. rice) (present (=1) or not (=0)). |
| IBAL | I | iTD | Option for output summary water balance: 0 (no summary), 1 (for whole system), 2 (for root zone), or 3 (for whole system and root zone). |
| IDAYEN | I | iTD | Ultimate date of harvest (day of the year). |
| IDEM | I | iTD, oDR | Day of emergence (day of the year). |
| IDESOW | I | iTD | Earliest date of sowing (day of the year). |
| IDLSOW | I | iTD | Ultimate date of sowing (day of the year). |
| IDRAIN | I | iSD | Presence (1) or absence (0) of drains. |
| IDSEM | I | oDR | Number of days since emergence (d). |
| IDSL | I | iCF | Factor on which development rate between development stage 0 and 1 depends (temperature (0), photo period (1) or both (2)). |
| IDSOW | I | iTD | Date of sowing (day of the year). |
| IDURMX | I | iTD | Maximum number of days from emergence to the end of the simulation. |
| IENCHO | I | iTD | Option to determine end of simulation (fixed end date (1), maturity but no to exceed maximum duration (2), earliest of the two dates (3)). |
| IFUNRN | I | iSD | Indicates whether non-infiltrating fraction of rain is a function of storm size (1) or not (0). |
| INYEAR | I | iTD | Number of years to simulate. |
| INYRG | I | iTD | Number of runs with manipulated rain / number of rain years. |
| IOPT2 | I | iOF | Start/Stop option: 2 (run WOFOST with default input from data files), 4 (run WOFOST from reruns file without default run) and 5 (run FSEOPT for calibration of WOFOST; only possible in TERMINAL mode and not available in WCC). |
| IOXWL | I | iOF | Type of water-limited crop growth: 0 (effects of drought only), 1 (effects of both drought and oxygen shortage). |
| IPRODL | I | iOF | Production levels: 1 (simulation of potential crop growth), 2 (simulation of water limited crop growth), 3 (calculation of nutrient limited crop growth). |

| | | | |
|--------|---|----------|--|
| IRNDAT | I | iTD | Option for the use/selection of rainfall data: 0 (generates statistics with varying total monthly rainfall and number of rainy days), 1 (distributes monthly rainfall over given number of days), 2 (reads rainfall data out of separate file) or 3 (rainfall as it occurs in weather file). |
| ISDAY | I | iTD | Start date of water balance (day of the year). |
| ISTCHO | I | iTD | Options for the start of simulation (fixed emergence day (0), fixed sowing day (1) or variable sowing day (2)) (day of the year). |
| ISYR | I | iTD | First year of simulation (year) |
| ISYRR | I | iTD | First year of rainfall data (year) |
| IWEATH | I | iTD | Weather format: (WOFOST-monthly (0), WOFOST-climate (1), or CABO (2)). |
| IZT | I | iSD, oLT | Influence of groundwater: 0 (no) or 1 (yes). |
| KBASE | R | iSD | Basic supply of potassium by the unfertilized soil for one growing season of 120 days ($\text{kg}\cdot\text{ha}^{-1}$). |
| Kbas | R | oDR | Basic supply of potassium by the unfertilized soil in the actual growing season of the crop ($\text{kg}\cdot\text{ha}^{-1}$). |
| KDIFTB | R | iCF | Extinction coefficient for diffuse visible light as function of development stage. |
| KMAXSO | R | iCF | Maximum concentration of K in storage organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| KMAXVE | R | iCF | Maximum concentration of K in vegetative organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| KMINSO | R | iCF | Minimum concentration of K in storage organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| KMINVE | R | iCF | Minimum concentration of K in vegetative organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| KREC | R | iSD | Apparent recovery of K fertilizer. |
| Krec | R | oDR | Idem. |
| KSUB | R | iSF | Maximum percolation rate of water to subsoil ($\text{cm}\cdot\text{d}^{-1}$). |
| K0 | R | iSF | Hydraulic conductivity of saturated soil ($\text{cm}\cdot\text{d}^{-1}$). |
| LAI | R | oDR | Leaf area index: (leaf area)/(soil area) ($\text{ha}\cdot\text{ha}^{-1}$). |
| LAIEM | R | iCF | Leaf area index at emergence ($\text{ha}\cdot\text{ha}^{-1}$). |
| LAIM | R | oSY, oLT | Maximum leaf area index ($\text{ha}\cdot\text{ha}^{-1}$). |
| LOSST | R | oSY | Total water percolated to deep soil, not available for plant growth (cm water). |
| MRES | R | oDR | Maintenance respiration rate ($\text{kg}(\text{CH}_2\text{O})\cdot\text{ha}^{-1}\cdot\text{d}^{-1}$). |
| MREST | R | oDR, oSY | Total maintenance respiration ($\text{kg}(\text{CH}_2\text{O})\cdot\text{ha}^{-1}$). |
| NBASE | R | iSD | Basic supply of nitrogen by the unfertilized soil for one growing season of 120 days ($\text{kg}\cdot\text{ha}^{-1}$). |

| | | | |
|--------|---|----------|--|
| Nbas | R | oDR | Basic supply of nitrogen by the unfertilized soil in the actual growing season of the crop ($\text{kg}\cdot\text{ha}^{-1}$). |
| NFIX | R | iCF | Fraction of N uptake that originates from biological fixation ($\text{kg}\cdot\text{kg}^{-1}$). |
| NMAXSO | R | iCF | Maximum concentration of N in storage organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| NMAXVE | R | iCF | Maximum concentration of N in vegetative organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| NMINSO | R | iCF | Minimum concentration of N in storage organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| NMINVE | R | iCF | Minimum concentration of N in vegetative organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| NOTINF | R | iSD, oDR | Maximum fraction of rain not-infiltrating into the soil. |
| NREC | R | iSD | Apparent recovery of N fertilizer. |
| Nrec | R | oDR | Idem. |
| PBASE | R | iSD | Basic supply of phosphorus by the unfertilized soil for one growing season of 120 days ($\text{kg}\cdot\text{ha}^{-1}$). |
| Pbas | R | oDR | Basic supply of phosphorus by the unfertilized soil in the actual growing season of the crop ($\text{kg}\cdot\text{ha}^{-1}$). |
| PERDL | R | iCF | Maximum relative death rate of leaves due to water stress (-; $\text{kg}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$). |
| PMAXSO | R | iCF | Maximum concentration of P in storage organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| PMAXVE | R | iCF | Maximum concentration of P in vegetative organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| PMINSO | R | iCF | Minimum concentration of P in storage organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| PMINVE | R | iCF | Minimum concentration of P in vegetative organs ($\text{kg}\cdot\text{kg}^{-1}$). |
| PRDEL | I | iTD | Number of time steps between output lines (days). |
| PREC | R | iSD | Apparent recovery of P fertilizer. |
| Prec | R | oDR | Idem. |
| PS | C | oLT | Production level (production situation) (PP = potential; WP = water-limited). |
| Q10 | R | iCF | Relative change in respiration rate per 10 °C temperature change. |
| RAFILE | C | iTD | Filename of rainfall station. |
| RAGP | R | oSY, oLT | Relative total above ground production: (water-limited production) / (potential production). |
| RAIN | R | oDR | Total rainfall in the simulation period (mm water). |
| RAINAM | C | iTD | Description of rainfall station. |
| RAINT | R | oSY | Total rainfall in the simulation period (cm water). |

| | | | |
|--------|---|-------------------------|--|
| RD | R | oDR | Depth of actual root zone (cm). |
| RDI | R | iCF | Initial rooting depth (cm). |
| RDM | R | oDR | Actual rooting depth (cm). |
| RDMCR | R | iCF | Maximum rooting depth of mature crop (plant characteristic) (cm). |
| RDMSOL | R | iSD, oLT | Maximum rooting depth allowed by soil (cm). |
| RDMso | R | oDR | Maximum rooting depth allowed by soil (cm). |
| RDRRTB | R | iCF | Relative death rate of roots as a function of development stage ($\text{kg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}; -$). |
| RDRSTB | R | iCF | Relative death rate of stems as a function of development stage ($\text{kg} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}; -$). |
| REPORT | I | iOF | Report: 1 (one line per year and statistics). This is the only valid option also for running WOFOST in TERMINAL mode. |
| RESRV | R | oDR | Available soil water in potential root zone (in and below actual root zone) (cm water). |
| RFSETB | R | iCF | Reduction factor for senescence as function of development stage. |
| RGRLAI | R | iCF | Maximum relative increase in LAI ($\text{ha} \cdot \text{ha}^{-1} \cdot \text{d}^{-1}$). |
| RML | R | iCF | Relative maintenance respiration rate leaves ($\text{kg} (\text{CH}_2\text{O}) \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$). |
| RMO | R | iCF | Relative maintenance respiration rate storage organs ($\text{kg} (\text{CH}_2\text{O}) \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$). |
| RMR | R | iCF | Relative maintenance respiration rate roots ($\text{kg} (\text{CH}_2\text{O}) \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$). |
| RMS | R | iCF | Relative maintenance respiration rate stems ($\text{kg} (\text{CH}_2\text{O}) \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$). |
| RQUIRD | I | iOF | Long term means results. This is a summary file of the summary files of potential and water limited production: 0 (no), 1 (yes). In WCC the summary is only shown when there are more than two years (because of calculating statistics) and the rerun option is used. |
| RRI | R | iCF | Maximum daily increase in rooting depth ($\text{cm} \cdot \text{d}^{-1}$). |
| RUNNAM | C | iTD, iRF, oDR, oSY, oLT | Characterization of the simulation runs. |
| RYLD | R | oSY, oLT | Relative yield: (water-limited yield/potential yield). |
| SERIES | I | iOF | Final results for series of years: 0 (no), 1 (yes). This option has only meaning when running WOFOST in TERMINAL mode. The WCC gives always output when the run covers more than 1 year. |
| SITFIL | C | iOF | Site filename. |

| | | | |
|--------|---|---------------|---|
| SLATB | R | iCF | Specific leaf area as a function of development stage ($\text{ha}\cdot\text{kg}^{-1}$; -). |
| SM | R | oDR | Soil moisture content ($\text{cm}^3\cdot\text{cm}^{-3}$). |
| SMFCF | R | iSF, oDR | Soil moisture content at field capacity ($\text{cm}^3\cdot\text{cm}^{-3}$). |
| SMLIM | R | iSD, oDR | Initial maximum moisture content in initial rooting depth (-). |
| SMTAB | R | iSF | Soil water retention; volumetric moisture content (second column) as function of pF (first column) ($\log(\text{cm})$; $\text{cm}^3\cdot\text{cm}^{-3}$). |
| SMW | R | iSF, oDR | Soil moisture content at wilting point ($\text{cm}^3\cdot\text{cm}^{-3}$). |
| SMO | R | iSF, oDR | Soil moisture content of saturated soil ($\text{cm}^3\cdot\text{cm}^{-3}$). |
| SOFILE | C | iSD | Filename of soil. |
| SOLNAM | C | iSF | Soil name. |
| SOPE | R | iSF | Maximum percolation rate root zone ($\text{cm}\cdot\text{d}^{-1}$). |
| SOW | I | oSY, oLT | Day of sowing (day of the year). |
| SPA | R | iCF | Specific pod area ($\text{ha}\cdot\text{kg}^{-1}$). |
| SPADS | R | iSF | 1st topsoil seepage parameter deep seedbed (soil workability parameter). |
| SPAN | R | iCF | Life span of leaves growing at 35 °C (days). |
| SPASS | R | iSF | 1st topsoil seepage parameter shallow seedbed (soil workability parameter). |
| SPODS | R | iSF | 2nd topsoil seepage parameter deep seedbed (soil workability parameter). |
| SPOSS | R | iSF | 2nd topsoil seepage parameter shallow seedbed (soil workability parameter). |
| SSATB | R | iCF | Specific stem area as function of development stage ($\text{ha}\cdot\text{kg}^{-1}$; -). |
| SSI | R | iSD | Initial surface storage (cm water). |
| SSMAX | R | iSD, oDR | Maximum surface storage capacity (cm water) |
| TAGP | R | oDR, oSY, oLT | Total above ground production (dead and living plant organs) ($\text{kg}\cdot\text{ha}^{-1}$) (for potato and beet: TAGP= total above ground production + storage organ). |
| TBASE | R | iCF | Lower threshold temperature for ageing of leaves (°C). |
| TBASEM | R | iCF | Lower threshold temperature for emergence (°C). |
| TDWI | R | iCF | Initial total crop dry weight ($\text{kg}\cdot\text{ha}^{-1}$). |
| TEFFMX | R | iCF | Maximum effective temperature for emergence (°C). |
| TIMFIL | C | iOF | Timer filename. |
| TMNFTB | R | iCF | Reduction factor of gross assimilation rate as function of |

| | | | |
|--------|---|---------------|---|
| | | | low minimum temperature (-; °C). |
| TMPFTB | R | iCF | Reduction factor of AMAX as function of average temperature (°C). |
| TRA | R | oDR | Transpiration rate (mm•d ⁻¹). |
| TRANSP | R | oDR, oSY | Total transpiration (cm water). |
| TRAT | R | oSY | Total transpiration (cm water). |
| TRC | R | oDR, oSY, oLT | Transpiration coefficient (kg water per kg dry matter). |
| TSR | R | oSY | Total surface runoff during simulation run (cm water). |
| TSUM | R | oDR | Thermal time (temperature sum) (°C•d ⁻¹). |
| TSUMEM | R | iCF | Thermal time from sowing to emergence (°C•d ⁻¹). |
| TSUM1 | R | iCF | Thermal time from emergence to anthesis (°C•d ⁻¹). |
| TSUM2 | R | iCF | Thermal time from anthesis to maturity (°C•d ⁻¹). |
| TWLV | R | oDR, oSY, oLT | Total dry weight of leaves (dead and living) (kg•ha ⁻¹). |
| TWRT | R | oDR, oSY | Total dry weight of roots (dead and living) (kg•ha ⁻¹). |
| TWSO | R | oDR, oSY, oLT | Total dry weight of storage organs (dead and living) (kg•ha ⁻¹). |
| TWST | R | oDR, oSY, oLT | Total dry weight of stems (dead and living) (kg•ha ⁻¹). |
| var% | R | oLT | Coefficient of variation. |
| WAV | R | iSD, oDR | Initial amount of available water in total rootable soil (moisture content above wilting point) (cm water). |
| WLV | R | oDR | Dry weight of living leaves (kg•ha ⁻¹). |
| WOFOUT | C | iOF | Filename detailed output. |
| WOFRER | C | iOF | Rerun filename. |
| WSO | R | oDR | Dry weight of living storage organs (kg•ha ⁻¹). |
| WST | R | oDR | Dry weight of living stems (kg•ha ⁻¹). |
| YEAR | I | oSY | Year (water limited). |
| YR | I | oSY | Year (potential production). |
| YZERO | R | iCF | Maximum amount of vegetative organs at zero yield (kg•ha ⁻¹) (to calculate nutrient uptake). |
| ZTI | R | iSD | Initial depth of groundwater table (cm). |
| wet | I | oDR | total number of days characterized by reduced crop growth due to oxygen shortage (d). |
| dry | I | oDR | total number of days characterized by reduced crop growth due to water shortage |

(d).

Annex C Troubleshooting

C.1 Problems with WCC

In this section some examples of problems that might happen are collected. Of course you can avoid many problems by first consulting the digital help file (see Section 3.3.7) of the WCC and underlying technical document. Possible problems:

- extraordinary value (fixed sowing data of 400)

```
Value out of range: 400
Allowed range: 1 - 366
```

Solution: you can change the variable into a more plausible value or in case you really want to enter an extraordinary value (e.g. relatively high TSUM etc.) you can exit WCC and change the lower and upper limit of the variable in the file `..\EXEC\WCC_VAR.DBF`.

- wrong directory name (`..\RUNIO1` instead of `..\RUNIO`)

```
The message 'File not found: ..\RUNIO\RUNOPT.DAT' appears followed by the normal WCC window. But if you run WOFOST the WCC replies with the message 'I/O error 103' and you are not able to run WOFOST.
```

Solution: You can either rename the directory or change the contents in the file "WOFOST Control Centre\DIRECT.INI" according to the new directory name.

- missing file (WOFOST.EXE)

```
'<path to WCC>\WOFOST.EXE' not found!
```

Solution: Search for WOFOST.EXE on your system and place this file under the main WOFOST Control Centre directory or reinstall WOFOST/WCC.

- crop input tab is empty

Solution: There are no crop files in directory `.\CROPD\`, so transfer crop files to this directory, or reinstall WOFOST/WCC or create crop files according to the guidelines in Section 4.2.

C.2 Problems with WOFOST

C.2.1 Introduction

When you run WOFOST version 7.1, a Command Box window appears with the message **'Running the simulation. Please wait...'**. After this message, three things can happen:

- the message **'Press any key to continue'** appears. Press any key and close the Command box. A window with the message **'Simulation successful'** appears. You can now look at the results.
- the message **'Press any key to continue'** appears. Press any key and close the Command box. A window with the message **'Runtime error while running the simulation. Show log-file?'** appears. In this case, you can have a look at the WCC.LOG that contains information on the

simulation run. The log-file should lead you to the cause of the runtime error. Sometimes you may get a runtime error message in the MS DOS-box.

- no message appears and the simulation seems to be taking longer than expected. Stop the simulation by pressing **'Enter'**. The message **'Press any key to continue'** appears. Press any key and close the Command box. A window with the message **'Runtime error while running the simulation. Show log-file?'** appears. Have a look at the WCC.LOG that contains information on the simulation run. The log-file should lead you to the cause of the runtime error.

The WCC.LOG contains error messages. The error messages you can expect are probably due to erroneous input data. The most common error messages are selected and presented.

C.2.2 Error messages related errors in crop and soil files

- Variable is missing (TSUM1)

```
Routine RDDATA, called by RDSREA, attempts to read
a single value from file ..\CROPD\WWH101.CAB
into REAL variable TSUM1
ERROR in RDDATA: Variable name not in data file
```

- Value of variable is missing (second value of AMAXTB)

```
Error(s) while reading from ..\croprd\wwh101.cab

Line Error text                               Somewhere here
==== =====
58 There must be another value                 [AMAXTB = 0.00, ,]
```

- Wrong variable type (TSUM1 is a real instead of integer)

```
Routine RDDATA, called by RDSREA, attempts to read
a single value from file ..\CROPD\WWH101.CAB
into REAL variable TSUM1
ERROR in RDDATA: On data file this variable is INTEGER
```

- Wrong character in number ('o' instead of '0')

```
Error(s) while reading from ..\croprd\wwh101.cab

Line Error text                               Somewhere here
==== =====
30 Illegal after INTEGER value                 [TSUM1 =10o0. ]
```

- The equal sign is missing

```
Error(s) while reading from ..\croprd\wwh101.cab

Line Error text                               Somewhere here
```

```
==== =====
30 Next variable name or = expected [TSUM1 1050. ]
```

- The `;` is missing between previous value and next variable

```
Error(s) while reading from ..\cropld\wwh101.cab

Line Error text                               Somewhere here
==== =====
140 After a value this is illegal              [ = 0.0110 NMINVE = ]
```

C.2.3 Error messages related to weather

- Missing value in weather file (WOFOST-format)

```
ERROR in CLIMRD: error while reading climate data
```

- Missing year in weather file (WOFOST-format)

```
1954
ERROR in CLIMRD: cannot find requested year
```

- Missing station name in weather file (WOFOST-format) (when you omit station name, WOFOST assumes that the next line with year number indicates the station name; the consequence is that WOFOST cannot find the year anymore)

```
1955
ERROR in CLIMRD: cannot find requested year
```

- No hard return after last data line in file (WOFOST-format)

```
ERROR in CLIMRD: error while reading climate data
```

- Comments after the last data line in file (CABO-format)

```
Error in STINFO: incorrect data file
Error in WEATHR: called after error from STINFO or STINFO not called
```

- Missing value (CABO-weather)

```
Error in WEATHR: missing data, in: PHL1.979 day: 1 attr.: -444444
```

- Missing comment leader (`*') in header. Now WOFOST wants to read first data line while this line contain comments.

```
Error in STINFO: incorrect geographical data line
Error in WEATHR: called after error from STINFO or STINFO not called
```


Annex D Julian day calendar

Perpetual

| Day | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 1 | 32 | 60 | 91 | 121 | 152 | 182 | 213 | 244 | 274 | 305 | 335 |
| 2 | 2 | 33 | 61 | 92 | 122 | 153 | 183 | 214 | 245 | 275 | 306 | 336 |
| 3 | 3 | 34 | 62 | 93 | 123 | 154 | 184 | 215 | 246 | 276 | 307 | 337 |
| 4 | 4 | 35 | 63 | 94 | 124 | 155 | 185 | 216 | 247 | 277 | 308 | 338 |
| 5 | 5 | 36 | 64 | 95 | 125 | 156 | 186 | 217 | 248 | 278 | 309 | 339 |
| 6 | 6 | 37 | 65 | 96 | 126 | 157 | 187 | 218 | 249 | 279 | 310 | 340 |
| 7 | 7 | 38 | 66 | 97 | 127 | 158 | 188 | 219 | 250 | 280 | 311 | 341 |
| 8 | 8 | 39 | 67 | 98 | 128 | 159 | 189 | 220 | 251 | 281 | 312 | 342 |
| 9 | 9 | 40 | 68 | 99 | 129 | 160 | 190 | 221 | 252 | 282 | 313 | 343 |
| 10 | 10 | 41 | 69 | 100 | 130 | 161 | 191 | 222 | 253 | 283 | 314 | 344 |
| 11 | 11 | 42 | 70 | 101 | 131 | 162 | 192 | 223 | 254 | 284 | 315 | 345 |
| 12 | 12 | 43 | 71 | 102 | 132 | 163 | 193 | 224 | 255 | 285 | 316 | 346 |
| 13 | 13 | 44 | 72 | 103 | 133 | 164 | 194 | 225 | 256 | 286 | 317 | 347 |
| 14 | 14 | 45 | 73 | 104 | 134 | 165 | 195 | 226 | 257 | 287 | 318 | 348 |
| 15 | 15 | 46 | 74 | 105 | 135 | 166 | 196 | 227 | 258 | 288 | 319 | 349 |
| 16 | 16 | 47 | 75 | 106 | 136 | 167 | 197 | 228 | 259 | 289 | 320 | 350 |
| 17 | 17 | 48 | 76 | 107 | 137 | 168 | 198 | 229 | 260 | 290 | 321 | 351 |
| 18 | 18 | 49 | 77 | 108 | 138 | 169 | 199 | 230 | 261 | 291 | 322 | 352 |
| 19 | 19 | 50 | 78 | 109 | 139 | 170 | 200 | 231 | 262 | 292 | 323 | 353 |
| 20 | 20 | 51 | 79 | 110 | 140 | 171 | 201 | 232 | 263 | 293 | 324 | 354 |
| 21 | 21 | 52 | 80 | 111 | 141 | 172 | 202 | 233 | 264 | 294 | 325 | 355 |
| 22 | 22 | 53 | 81 | 112 | 142 | 173 | 203 | 234 | 265 | 295 | 326 | 356 |
| 23 | 23 | 54 | 82 | 113 | 143 | 174 | 204 | 235 | 266 | 296 | 327 | 357 |
| 24 | 24 | 55 | 83 | 114 | 144 | 175 | 205 | 236 | 267 | 297 | 328 | 358 |
| 25 | 25 | 56 | 84 | 115 | 145 | 176 | 206 | 237 | 268 | 298 | 329 | 359 |
| 26 | 26 | 57 | 85 | 116 | 146 | 177 | 207 | 238 | 269 | 299 | 330 | 360 |
| 27 | 27 | 58 | 86 | 117 | 147 | 178 | 208 | 239 | 270 | 300 | 331 | 361 |
| 28 | 28 | 59 | 87 | 118 | 148 | 179 | 209 | 240 | 271 | 301 | 332 | 362 |
| 29 | 29 | | 88 | 119 | 149 | 180 | 210 | 241 | 272 | 302 | 333 | 363 |
| 30 | 30 | | 89 | 120 | 150 | 181 | 211 | 242 | 273 | 303 | 334 | 364 |
| 31 | 31 | | 90 | | 151 | | 212 | 243 | | 304 | | 365 |

For Leap Years Only

(Use in the year 2000, 2004, 2008, 2012, etc.)

| Day | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 1 | 32 | 61 | 92 | 122 | 153 | 183 | 214 | 245 | 275 | 306 | 336 |
| 2 | 2 | 33 | 62 | 93 | 123 | 154 | 184 | 215 | 246 | 276 | 307 | 337 |
| 3 | 3 | 34 | 63 | 94 | 124 | 155 | 185 | 216 | 247 | 277 | 308 | 338 |
| 4 | 4 | 35 | 64 | 95 | 125 | 156 | 186 | 217 | 248 | 278 | 309 | 339 |
| 5 | 5 | 36 | 65 | 96 | 126 | 157 | 187 | 218 | 249 | 279 | 310 | 340 |
| 6 | 6 | 37 | 66 | 97 | 127 | 158 | 188 | 219 | 250 | 280 | 311 | 341 |
| 7 | 7 | 38 | 67 | 98 | 128 | 159 | 189 | 220 | 251 | 281 | 312 | 342 |
| 8 | 8 | 39 | 68 | 99 | 129 | 160 | 190 | 221 | 252 | 282 | 313 | 343 |
| 9 | 9 | 40 | 69 | 100 | 130 | 161 | 191 | 222 | 253 | 283 | 314 | 344 |
| 10 | 10 | 41 | 70 | 101 | 131 | 162 | 192 | 223 | 254 | 284 | 315 | 345 |
| 11 | 11 | 42 | 71 | 102 | 132 | 163 | 193 | 224 | 255 | 285 | 316 | 346 |
| 12 | 12 | 43 | 72 | 103 | 133 | 164 | 194 | 225 | 256 | 286 | 317 | 347 |
| 13 | 13 | 44 | 73 | 104 | 134 | 165 | 195 | 226 | 257 | 287 | 318 | 348 |
| 14 | 14 | 45 | 74 | 105 | 135 | 166 | 196 | 227 | 258 | 288 | 319 | 349 |
| 15 | 15 | 46 | 75 | 106 | 136 | 167 | 197 | 228 | 259 | 289 | 320 | 350 |
| 16 | 16 | 47 | 76 | 107 | 137 | 168 | 198 | 229 | 260 | 290 | 321 | 351 |
| 17 | 17 | 48 | 77 | 108 | 138 | 169 | 199 | 230 | 261 | 291 | 322 | 352 |
| 18 | 18 | 49 | 78 | 109 | 139 | 170 | 200 | 231 | 262 | 292 | 323 | 353 |
| 19 | 19 | 50 | 79 | 110 | 140 | 171 | 201 | 232 | 263 | 293 | 324 | 354 |
| 20 | 20 | 51 | 80 | 111 | 141 | 172 | 202 | 233 | 264 | 294 | 325 | 355 |
| 21 | 21 | 52 | 81 | 112 | 142 | 173 | 203 | 234 | 265 | 295 | 326 | 356 |
| 22 | 22 | 53 | 82 | 113 | 143 | 174 | 204 | 235 | 266 | 296 | 327 | 357 |
| 23 | 23 | 54 | 83 | 114 | 144 | 175 | 205 | 236 | 267 | 297 | 328 | 358 |
| 24 | 24 | 55 | 84 | 115 | 145 | 176 | 206 | 237 | 268 | 298 | 329 | 359 |
| 25 | 25 | 56 | 85 | 116 | 146 | 177 | 207 | 238 | 269 | 299 | 330 | 360 |
| 26 | 26 | 57 | 86 | 117 | 147 | 178 | 208 | 239 | 270 | 300 | 331 | 361 |
| 27 | 27 | 58 | 87 | 118 | 148 | 179 | 209 | 240 | 271 | 301 | 332 | 362 |
| 28 | 28 | 59 | 88 | 119 | 149 | 180 | 210 | 241 | 272 | 302 | 333 | 363 |
| 29 | 29 | 60 | 89 | 120 | 150 | 181 | 211 | 242 | 273 | 303 | 334 | 364 |
| 30 | 30 | | 90 | 121 | 151 | 182 | 212 | 243 | 274 | 304 | 335 | 365 |
| 31 | 31 | | 91 | | 152 | | 213 | 244 | | 305 | | 366 |

Annex E Upper and lower limits of parameters

The upper and lower limits described in Table 38 should be used with care. Some of the limits given are hard boundary values that should not be crossed. Others are suggestions for a reasonable range of the parameter but not an absolute boundary. Moreover, often the valid range of a particular parameter is depending on the type of crop while the ranges given in Table 38 are basically covering the full range over all crop types. Therefore, it is generally a poor idea to use the ranges provided for analysis of sensitivity. Instead a crop/cultivar specific interpretation of the parameter ranges should be made in order to obtain meaningful results.

Table 38. Upper and lower limits for parameters in the WOFOST model.

| PARAMETER | LOWER | UPPER |
|------------------|--------------|--------------|
| AMAXTB | 1.00000 | 70.00000 |
| CFET | 0.80000 | 1.20000 |
| CONTAB | -8.00000 | 2.00000 |
| CRAIRC | 0.04000 | 0.10000 |
| CVL | 0.60000 | 0.76000 |
| CVO | 0.45000 | 0.85000 |
| CVR | 0.65000 | 0.76000 |
| CVS | 0.63000 | 0.76000 |
| DD | 20.00000 | 300.00000 |
| DEFLIM | -0.30000 | 0.00000 |
| DEPNR | 1.00000 | 5.00000 |
| DLC | 6.00000 | 18.00000 |
| DLO | 6.00000 | 18.00000 |
| DTSMTB | 0.00000 | 38.00000 |
| DVSI | 0.00000 | 0.50000 |
| DVSEND | 1.00000 | 2.50000 |
| EFFTB | 0.40000 | 0.50000 |
| FLTB | 0.00000 | 1.00000 |
| FOTB | 0.00000 | 1.00000 |
| FRTB | 0.00000 | 1.00000 |
| FSTB | 0.00000 | 1.00000 |
| IAIRDU | 0.00000 | 1.00000 |
| IBAL | 0.00000 | 3.00000 |

| | | |
|---------|---------|------------|
| IDAYEN | 1.00000 | 366.00000 |
| IDEM | 1.00000 | 366.00000 |
| IDESOW | 1.00000 | 366.00000 |
| IDL SOW | 1.00000 | 366.00000 |
| IDRAIN | 0.00000 | 1.00000 |
| IDSL | 0.00000 | 1.00000 |
| IDSOW | 1.00000 | 366.00000 |
| IDURMX | 1.00000 | 366.00000 |
| IENCHO | 1.00000 | 3.00000 |
| IFUNRN | 0.00000 | 1.00000 |
| INYEAR | 1.00000 | 1000.00000 |
| INYRG | 1.00000 | 1000.00000 |
| IRNDAT | 0.00000 | 3.00000 |
| ISTCHO | 0.00000 | 2.00000 |
| ISYR | 1.00000 | 4000.00000 |
| ISYRR | 1.00000 | 4000.00000 |
| IWEATH | 0.00000 | 2.00000 |
| IZT | 0.00000 | 1.00000 |
| KBASE | 0.00000 | 100.00000 |
| KDIFTB | 0.44000 | 1.00000 |
| KMAXSO | 0.00500 | 0.05000 |
| KMAXVE | 0.00500 | 0.05000 |
| KMINSO | 0.00200 | 0.01800 |
| KMINVE | 0.00200 | 0.01800 |
| KREC | 0.00000 | 1.00000 |
| KSUB | 0.10000 | 100.00000 |
| K0 | 0.10000 | 100.00000 |
| LAIEM | 0.00070 | 0.30000 |
| NBASE | 0.00000 | 100.00000 |
| NFIX | 0.00000 | 0.75000 |
| NMAXSO | 0.00900 | 0.05600 |
| NMAXVE | 0.00900 | 0.04600 |
| NMINSO | 0.00220 | 0.03500 |
| NMINVE | 0.00220 | 0.01800 |
| NOTINF | 0.00000 | 1.00000 |

| | | |
|--------|----------|-----------|
| NREC | 0.00000 | 1.00000 |
| PBASE | 0.00000 | 100.00000 |
| PERDL | 0.00000 | 0.10000 |
| PMAXSO | 0.00160 | 0.01000 |
| PMAXVE | 0.00160 | 0.01000 |
| PMINSO | 0.00070 | 0.04000 |
| PMINVE | 0.00030 | 0.00200 |
| PRDEL | 1.00000 | 366.00000 |
| PREC | 0.00000 | 1.00000 |
| Q10 | 1.50000 | 2.00000 |
| RDI | 10.00000 | 50.00000 |
| RDMCR | 50.00000 | 400.00000 |
| RDMSOL | 10.00000 | 150.00000 |
| RDRRTB | 0.00000 | 0.02000 |
| RDRSTB | 0.00000 | 0.04000 |
| RFSETB | 0.25000 | 1.00000 |
| RGRLAI | 0.00700 | 0.50000 |
| RML | 0.02700 | 0.03000 |
| RMO | 0.00300 | 0.01700 |
| RMR | 0.01000 | 0.01500 |
| RMS | 0.01500 | 0.02000 |
| RRI | 0.00000 | 3.00000 |
| SLATB | 0.00070 | 0.00420 |
| SMFCF | 0.05000 | 0.74000 |
| SMLIM | 0.01000 | 0.90000 |
| SMTAB | 0.01000 | 0.90000 |
| SMW | 0.01000 | 0.35000 |
| SM0 | 0.30000 | 0.90000 |
| SOPE | 0.10000 | 100.00000 |
| SPA | 0.00080 | 0.00300 |
| SPADS | 0.02000 | 0.80000 |
| SPAN | 17.00000 | 50.00000 |
| SPASS | 0.05000 | 0.90000 |
| SPODS | 0.02000 | 0.04000 |
| SPOSS | 0.03000 | 0.07000 |

| | | |
|--------|-----------|------------|
| SSATB | 0.00030 | 0.00030 |
| SSI | 0.00000 | 20.00000 |
| SSMAX | 0.00000 | 20.00000 |
| TBASE | -10.00000 | 10.00000 |
| TBASEM | -10.00000 | 8.00000 |
| TDWI | 0.50000 | 300.00000 |
| TEFFMX | 18.00000 | 32.00000 |
| TMNFTB | 0.00000 | 1.00000 |
| TMPFTB | 0.00000 | 1.00000 |
| TSUMEM | 0.00000 | 170.00000 |
| TSUM1 | 150.00000 | 1050.00000 |
| TSUM2 | 600.00000 | 1550.00000 |
| WAV | 0.00000 | 45.00000 |
| YZERO | 0.00000 | 400.00000 |
| ZTI | 0.00000 | 999.00000 |
| ISDAY | 1.00000 | 366.00000 |

Annex F Description of subroutines

| | |
|---------|--|
| AFGEN* | This function allows linear interpolation in table TABLE for a given value of the independent variable X. |
| ASSIM | This routine calculates the gross CO ₂ assimilation rate of the whole crop, FGROS, by performing a Gaussian integration over depth in the crop canopy. At three different depths in the canopy, i.e. for different values of LAI, the assimilation rate is computed for given fluxes of photosynthetically active radiation, where after integration over depth takes place. The input variables SINB, PARDIR and PARDIF are calculated in routine TOTASS. |
| ASTRO | This subroutine calculates astronomic day length, diurnal radiation characteristics such as the atmospheric transmission, diffuse radiation etc. |
| CLIMRD | Reads weather data from WOFOST format files including the generation of rainfall. The routine searches the file for the requested year and reads weather data, latitude and altitude of the site. Years with weather data must be in consecutive order on file. |
| CONVR2 | Converts weather data from 'repaired DBMETEO' files to appropriate units, and vice versa. The data type is converted from integer to real, or back, depending on the ACTION required. The method by which data are stored in the repaired weather files is with INTEGER*2 variables to reduce file size. The routine can undertake two different actions 1) convert 'repaired DBMETEO' INTEGER*2 values to REAL values needed after reading a record (ACTION='DECODE_REPAIRED'); 2) convert REAL values to INTEGER*2 values, needed before writing a record in the 'repaired DBMETEO' file (ACTION='CODE_REPAIRED'). |
| CROPNO* | This subroutine is called to assign the right values to EVWMX, EVSMX, TRA and RD during the simulation of the water balance before emergence. After emergence these values are calculated in CROPSI. |
| CROPSI | In this routine the simulation of the potential or the water-limited crop growth is performed. Called by WOFSIM to perform a specific task. Four different tasks are distinguished: ITASK = 1, initialization; ITASK = 2, rate calculation; ITASK = 3, integration; ITASK = 4, finish section. |
| DATES | Converts either a year and day number to a month number and a day number within that month (ACTION='TO_MONTHS') or the inverse, from a day number in a certain month to a day number within the year (ACTION='TO_YEAR'). Leap years are recognized. |
| EVTRA | This routine calculates for a given crop cover the maximum evaporation rate from a shaded wet soil surface and from a shaded water surface, and the maximum and actual crop transpiration rate. |
| GAMMA2 | This function calculates gamma-distributed numbers for the specified gamma distribution parameters BETA and ALFA. |
| METEO | Provides the calling program with weather data (including rainfall) and evapotranspiration values. Different file formats can be used depending on the value of IWEATH. Random rainfall generation or distribution takes place depending on IWEATH. Depending on the value of IWEATH, different variables are used to define the data file to be used. |

NUTRIE This routine calculates nutrient requirements and nutrient-limited yields according to the QUEFTS-system (Janssen et al., 1990) and generates output.

PAUZE Waits for <RETURN> key from keyboard.

PENMAN This routine calculates the potential evapo(transpi)ration rates from a free water surface (E0), a bare soil surface (ES0), and a crop canopy (ET0) in mm/d. For these calculations the analysis by Penman is followed (Frère and Popov, 1979; Penman, 1956).

PRHEAD Write headers to output file.

PRIJRC Output format, used for specific purpose of JRC, Ispra, Italy.

PRIWFD Prints on unit IUOUT part of WOFOST.OUT (standard output table showing variables of crop growth and water balance at interval of PRDEL days) relative to water-limited production calculated on the basis of soil water balance routine WATFD (free drainage).

PRIWGW Prints on unit IUOUT part of WOFOST.OUT (standard output table showing variables of crop growth and water balance at interval of PRDEL days) relative to water-limited production calculated on the basis of soil water balance routine WATGW.

PRIWPP Prints part of WOFOST.OUT (standard output table for single run) on potential production.

RANDOM This function generates pseudo-random numbers uniformly distributed between 0 and 1.

RDMINF Reads in METEO.INF file and returns stations names, latitudes and altitudes.

REPRD Reads weather data from 'repaired DBMETEO' files. This routine automatically detects changes in input data such as weather station, year etc.

RNDIS This routine calculates the daily rainfall (RSERIE) by distributing the given monthly rainfall (RAINTB) over a defined number of randomly chosen rainy days. Monthly rain and number of rainy days equal the given values. Revision includes a minor modification in the random number call and modification to distribute rain in leap years.

RNGEN This routine generates one year of daily rainfall data (RSERIE) on the basis of the given long term average monthly rainfall (RAINTB) and number of rainy days (RAIND) (wet is >0. or > .1 mm). The method follows the proposal of Geng et al. (1986). The procedure is a combination of a Markov chain and a gamma distribution function.

RNREAL Reads rainfall data from an external file called RAFILE. The file should contain the rainfall data for the requested year.

ROOTD In this routine the depth of the root zone is calculated for each day of the crop cycle.
Called by WOFOST: ITASK = 1, initialization; ITASK = 2, rate calculation; ITASK = 3, integration; ITASK = 4, finish section.

STATPP Statistics of potential production. Subroutine for statistical treatment of yield variables, simulated in a series of simulation runs with WOFOST.

STATWP Statistics of production, limited by availability of water. Subroutine for statistical treatment of yield variables, simulated in a series of simulation runs with WOFOST, using the soil water balance model WATFD (free drainage).

STDAY Determines sowing date.

- SUBSOL This routine calculates the rate of capillary flow or percolation between groundwater table and root zone.
- SWEAF The fraction of easily available soil water between field capacity and wilting point is a function of the potential evapotranspiration rate (for a closed canopy) in $\text{cm}\cdot\text{day}^{-1}$, ET_0 , and the crop group number, CGNR (from 1 (=drought-sensitive) to 5 (=drought-resistant)). The function SWEAF describes this relationship given in tabular form by Doorenbos and Kassam (1979) and by Van Keulen and Wolf (1986; p.108, table 20).
- TOTASS This routine calculates the daily total gross CO_2 assimilation by performing a Gaussian integration over time. At three different times of the day, irradiance is computed and used to calculate the instantaneous canopy assimilation, where after integration takes place. Goudriaan and Van Laar (1994) give more information.
- WATFD In routine WATFD the simulation of the soil water balance is performed for FREELY DRAINING soils in the water-limited production situation.
- WATGW In routine WATGW the simulation of the soil water balance is performed for soils influenced by the presence of groundwater. Two situations are distinguished: with or without artificial drainage. The soil water balance is calculated for a cropped field in the water-limited production situation.
- WATPP In this routine the variables of the soil water balance in the potential production situation are calculated. The purpose is to quantify the crop water requirements for continuous growth without drought stress. It is assumed that the soil is permanently at field capacity.
- W70MAIN This subroutine is the main driver routine. It reads the directories and opens and closes input, output and log files. The subroutine reads the run files (run options, timer and site file). Further it controls the reruns, the different weather years and the different randomized rainfall years in different loops. Within the hart of these loops it calls the subroutines WOFSIM (two times: for potential and water limited) and NUTRIE (for nutrient limited) and PRHEAD, STATPP and STATWP for writing headers and summarize output and statistics.
- WOFOST7 *This file has been removed from the source distribution, note that the figure on the following page still shows this file.*
- WOFSIM This routine organizes the simulation of crop growth and of soil water conditions, the generation of weather data and the writing of reports by successive calls to the relevant weather, crop, soil water and printing subroutines, in that order.

*Not taken-up in diagram model structure

