AQUACROP-OS

Reference Manual

Version 2

October 2019 (Updated July 2022)

Developed by:

Tim Foster

University of Manchester

timothy.foster@manchester.ac.uk

Contents

1 Citation **2**

2 Release Notes and Disclaimer **2**

3 Getting Started **2**

4 Input files **2**

4.1 Essential . . . 3

4.1.1 File setup input file . . . 3

4.1.2 Clock input file . . . 3

4.1.3 Weather input file . . . 3

4.1.4 CO_2 input file . . . 3

4.1.5 Soil input file . . . 3

4.1.6 Soil profile input file . . . 4

4.1.7 Crop mix input file . . . 4

4.1.8 Crop input file . . . 4

4.1.9 Irrigation management input file . . . 4

4.1.10 Field management input file . . . 5

4.1.11 Groundwater input file . . . 5

4.1.12 Initial water content input file . . . 5

4.2 Optional . . . 6

4.2.1 Soil texture input file . . . 6

4.2.2 Soil hydrology input file . . . 6

4.2.3 Crop rotation input file . . . 6

4.2.4 Irrigation schedule input file . . . 7

5 Output Files **7**

5.1 Water contents output file . . . 7

5.2 Water fluxes output file . . . 7

5.3 Crop growth output file . . . 8

5.4 Final output file . . . 8

6 Running Simulations **8**

6.1 Single simulations . . . 8

6.2 Parallel simulations . . . 9

Summary

This document describes how to get started using AquaCrop-OS v2.0 (FAO model version 6.0). 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 (**?**) and/or associated key publications (Raes et al., 2009; Steduto et al., 2009, 2012).

2 Release Notes and Disclaimer

This document relates to AquaCrop-OS (Matlab and Octave) v2.0. AquaCrop-OS (Matlab and Octave) v2.0 implements all calculation procedures and features performed by the original FAO AquaCrop v6.0 model, with the exception of the following features: (i) soil fertility stress, (ii) soil salinity stress, and (iii) weed management. These routines have not been included in AquaCrop-OS v6.0a as they have yet to be tested extensively for different crop types and environments worldwide, and, as such, remain largely theoretical at present. However, these routines may be included in future releases of the open-source code.

AquaCrop-OS has been extensively tested to ensure the ability of the software to reproduce accurately the original FAO AquaCrop model, and has been validated under a range of environmental and crop management regimes. However, the developers make no claim that the model predictions are accurate under all conditions. The developers assume no responsibility for any errors or omissions in either the software or documentation, and in no event shall the developers be liable for any damages incurred by you or any third parties resulting from use of this software.

3 Getting Started

To access the AquaCrop-OS model source code, navigate to the GitHub repository (`https://github.com/aquacropos/aquacrop-matlab`). From here you can download a copy of the files from this repository and extract the files to a directory on your machine. Alternatively, you can clone this repository onto your own machine if you wish. In the following sections, descriptions are provided about how to create/modify input files, run the model, and subsequently interpret output files.

Please note, **AquaCrop-OS is distributed under the Apache 2.0 license**, full details of which are provided in the GitHub repository. All works using the model must also explicitly cite the model publication as highlighted in the citation section of this document above.

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 the different 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 from its default otherwise a model error will occur.

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:

- Time when the simulation starts (yyyy-mm-dd).
- Time when the simulation ends (yyyy-mm-dd).
- 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 the values 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 space-delimited columns where each row of data contains the following variables: (1) Day, (2) Month, (3) Year, (4) Minimum temperature (^{o}C), (5) Maximum temperature (^{o}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 space-delimited columns where each row of data 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. Following the two header lines, the first three variables that must be specified define the filenames (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 out of the soil texture and soil hydrology input files will be used in a given model simulation. 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'), or this value can simply be left empty.

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. For each variable, a description is given on the right-hand side after the colon symbol, and also notes any specific conditions or units for each variable. Sample soil files for 12 main textural classes are also provided in the AquaCrop-OS input folder, which are identical to the values defined for these classes in version 6.0 of the FAO AquaCrop model.

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 space-delimited columns where each row of data 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 to be simulated.
- 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 (i.e. if only one crop type is modelled).
- Information about each crop type and its management practices formatted as space-delimited columns specifying: (1) Crop name; (2) Crop input filename (including .txt extension); (3) Irrigation management input filename (including .txt extension); and (4) Field 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 considered in the simulation period, as defined by the crop mix (Section 4.1.7) and crop rotation (Section 4.2.3) input files.

For each variable given after the two header lines, a description is given on the right-hand side after the colon symbol. The description also notes any specific conditions or units for each variable, and relates directly to variable descriptions given in the FAO AquaCrop version 6.0 crop input files. Guidance on appropriate parameter values for different crop types can be obtained from the FAO AquaCrop manual (Raes et al., 2018).

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 (e.g. 'N/A') or blank name can be specified.
- 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 calculation.
- Time interval between irrigation events (days), if triggering based on a fixed interval.
- 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.
- Maximum irrigation depth (mm day^{-1}).
- Irrigation application efficiency (%), which considers additional losses (e.g. wind drift, canopy/air evaporation) that are not simulated by AquaCrop (note AquaCrop already acconts for losses due to surface runoff, soil evaporation, and deep percolation).

- Percentage of total available water to maintain when running in net irrigation simulation mode.
- Soil surface area wetted by irrigation (%).

When multiple crop types are considered in a single simulation, a unique irrigation management file can be created for each crop type, and is assigned to each crop 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:

- If the soil surface is covered by mulches, denoted by a 'Y' or 'N' character.
- If soil bunds are present on the field, denoted by a 'Y' or 'N' character.
- If field management practices affect the runoff curve number, denoted by a 'Y' or 'N' character.
- If field management practices fully inhibit surface runoff, denoted by a 'Y' or 'N' character.
- Soil surface area (%) covered by any mulches.
- Factor defining the proportional reduction of soil evaporation due to presence of mulches.
- Height of any soil bunds (m).
- Initial depth of water between any soil bunds (mm).
- Change in the runoff curve number (%) if affected by field management practices

A seperate version of the field management input file should be created to specify field management practices both during and outside of the crop growth season. When multiple crop types are considered in a single simulation, a unique field management file can also be created for each crop type, and is assigned to each crop in the crop mix input file (Section 4.1.7). However, note that field management practices outside of the growing season are assumed to not change over time for a multi-year simulation.

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 specified as a 'Constant' or 'Variable' value during the simulation period.
- Observations of groundwater depth specified as space-delimited columns, where each row of data defines the: (1) Date (dd/mm/yyyy) of water table observation; (2) Water table depth below land surface (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 given soil layer.
- Number of input soil moisture data points to be specified.
- Soil moisture data points as space-delimited columns, where each row of data contains two variables: (1) Point depth (m) or layer number to assign value to; (2) Soil moisture value.

The format in which to define the soil moisture values depends on the pre-defined format for input data specified earlier in the input file. Specifically, values should be formtted as:

- Prop : values must be specified as either 'SAT' (Saturation), 'FC' (Field capacity), or 'WP' (Wilting point).
- Num : values must have units of m^3 m^{-3}.
- Pct : values must have units of %, and range between 0 and 100.

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 should be specified as space-delimited columns where each row of data contains the following variables: (1) Soil layer number; (2) Thickness of the soil layer (m); (3) Sand content (%); (4) Clay content (%); (5) Organic matter content (% by weight); (6) Penetrability (%). 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 should be specified as space-delimited columns where each row of data contains the following variables: (1) Soil layer number; (2) Thickness of the soil 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}); and (7) Penetrability of the soil (%). 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 space-delimited columns where each row of data 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 of crop names in the crop mix input file (Section 4.1.7). Care must also be taken to ensure that growing seasons do not overlap in time otherwise a model error will occur (as it is not possible to sow/transplant a new crop before the previous crop has reached maturity). Note that crop harvesting can occur before the latest possible harvest date depending on weather and crop phenology. The latest harvest date is 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 space-delimited columns where each row of data 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_v60a/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 has 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 -999 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 in surface layer (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 -999 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.
- Zr : Crop effective rooting depth (m).
- CC : Fractional canopy cover.
- CCPot : Fractional canopy cover under no water-stress conditions.
- Bio : Accumulated aboveground biomass (g m^{-2}).
- BioPot : 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. Outside of the growing season, values for crop growth parameters are set equal to -999.

5.4 Final output file

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

- PlantDate : Calendar planting date (dd/mm/yyyy).
- PlantSimDate : Simulation day of planting.
- HarvestDate : Calendar harvest date (dd/mm/yyyy).
- HarvestSimDate : 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'.

Users are also free to adapt code to perform alternative parallel model executions, which may be more efficient if running large batches of simulations that would otherwise create too many input text files.

```
%% Run AquaCrop-OS v6.0a in parallel (Matlab) %%

%% Set path %%
addpath('C:/AquaCropOS_v60a');

%% Define main directories for inputs and outputs %%
DirInMain = 'C:/AquaCropOS_v60a/Input/BatchRun/';
DirOutMain = 'C:/AquaCropOS_v60a/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 v6.0a in parallel (Octave) %%

%% Set path %%
addpath('C:/AquaCropOS_v60a');

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

%% Define main directories for inputs and outputs %%
DirInMain = 'C:/AquaCropOS_v60a/Input/BatchRun/';
DirOutMain = 'C:/AquaCropOS_v60a/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

Raes, D., Steduto, P., Hsiao, T. C., & Fereres, E. (2009). AquaCrop - The FAO crop model to simulate yield response to water: II. Main algorithms and software description. *Agronomy Journal*, *101*(3), 438–447.

Raes, D., Steduto, P., Hsiao, T. C., & Fereres, E. (2018). *AquaCrop Version 6.0-6.1 Reference Manual*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Saxton, K. E., & Rawls, W. J. (2006). Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil Science Society of America Journal*, *25*(3), 1569–1578.

Steduto, P., Hsiao, T. C., Fereres, E., & Raes, D. (2012). *Crop yield response to water. FAO Irrigation and Drainage Paper No.66*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. (2009). AquaCrop - The FAO crop model to simulate yield response to water: I. concepts and underlying principles. *Agronomy Journal*, *101*(3), 426–437.