AQUACROP-OS

Reference Manual

Version 5.0a

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Contents

Summary

This document describes how to get started using AquaCrop-OS v5.0a. Details are provided about how to install the model, set up input files, perform a variety of simulations, and interpret model outputs. Note that **this document does not provide details about the calculation procedures in AquaCrop-OS, or about specific parameter values for particular crops or environmental conditions**. For further information about AquaCrop calculation procedures and model parameterisation the user is referred to the FAO AquaCrop manual and associated publications, which are cited in the reference list at the end of this document.

1 Citation

When using AquaCrop-OS in your work, please ensure that you always citate the model as below:

T. Foster, N. Brozović, A.P. Butler, C.M.U. Neale, D. Raes, P. Steduto, E. Fereres, T.C. Hsiao (2017) AquaCrop-OS: An open source version of FAO's crop water productivity model. Agricultural Water Management. 181:18-22. http://dx.doi.org/10.1016/j.agwat.2016.11.015.

In addition, please also acknowledge appropriately the original FAO AquaCrop model by citing the manual (Raes et al., 2016) and/or associated key publications (Raes et al., 2009; Steduto et al., 2009, 2012).

2 Release Notes

This document relates to AquaCrop-OS v5.0a. AquaCrop-OS v5.0a implements all calculation procedures performed by the original FAO AquaCrop v5.0 model, with the exception of the following features:

- Soil fertility stress.
- Soil salinity stress.

Note also that the capillary rise sub-routine in AquaCrop-OS v5.0a is still subject to further testing and revisions.

3 Installation

To receive a free copy of the AquaCrop-OS model, open your web browser and navigate to: `www.AquaCropOS.com`. Once on the website, click the download tab and fill in all relevant details on the software request form. Once these details have been received and checked, a link will be sent to your specified email address where you can download the model. Please note, **AquaCrop-OS may only be used for the non-commerical research and education purposes** as per the terms of the software licence that you must agree to when requesting a copy of the model.

Once you have downloaded the model, to install simply unzip the contents and place the folder 'AquaCropOS_v50a' in a chosen location on your computer. Installation is now complete. In the following sections, descriptions are provided about how to create/modify input files, run the model, and subsequently interpret output files.

4 Input files

In order to run AquaCrop-OS, a variety of input text files must be created. Examples of each input file are provided as part of the model download, and can be found in the folder 'AquaCropOS_v50a/Input'. Input files fall in to two main categories: (1) Essential input files that are required for all model runs; (2) Optional input files that may be needed depending on the type of simulation being conducted. In the sub-sections below, a description is provided of the purpose and structure of each of the input text files.

4.1 Essential

4.1.1 File setup input file

The file setup input file ('FileSetup.txt') defines the names of input files needed to run AquaCrop-OS. Names should be changed to match the exact name (including the .txt extension) of each input file you create for your simulation.

The final line of the file specifies whether or not daily outputs are written during a model simulation (see Section 5 for a description of output files). Note, the name of this input file should not be changed.

4.1.2 Clock input file

The clock input file ('Clock.txt') is used to set the duration of the AquaCrop-OS simulation. Three parameters must be specified:

- SimulationStartTime : Time when the simulation starts (yyyy-mm-dd).
- SimulationEndTime : Time when the simulation ends (yyyy-mm-dd).
- OffSeason : If the soil water balance is simulated outside the growing season, denoted by a 'Y' or 'N' character.

If the off-season soil water balance is not simulated and the model simulation extends over multiple growing seasons, then the soil moisture content at the start of each growing season will be equal to that specified in the Initial Water Content input file (Section 4.1.12).

4.1.3 Weather input file

The weather input file ('Weather.txt') defines time-series of daily weather inputs needed to run AquaCrop-OS. Following the two header lines, data should be specified as tab-delimited rows where each row contains the following variables: (1) Day; (2) Month; (3) Year; (4) Minimum temperature (°C); (5) Maximum temperature (°C); (6) Daily precipitation (mm); (7) Daily reference evapotranspiration (mm). Data must be provided for all days in the simulation period, as defined by the Clock input file (Section 4.1.2).

4.1.4 CO_2 input file

The CO_2 input file ('CO2.txt') defines an annual time-series of atmospheric carbon dioxide (CO_2) concentrations, which affect crop water productivity in AquaCrop-OS. Following the two header lines, data is specified as tab-delimited rows where each row contains two variables: (1) Year; (2) CO_2 concentation (ppm). Values do not have to be specified for every year of a simulation. Where data are missing, AquaCrop-OS will automatically apply linear interpolation to estimate the CO_2 concentration in that year.

4.1.5 Soil input file

The soil input file ('Soil.txt') defines the input variables needed to parameterise the soil component of AquaCrop-OS. The first three variables that must be specified define the exact names (including .txt extension) of additional input files related to the soil component of AquaCrop-OS:

- Soil profile filename (Section 4.1.6).
- Soil texture filename (Section 4.2.1).
- Soil hydrology filename (Section 4.2.2).

Only one of the soil texture and soil hydrology input files will be used. The file that is used will depend on whether the user chooses to calculate soil hydraulic properties from textural characteristics, or pre-specify hydraulic properties according to observation data. A dummy string can be specified in the input row for the unused filename (e.g. 'N/A').

Following the specification of input file names, the remaining variables in the soil input file are used to define various properties of the soil profile. Appendix A provides a description of each of these parameters, noting their units and any default values.

4.1.6 Soil profile input file

The soil profile input file ('SoilProfile.txt') defines the discretisation of the soil profile in to compartments and layers. Following the two header lines, data should be specified as tab-delimited rows where each row contains the following variables: (1) Soil compartment number; (2) Compartment thickness (m); (3) Associated soil layer number. Note that the number of soil compartments, the number of soil layers, and the total thickness of the soil profile must match the values specified in the soil input file (Section 4.1.5).

4.1.7 Crop mix input file

The crop mix input file ('CropMix.txt') defines the crop types and any specified rotation to be simulated by AquaCrop-OS. Four parameters must be defined:

- Number of crop types modelled.
- If a crop rotation calendar is specified, denoted by a 'Y' or 'N' character.
- The full name (including .txt extension) of the crop rotation input file. A dummy string (e.g. 'N/A') can be specified if a rotation is not considered.
- Information about each crop type and its management practices formatted as comma-delimited rows, where each row contains four variables: (1) Crop name; (2) Crop input filename (including .txt extension); (4) Irrigation management input filename (including .txt extension). The number of rows must equal the number of crop types.

A rotation calendar must be specified if more than one crop type is considered. When a rotation calendar is specified, the planting and latest harvest dates specified in each crop input file (Section 4.1.8) will be overwritten by the values given in the rotation calendar (Section 4.2.3).

4.1.8 Crop input file

The crop input file ('Crop.txt') defines the input variables needed to parameterise the crop component of AquaCrop-OS. A unique version of the crop input file should be created with a different name for each individual crop type modelled during the simulation period, as defined by the crop mix (Section 4.1.7) and crop rotation (Section 4.2.3) input files.

Appendix B provides a description of each crop parameter, noting the units and any default values that are not unique to a specific crop type. Guidance on appropriate parameter values for different crop types can be obtained from the FAO AquaCrop manual (Raes et al., 2016).

4.1.9 Irrigation management input file

The irrigation management input file ('IrrigationManagement.txt') defines the input variables controlling irrigation practices in AquaCrop-OS. The following parameters must be specified:

- Full name (including .txt extension) of an irrigation schedule file (Section 4.2.4). This file will only be used if triggering irrigation based on an input time series, otherwise a dummy name can be specified (e.g. 'N/A').
- IrrMethod : Method of irrigation, where: (0) rainfed; (1) irrigation based on soil moisture status; (2) irrigation on a fixed interval; (3) pre-specified irrigation time-series; (4) net irrigation.
- IrrInterval : Time interval between irrigation events (days), if triggering based on a fixed interval.
- SMT1/SMT2/SMT3/SMT4 : Percentage of total available water at which irrigation is initiated in each of the four main crop growth stages, if triggering based on soil moisture status.
- MaxIrr : Maximum irrigation depth (mm day^{-1}).
- AppEff : Irrigation application efficiency (%).
- NetIrrSMT : Percentage of total available water to maintain when in net irrigation mode.
- WetSurf : Soil surface area wetted by irrigation (%).

When multiple crop types are considered in a single simulation, a unique irrigation management file can be created, and is assigned to each crop type in the crop mix input file (Section 4.1.7).

4.1.10 Field management input file

The field management input file ('FieldManagement.txt') defines the input variables controlling field management practices in AquaCrop-OS. The following parameters must be specified:

- Mulches : If the soil surface is covered by mulches, where '0' is 'No' and '1' is 'Yes'.
- MulchPctGS : Soil surface area (%) covered by any mulches during the growing season.
- MulchPctOS : Soil surface area (%) covered by any mulches during the off season.
- fMulch : Factor defining the proportional reduction of soil evaporation due to presence of mulches.
- Bunds : If soil bunds are present on the field, where '0' is 'No' and '1' is 'Yes'.
- zBund : Height of any soil bunds (m).
- BundWater : Initial depth of water between any soil bunds (mm).

4.1.11 Groundwater input file

The groundwater input file ('Groundwater.txt') defines any shallow water table conditions that may influence soil moisture levels. The user must define the following variables:

- If water table is present, denoted by a 'Y' or 'N' character.
- If a water table is present, whether it is 'Constant' or 'Variable'.
- Observations of groundwater depth as tab-delimited rows, where each row contains two variables: (1) Date (dd/mm/yyyy); (2) Water table depth (m).

When a constant water table is present, one observation value should be provided. However, if a variable water table is present, more than one observation point must be included for the simulation period. AquaCrop-OS will automatically apply linear interpolation to obtain values on each day of the simulation.

4.1.12 Initial water content input file

The initial water content input file ('InitialWaterContent.txt') defines the initial moisture conditions throughout the soil profile at the start of the simulation, and also at the beginning of each growing season if the model does not simulate the soil water balance in the off-season (Section 4.1.2). The user must define the following variables:

- Format in which soil moisture input data is provided. Options available are to specify values based on: soil hydraulic properties ('Prop'); as numerical values ('Num'); or as percentages of total available water ('Pct').
- Method used to calculate compartment water contents. If method is depth-based ('Depth'), observations will be linearly interpolated to the centre of each compartment. Alternatively, a layer-based method ('Layer') will apply uniform values to all compartments within a soil layer.
- Number of input soil moisture data points.
- Soil moisture data points as tab-delimited rows where each row contains two variables: (1) Point depth (m) or layer number; (2) Soil moisture value (defined format). If the format of soil moisture values is:
  - Prop : values must be specified as either 'SAT' (Satuation), 'FC' (Field capacity), or 'WP' (Wilting point).
  - Num : values must have units of m^3 m^{-3}.
  - Pct : values must have units of %.

4.2 Optional

4.2.1 Soil texture input file

If the user specifies in the soil input file (Section 4.1.5) to calculate soil hydraulic properties from textural properties, the soil texture input file ('SoilTexture.txt') must be provided. The soil texture input file defines the textural properties of each soil layer, which are then assigned to individual soil compartments according to the discretisation of the soil profile (Section 4.1.6).

Following the two header lines, data are specified as tab-delimited rows where each row contains the following variables: (1) Soil layer number; (2) Thickness of the layer (m); (3) Sand content (%); (4) Clay content (%); (5) Organic matter content (% by weight); (6) Density factor (default value of 1). The number of data rows should equal exactly the number of soil layers specified in the soil input file (Section 4.1.5).

Using these input values, AquaCrop-OS automatically calculates the hydraulic properties of each soil layer (water contents at saturation, field capacity, and permanent wilting, along with the saturated hydraulic conductivity) based on the pedotransfer function model developed by (Saxton & Rawls, 2006).

4.2.2 Soil hydrology input file

If the user specifies in the soil input file (Section 4.1.5) that soil hydraulic properties are pre-defined, a soil hydrology input file ('SoilHydrology.txt') must be provided. The soil hydrology input file defines the hydraulic properties of each soil layer, which are then assigned to individual soil compartments according to the discretisation of the soil profile (Section 4.1.6).

Following the two header lines, data are specified as tab-delimited rows where each row contains the following variables: (1) Soil layer number; (2) Thickness of the layer (m); (3) Water content at saturation (m^3 m^{-3}); (4) Water content at field capacity (m^3 m^{-3}); (5) Water content at permanent wilting point (m^3 m^{-3}); (6) Saturated hydraulic conductivity (mm day^{-1}). The number of data rows should equal exactly the number of soil layers specified in the soil input file (Section 4.1.5)

4.2.3 Crop rotation input file

If the user specifies multiple crop types in the crop mix input file (Section 4.1.7), or wishes to consider variable planting dates over a multi-season simulation, a crop rotation input file ('CropRotation.txt') must be provided that defines the time series of growing seasons that will be simulated by AquaCrop-OS.

Following the two header lines, data should be specified as tab-delimited rows where each row contains the following variables: (1) Planting date (dd/mm/yyyy); (2) Latest possible harvest date (dd/mm/yyyy); (3) Crop type.

Names of crop types must match exactly the spelling in the crop mix input file (Section 4.1.7), and care must be taken to ensure that growing seasons do not overlap in time. Note that crop harvesting can occur before the latest possible harvest date depending on weather conditions and crop phenology. The latest harvest date is merely specified to ensure that the crop growing season is terminated by some realistic end date in the event that sufficient growing degree days are not accumulated to reach full physiological maturity.

4.2.4 Irrigation schedule input file

If the user specifies that irrigation is based on a pre-specified time-series (Section 4.1.9), an irrigation schedule input file must be provided. Following the two header lines, data should be specified as tab-delimited rows where each row contains the following variables: (1) Day; (2) Month; (3) Year; (4) Irrigation depth (mm). Data only need to be specified for days when irrigation occurs. AquaCrop-OS will automatically apply zero irrigation values to all other simulation days.

5 Output Files

During a simulation, AquaCrop-OS will generate output files detailing crop growth, water contents, and water fluxes at both daily and seasonal timescales. Examples of each output file are provided as part of the model download, and can be found in the folder 'AquaCropOS_v50a/Output'. In the following sub-sections, a description is provided of the data reported in each output file.

5.1 Water contents output file

The water contents output file ('WaterContents.txt') reports the simulated water content (m^3 m^{-3}) in each soil compartment at the end of each simulation day. A variable, 'Season', is also reported that takes a value of 1 on days during a growing season, and a value of 0 on days outside a growing season. Note that if the soil water balance is not simulated in the off-season, water contents on these days will be denoted by zero values.

5.2 Water fluxes output file

The water fluxes output file ('WaterFluxes.txt') reports various simulated water fluxes and states on each simulation day, including:

- wRZ : Water in the crop root zone (mm).
- zGW : Water table depth (m). A value of -999 indicates no groundwater table was considered.
- wSurf : Ponded water (mm).
- Irr : Irrigation (mm).
- Infl : Infiltration (mm).
- RO : Surface runoff (mm).
- DP : Deep percolation below the base of the soil profile (mm).
- CR : Capillary rise in to the soil profile (mm).
- GWin : Horizontal groundwater inflow to the soil profile (mm).
- Es : Soil evaporation (mm).
- EsX : Potential soil evaporation (mm).
- Tr : Crop transpiration (mm).
- TrX : Potential crop transpiration (mm).

As previously noted, the variable 'Season' denotes whether a growing season was active on a given day and values of zero are assigned to all fluxes/states outside of the growing season if the off-season soil water balance is not simulated.

5.3 Crop growth output file

The crop growth output file ('CropGrowth.txt') reports various simulated aspects of crop development on each simulation day, including:

- GDD : Number of growing degree days on the current day.
- TotGDD : Cumulative growing degree days in the current season.
- RootDepth : Crop effective rooting depth (m).
- CC : Fractional canopy cover.
- RefCC : Fractional canopy cover under no water-stress conditions.
- Bio : Accumulated aboveground biomass (g m^{-2}).
- RefBio : Accumulated aboveground biomass under no water stress conditions (g m^{-2}).
- HI : Fractional reference harvest index.
- HIadj : Fractional harvest index adjusted for water stress effects.
- Yield : Crop yield (tonne ha^{-1}).

As previously noted, the variable 'Season' denotes whether a growing season was active on a given day.

5.4 Final output file

The final output file ('FinalOutput.txt') reports summaries and totals of key simulated variables in each growing season, including:

- PlantD : Calendar planting date (dd/mm/yyyy).
- PlantSD : Simulation day of planting.
- HarvestD : Calendar harvest date (dd/mm/yyyy).
- HarvestSD : Simulation day of harvesting.
- Yield : Final crop yield (tonne ha^{-1}).
- TotIrr : Total irrigation use (mm).

6 Running Simulations

AquaCrop-OS can be run as a single simulation, or in parallel for batch simulations. A description of how to perform each type of simulation is provided in the sub-sections below.

6.1 Single simulations

To run a single simulation of AquaCrop-OS, the first step is to create the input files using the instructions provided in Section 4. In addition, the user must modify the paths for input and output folders that are defined in the file 'FileLocations.txt'. Note that the name of this file should not be changed.

Once the above steps have been completed, run the script 'AquaCropOS_RUN.m'. The simulation will be performed, and outputs written to the specified output directory. AquaCrop-OS will write an error message to the command window if any of the required input files cannot be found, or if inappropriate input data has been specified (e.g. if weather inputs do not cover all growing seasons to be simulated).

6.2 Parallel simulations

To run a parallel simulation of AquaCrop-OS, first create a unique set of input folders that contain the input files needed to run each individual simulation. Then create a set of sub-directories within the AquaCrop-OS output folder with identical names.

Once input and output files/folders have been created, run the function 'AquaCropOS_BatchRUN.m' in parallel. Parallel execution can be achieved in Matlab by following the steps below. Figure 1 also provides an example of a Matlab script used to run AquaCrop-OS in parallel.

- Define the input and output folder locations for each simulation, the total number of simulations, the number of CPU's to use, and the cluster name.
- Open a parallel pool using the function 'parpool'.
- Run the function 'AquaCropOS_BatchRUN.m' within a 'parfor' loop, providing the full pathnames of the input and output folders for the iteration as individual cell array inputs.
- AquaCrop-OS will be run in parallel until all simulations have been completed, with the number of simultaneous model runs determined by the number of CPU's utilised.
- Outputs for each individual simulation will be written to the directory provided as an input for the respective iteration of the 'parfor' loop.

AquaCrop-OS may also be run in parallel in Octave by following the steps below. Figure 2 also provides an example of an Octave script used to run AquaCrop-OS in parallel.

- Define the input and output folder locations for each simulation, and the total number of CPU's to use.

- Load the parallel package (when running in parallel for the first time).
- Run the function 'AquaCropOS_BatchRUN.m' using the function 'parcellfun', providing two 1 x N cell arrays that contain the full pathnames of the input and output folders, respectively, for all N iterations.
- AquaCrop-OS will be run in parallel until all simulations have been completed, with the number of simultaneous model runs determined by the number of CPU's utilised.
- Outputs for each individual simulation will be written to the sub-directory provided as an input for the respective iteration of 'parcellfun'.

```
%% Run AquaCrop-OS v5.0a in parallel (Matlab) %%

%% Set path %%
addpath('C:/AquaCropOS_v50a');

%% Define main directories for inputs and outputs %%
DirInMain = 'C:/AquaCropOS_v50a/Input/BatchRun/';
DirOutMain = 'C:/AquaCropOS_v50a/Output/BatchRun/';

%% Define simulations %%
Sims = 1:1000;
nSims = length(Sims);

%% Create cell array of input and output directory names %%
for ii = 1:nSims
    DirIn{ii} = strcat(DirInMain,'Sim',num2str(ii));
    DirOut{ii} = strcat(DirOutMain,'Sim',num2str(ii));
end

%% Define number of CPU's to utilise %%
nCPU = 4;

%% Define cluster name %%
Cluster = 'local';

%% Open parallel cluster %%
poolobj = parpool(Cluster,nCPU);

%% Perform parallel simulations %%
parfor ii = 1:nSims
    AquaCropOS_BatchRUN(DirIn(ii),DirOut(ii));
end

%% Close down parallel cluster %%
delete(poolobj);
```

Figure 1: Sample code for running AquaCrop-OS in parallel in Matlab

```
%% Run AquaCrop-OS v5.0a in parallel (Octave) %%

%% Set path %%
addpath('C:/AquaCropOS_v50a');

%% Install parallel package (when using for first time) %%
pkg load parallel;

%% Define main directories for inputs and outputs %%
DirInMain = 'C:/AquaCropOS_v50a/Input/BatchRun/';
DirOutMain = 'C:/AquaCropOS_v50a/Output/BatchRun/';

%% Define simulations %%
Sims = 1:1000;
nSims = length(Sims);

%% Create cell array of input and output directory names %%
for ii = 1:nSims
    DirIn{ii} = strcat(DirInMain,'Sim',num2str(ii));
    DirOut{ii} = strcat(DirOutMain,'Sim',num2str(ii));
end

%% Define number of CPU's to utilise %%
nCPU = 4;

%% Run model in parallel %%
parcellfun(nCPU,@AquaCropOS_BatchRUN,DirIn,DirOut);
```

Figure 2: Sample code for running AquaCrop-OS in parallel in Octave

References

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A Soil parameters

Table 1: Soil input parameters for AquaCrop-OS

Parameter	Description	Units	Default value (if any)
CalcSHP	Determines if soil hydraulic properties are calculated from textural characteristics of soil layers	0 = No; 1 = Yes	-
zSoil	Total thickness of the soil profile	Metres	-
nComp	Number of soil compartments	-	-
nLayer	Number of soil layers	-	-
EvapZsurf	Thickness of the evaporating soil surface layer in direct contact with the atmosphere	Metres	0.04
EvapZmin	Minimum thickness of full soil surface evaporation layer	Metres	0.15
EvapZmax	Maximum thickness of full soil surface evaporation layer	Metres	0.30
Kex	Maximum soil evaporation coefficient	-	1.10
fevap	Shape factor describing the reduction in evaporation with decreasing water content in the soil surface layer	-	4
fWrelExp	Relative water content of the soil surface layer at which the evaporation layer depth expands	-	0.40
fwcc	Coefficient expressing the reduction in soil evaporation due to the sheltering effect of withered canopy cover	-	0.5
AdjREW	Determines if the calculated value of readily evaporable water (REW) is overwritten by a user-defined value	0 = No, 1 = Yes	
REW	User-defined REW depth (only used if adjusting from the calculated value)	Millimetres	-
AdjCN	Determines if the curve number (CN) is adjusted each day based on surface moisture conditions	0 = No, 1 = Yes	-
CN	Curve number	-	-
zCN	Thickness of the soil surface layer used to calculate moisture content to adjust the curve number	Metres	0.30
zGerm	Thickness of the soil surface layer used to calculate moisture content to determine if germination can occur	Metres	0.30
zRes	Depth of any restrictive soil layer that inhibits root deepening	Metres	Set to negative value if no restriction is present
fshape_cr	Shape factor describing the strength of the effect of any shallow groundwater table on soil water content	-	16

B Crop parameters

Table 2: Crop input parameters for AquaCrop-OS

Parameter	Description	Units	Default value
CropType	Determines the category of crop	-	1 = Leafy vegetable 2 = Root/tuber 3 = Fruit/grain
CalendarType	Determines time units for crop development	-	1 = Calendar days 2 = GDD's
SwitchGDD	Determines if inputs (when specified in calendar day mode) are converted to GDD's. Conversion is recommended to ensure accurate phenology.	-	0 = No 1 = Yes
PlantingDate	Default planting date (may be overwritten)	dd/mm	-
HarvestDate	Default latest harvest date (may be overwritten)	dd/mm	-
Emergence	Time from sowing/transplanting to emergence/transplant recovery	Days/GDD's	-
MaxRooting	Time from sowing/transplanting to maximum root development	Days/GDD's	-
Senescence	Time from sowing/transplanting to start of canopy senescence	Days/GDD's	-
Maturity	Time from sowing/transplanting to physiological maturity	Days/GDD's	-
HIstart	Time from sowing/transplanting to start of yield formation	Days/GDD's	-
Flowering	Duration of flowering (only for fruit/grain crops)	Days/GDD's	-
YldForm	Duration of yield formation	Days/GDD's	-
GDDmethod	Method used to calculate GDD's	-	-
Tbase	Base temperature below which crop growth does not occur	°C	-
Tupp	Upper temperature above which crop growth does not occur	°C	-
PolHeatStress	Determines if pollination is affected by heat stress	-	0 = No; 1 = Yes
Tmax_up	Maximum temperature above which pollination begins to fail	°C	-
Tmax_lo	Maximum temperature above which pollination fails completely	°C	-
PolColdStress	Determines if pollination is affected by cold stress	-	0 = No; 1 = Yes
Tmin_up	Minimum temperature below which pollination begins to fail	°C	-
Tmin_lo	Minimum temperature below which pollination fails completely	°C	-
BioHeatStress	Determines if biomass production is affected by temperature stress	-	0 = No; 1 = Yes

GDD_up	Minimum number of GDD's required for full biomass production	GDD's	-
GDD_lo	Minimum number of GDD's required for any biomass production to occur	GDD's	-
fshape_b	Shape factor describing the reduction in biomass production due to insufficient GDD's	GDD's	-
PctZmin	Percentage of minimum effective rooting depth at sowing/transplanting	%	70
Zmin	Minimum effective rooting depth	Metres	-
Zmax	Maximum effective rooting depth	Metres	-
fshape_r	Shape factor describing the decreasing speed of root expansion over time	-	1.5
fshape_ex	Shape factor describing the effects of water stress on root expansion	-	-6
SxTopQ	Maximum water extraction at the top of the root zone	m^3 m^{-3} day^{-1}	-
SxBotQ	Maximum water extraction at the bottom of the root zone	m^3 m^{-3} day^{-1}	-
a_Tr	Exponent parameter describing the effect of canopy decline on transpiration/photosynthetic capacity	-	1
SeedSize	Soil surface area covered by an individual seedling at 90% emergence	cm^2	-
PlantPop	Plant population	plants ha^{-1}	-
CCmin	Minimum fractional canopy cover size below which yield formation does not occur	-	-
CCx	Maximum fractional canopy cover size	-	-
CDC	Canopy decline coefficient	day^{-1}/GDD^{-1}	-
CGC	Canopy growth coefficient	day^{-1}/GDD^{-1}	-
Kcb	Maximum crop coefficient when canopy is fully developed	-	-
fage	Decline of crop coefficient due to ageing of the canopy	% day^{-1}	-
WP	Water productivity normalised for reference evapotranspiration and atmospheric carbon dioxide	g m^{-2}	-
WPy	Adjustment of water productivity parameter in yield formation stage	% of WP	-
fsink	Crop sink strength coefficient	-	-
bsted	Water productivity adjustment parameter for CO_2 effects given by (Steduto et al., 2007)	-	0.000138
bface	Water productivity adjustment parameter for CO_2 effects given by FACE experiments	-	0.001165
HI0	Reference harvest index	-	-
HIini	Initial harvest index	-	-
dHI_pre	Possible increase of harvest index due to pre-anthesis water stress	%	-

a_HI	Coefficient describing the positive impact on harvest index of restricted vegetative growth post-anthesis	-	-
b_HI	Coefficient describing the negative impact on harvest index of stomatal closure post-anthesis	-	-
dHI0	Maximum possible increase in harvest index above reference value	%	-
Determinant	Crop determinacy, which affects period of potential vegetative growth	-	0 = Indeterminant 1 = Determinant
exc	Excess of potential fruits that is produced by the crop	%	-
MaxFlowPct	Percentage of total flowering period at which peak flowering occurs	%	33.33
p_up1	Upper soil water depletion threshold for water stress effects on canopy expansion	-	-
p_up2	Upper soil water depletion threshold for water stress effects on stomatal control	-	-
p_up3	Upper soil water depletion threshold for water stress effects on canopy senescence	-	-
p_up4	Upper soil water depletion threshold for water stress effects on crop pollination	-	-
p_lo1	Lower soil water depletion threshold for water stress effects on canopy expansion	-	-
p_lo2	Lower soil water depletion threshold for water stress effects on stomatal control	-	-
p_lo3	Lower soil water depletion threshold for water stress effects on canopy senescence	-	-
p_lo4	Lower soil water depletion threshold for water stress effects on crop pollination	-	-
fshape_w1	Shape factor describing water stress effects on canopy expansion	-	-
fshape_w2	Shape factor describing water stress effects on stomatal control	-	-
fshape_w3	Shape factor describing water stress effects on canopy senescence	-	-
fshape_w4	Shape factor describing water stress effects on crop pollination	-	-
ETadj	Determines if water stress thresholds are adjusted for variations in daily reference evapotranspiration		0 = No 1 = Yes
Aer	Water deficit below saturation at which aeration stress begins to occur	%	5
LagAer	Lag before aeration stress affects crop growth	days	3
beta	Reduction to p_lo3 parameter when early canopy senescence is triggered due to water stress	%	12
GermThr	Proportion of total available water needed in the root zone for the crop to germinate	-	0.20