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1. AquaCrop-GIS description

AquaCrop-GIS has been designed to facilitate the use of the AquaCrop model (Steduto et al., 2009) when a high number of simulations is needed, simplifying the task of generating input and projects files and the management of output files. The AquaCrop-GIS tool prepares the required inputs, executes AquaCrop, elaborates the results and shows them in a Geographic Information System. This Manual describes how to use AquaCrop-GIS to carry out as many AquaCrop simulations as required, while the tool is described in detail in Lorite et al. (2013). The user of AquaCrop-GIS should be familiar with the use of the AquaCrop model.

2. Requirements

AquaCrop-GIS is programmed for Windows operating system and has been successfully tested for Windows XP, Windows 7 and Windows 8 versions.

Software requirements are uniquely related with the .NET framework (at least version 4) that needs to be installed in the computer to run AquaCrop-GIS. Hardware requirements (computing processor and memory) will depend of the number of simulation and processing speed. However, minimum requirements of at least 128MB of memory and 2 processors are recommended.

AquaCrop-GIS needs at least 20MB of available hard disk space (plus the required space for simulations and results). If AquaCrop-GIS is installed in folders like *Program Files* or other protected folders, the software should be installed with administrator privileges.

AquaCrop-GIS is designed to work with the 32bits AquaCrop version by default. If the 64bits version is used, it is necessary to replace the name of the folder *ACsaV40_64bits* by *ACsaV40*.

3. Data preparation

In this section the procedure to build the input dataset for AquaCrop-GIS use is described.

3.1. Alphanumeric datasets (XLSX files)

AquaCrop-GIS has been designed to use with xlsx files (which can be generated and edited using OpenOffice or Microsoft Excel) in order to store all the information required to generate the input dataset required by AquaCrop.

AquaCrop-GIS uses up to five files to include the input datasets required for AquaCrop. These files are named *crops.xlsx*, *initials.xlsx*, *soils.xlsx*, *groundwater.xlsx* and *management.xlsx*.

and are located in the “Data” folder (for example in C:\AquaCrop-GIS\Data\). Finally, weather data are stored in specific xlsx files in the folder “Weather” (for example in C:\AquaCrop-GIS\Weather\); one for each weather station.

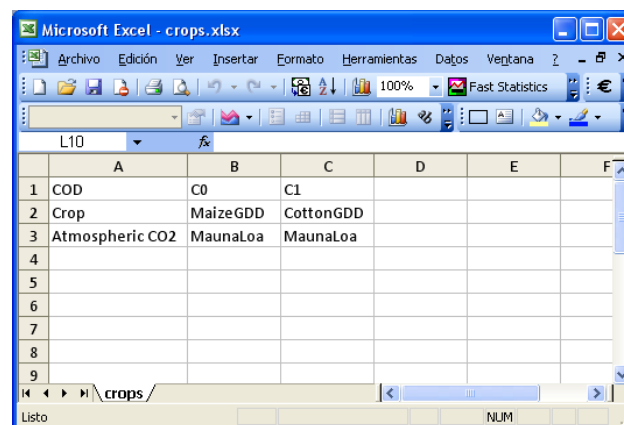
The information included in those files is used by AquaCrop-GIS to build the input files required by AquaCrop. The templates to build these input files are located in the templates folder (for example C:\AquaCrop-GIS\Templates\). If these files are modified, it will generate malfunctions of the AquaCrop-GIS software.

Finally, the control of the simulations prepared with AquaCrop-GIS is carried out with the batch.xlsx file, located in the “Data” folder (for example in C:\AquaCrop-GIS\Data\).

3.1.1. Crops (crops.xlsx file)

This file defines the available combinations of crop and CO2 files to be considered for the simulations with AquaCrop-GIS. Any additional combination (crop and CO2 files) could be built adding columns in the crops.xlsx file. Each column in the Excel file defines a combination and must be named correlatively from C0 until CN-1, where N is the number of considered combinations.

All the files included in each column must be available in the “Data” folder. For example for the following crop.xlsx file, MaizeGDD.CRO, CottonGDD.CRO and MaunaLoa.CO2 must be located in the folder C:\AquaCrop-GIS\Data\. Crops and CO2 configuration files are provided by AquaCrop.



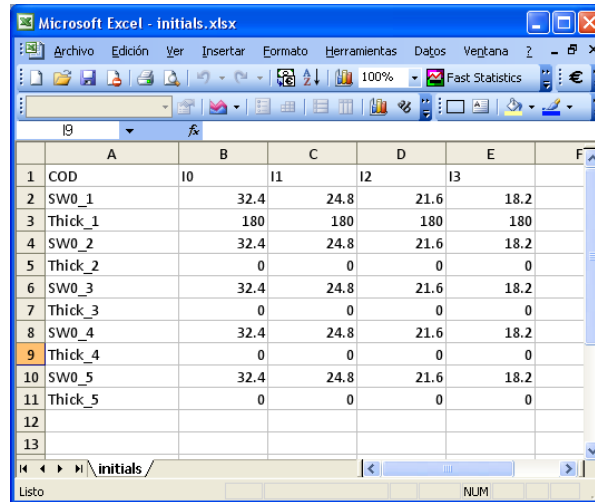
	A	B	C	D	E	F
1	COD	C0	C1			
2	Crop	MaizeGDD	CottonGDD			
3	Atmospheric CO2	MaunaLoa	MaunaLoa			
4						
5						
6						
7						
8						
9						

Fig 1. Crops.xlsx example considering two available combinations

3.1.2. Initial soil water conditions (initials.xlsx file)

This file contains the parameters to build the file *.SW0 required in AquaCrop. This file may include several initial soil water conditions that will be available for AquaCrop-GIS, including one column in the file for each initial condition (using columns labelled from I0 to IN-1 where N is the number of initial conditions). Up a maximum of five soil layers have been considered, and for each one its water content (%) and thickness (cm) must be included. If

there is only information for one layer, the rest of the layers are not considered by setting the thickness layer to zero.



	A	B	C	D	E	F
1	COD	I0	I1	I2	I3	
2	SW0_1	32.4	24.8	21.6	18.2	
3	Thick_1	180	180	180	180	
4	SW0_2	32.4	24.8	21.6	18.2	
5	Thick_2	0	0	0	0	
6	SW0_3	32.4	24.8	21.6	18.2	
7	Thick_3	0	0	0	0	
8	SW0_4	32.4	24.8	21.6	18.2	
9	Thick_4	0	0	0	0	
10	SW0_5	32.4	24.8	21.6	18.2	
11	Thick_5	0	0	0	0	
12						
13						

Fig. 2. Initials.xlsx example considering four available initial soil water conditions

3.1.3. Soil characteristics (soils.xlsx file)

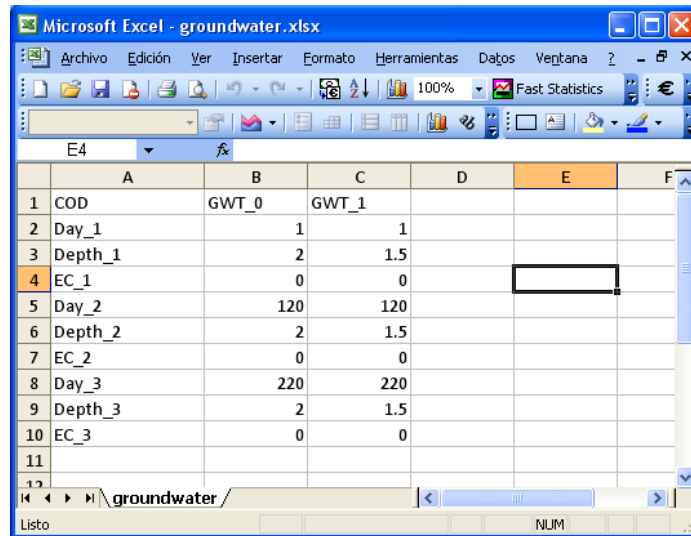
This file contains the parameters to build the file *.SOL required for AquaCrop. This file can include several soil types with their hydraulic characteristics that will be available for running AquaCrop-GIS, including one column in the file for each soil type (using columns labelled from S0 to SN-1 where N is the number of soil types). For each soil, curve number, water readily evaporated (mm), number of horizons and depth restrictions (m) must be included. In addition, up to a maximum of five layers have been considered and for each one, thickness (cm), the water content at saturation (mm), at field capacity (mm) and at wilting point (mm) must be included. If there is only information for one layer the rest of layers are not considered by setting the thickness layer to zero.

	A	B	C	D	E
1	COD	S0	S1		
2	Curve Number	72	65		
3	Readily evap.	10	8		
4	Number horizons	1	1		
5	Depth restric	1.8	1.8		
6	Thick_1	180	180		
7	Sat_1	50	40		
8	FC_1	36	27		
9	WP_1	18	16		
10	Ksat_1	120	500		
11	Thick_2	0	0		
12	Sat_2	50	40		
13	FC_2	36	27		
14	WP_2	18	16		
15	Ksat_2	120	500		
16	Thick_3	0	0		
17	Sat_3	50	40		
18	FC_3	36	27		
19	WP_3	18	16		
20	Ksat_3	120	500		
21	Thick_4	0	0		
22	Sat_4	50	40		
23	FC_4	36	27		
24	WP_4	18	16		
25	Ksat_4	120	500		

Fig. 3. Soils.xlsx example considering two available soil types

3.1.4. Ground water characteristics (groundwater.xlsx file)

This file contains the parameters to build the file *.GWT which is required when the simulations are to be carried out in the presence of a shallow groundwater table. This file can include several groundwater conditions that will be available for AquaCrop-GIS, including one column in the file for each condition (using columns labelled from G0 to GN-1 where N is the number of groundwater conditions). The generated *.GWT files can be of two types: constant depth and water quality (T1 nomenclature in groundwater.xlsx file) or variable depth or water quality (T2 nomenclature in groundwater.xlsx file). For the first case, only the water table depth (T1_Depth; m) and the EC of the water (T1_EC; dS/m) must be indicated. If the depth or water quality is variable during the season, up to a maximum of three dates can be considered and for each one, day (T2_Day; day number after initial day), the water table depth (T2_Depth; m) and EC (T2_EC; dS/m) must be included. In this case, it is also necessary to indicate the considered initial day (T2_Day; T2_Month; and T2_Year). Fields which do not apply, must be labelled with “-999”.



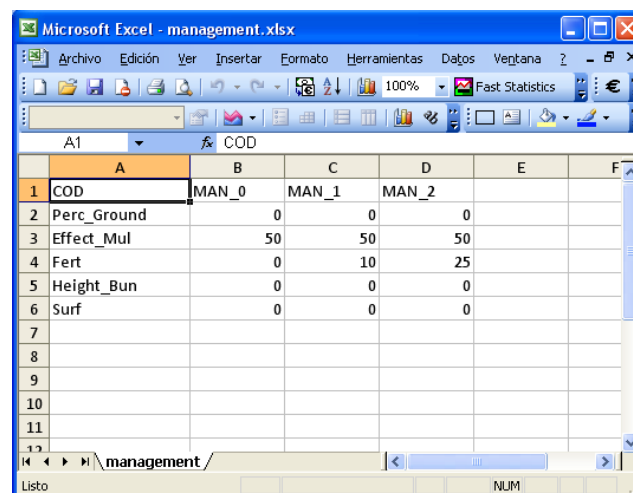
	A	B	C	D	E	F
1	COD	GWT_0	GWT_1			
2	Day_1	1	1			
3	Depth_1	2	1.5			
4	EC_1	0	0			
5	Day_2	120	120			
6	Depth_2	2	1.5			
7	EC_2	0	0			
8	Day_3	220	220			
9	Depth_3	2	1.5			
10	EC_3	0	0			
11						

Fig. 4. Groundwater.xlsx example considering two available groundwater conditions

3.1.5. Crop management (management.xlsx)

This file contains the parameters needed to build the file *.MAN required for AquaCrop model. This file can include several management options that are available in AquaCrop-GIS, including one column in the file for each option (using columns labelled from MAN0 to MANN-1 where N is the number of management options). For each one, percentage of ground surface covered by mulches, the effect of mulches in reduction of evaporation (%), reduction in biomass production caused by limited soil fertility (%), height of soil bunds (m) and surface runoff occurrence (1, surface runoff prevented by field surface practices; 0, surface runoff NOT prevented) must be included.

As the file *.MAN is not required for the execution of AquaCrop, the file management.xlsx file is not necessary to be included in the “Data” folder and then no-management effects would be considered in AquaCrop.



	A	B	C	D	E	F
1	COD	MAN_0	MAN_1	MAN_2		
2	Perc_Ground	0	0	0		
3	Effect_Mul	50	50	50		
4	Fert	0	10	25		
5	Height_Bun	0	0	0		
6	Surf	0	0	0		
7						
8						
9						
10						
11						

Fig. 5. Management.xlsx example considering three management options

3.1.6. Weather data

The weather data is stored in xlsx files and must be located in the “Weather” folder. Each file contains weather data for each weather station (Fig. 6). In this folder numerous files with weather data could be included (for example one for each weather station).

	A	B	C	D	E	F	G	H
	DAY	MONTH	YEAR	TMAX	TMIN	ETo	RAIN	
2	4	3	2013	0.00	0.00	0.00	0.00	
3	5	3	2013	0.00	0.00	0.00	0.00	
4	6	3	2013	0.00	0.00	0.00	0.00	
5	7	3	2013	0.00	0.00	0.00	0.00	
6	8	3	2013	0.00	0.00	0.00	0.00	
7	9	3	2013	0.00	0.00	0.00	0.00	
8	10	3	2013	0.00	0.00	0.00	0.00	
9	11	3	2013	18.20	6.30	3.24	0.00	
10	12	3	2013	15.60	11.10	1.86	2.20	
11	13	3	2013	16.00	9.90	3.27	0.00	
12	14	3	2013	15.90	9.60	3.93	0.00	
13	15	3	2013	16.70	9.00	3.16	0.00	
14	16	3	2013	17.30	9.00	2.30	0.00	
15	17	3	2013	17.80	8.80	1.85	1.00	
16	18	3	2013	20.20	10.20	3.42	0.00	
17	19	3	2013	18.50	8.10	2.68	3.80	
18	20	3	2013	19.30	11.30	3.15	0.00	
19	21	3	2013	18.20	9.50	3.11	0.00	
20	22	3	2013	21.10	7.70	3.59	0.20	
21	23	3	2013	18.80	10.40	2.81	0.40	
22	24	3	2013	18.40	8.10	3.13	0.40	
23	25	3	2013	19.00	10.30	3.29	0.00	
24	26	3	2013	19.60	9.50	2.83	0.00	

Fig. 6. Example of file containing weather data from “RIA0_1” weather station

Each file is composed by seven columns: DAY, MONTH, YEAR, TMAX, TMIN, ETo and RAIN. The weather data must be sorted in consecutive days. AquaCrop-GIS carries out some weather consistency analysis (such as daily maximum temperatures must be higher than daily minimum temperatures) in order to avoid errors in the execution of AquaCrop. ETo refers to reference evapotranspiration.

The weather data included in these files could exceed the analyzed period. AquaCrop-GIS looks for the analyzed period within the whole period of available weather data.

3.1.7. Irrigation files (*.IRR files)

Irrigation files (*.IRR files) include the irrigation scheduling (irrigation schedule mode) or the rules to generate it (determination of net irrigation requirements or schedule generation mode). These files are provided by AquaCrop and must be located in the “Data” folder (for example C:\AquaCrop-GIS\Data\). These files must be named “AquaCrop-GIS” plus a number (“AquaCrop-GIS+n”, e.g. AquaCrop-GIS3) that will be used to identify the irrigation management carried out in each field.

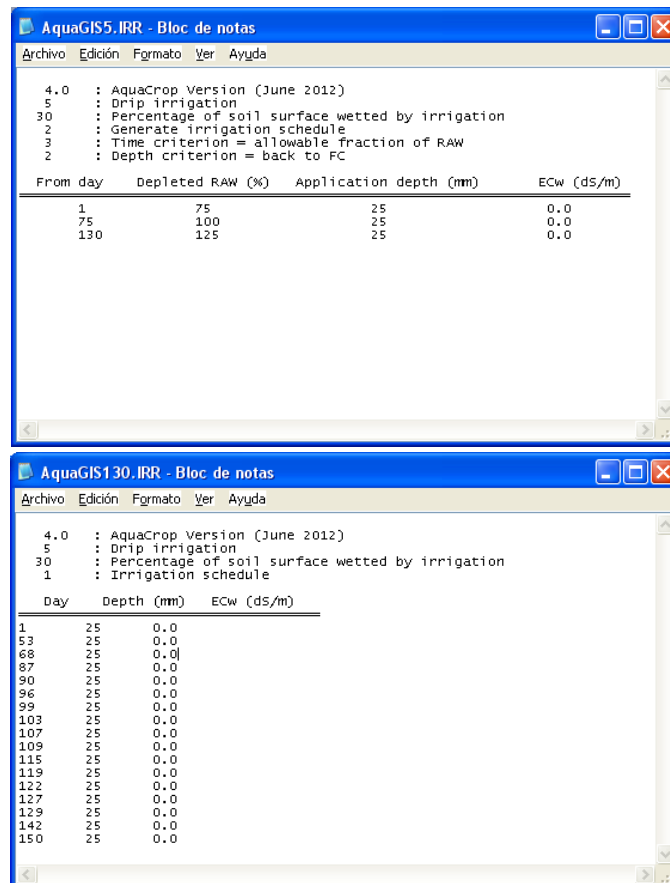


Fig. 7. Two examples of irrigation files defining irrigation scheduling rules (one mode for generation of irrigation schedule) and another that defines the date and volume of irrigation events (irrigation schedule mode).

3.1.8. Control file (batch.xlsx file)

The control file (batch.xlsx file) indicates to AquaCrop-GIS all the possible combinations of inputs for each field. All the analyzed fields are included in the batch.xlsx file in the first column (named WSTA). The following columns indicate the soil characteristics (SOIL column), weather station (WEATHER column), initial soil water conditions (INITIAL column), irrigation (IRRIGATION column), management (MAN column) and groundwater characteristics (GWT column) for each field.

In addition, simulation dates of and the start of the crop cycle are included in columns FIRST_I and FIRST_D, respectively. Similarly, the procedure to calculate the crop development cycle is included in the GDD column. For further explanations about the procedure to calculate the crop development cycle, the AquaCrop Manual describes three methods available to compute developmental time.

AquaCrop-GIS is capable of carrying out a very high number of simulations including the evaluation of different scenarios (S). For instance, AquaCrop-GIS may consider more than one sowing date, different soils or irrigation practices for each field. To consider these alternatives, additional columns for each input type (soil, crop, weather, etc.) can be added. Thus, the different input types are labelled from 0 to S-1, where S is the number of scenarios

considered for each input type. For example in Fig. 8 an example of batch.xlsx file is shown. Here there are two possible scenarios for soil (SOIL_0 and SOIL_1).

The figure consists of two screenshots of a Microsoft Excel spreadsheet named 'batch.xlsx'. The top screenshot shows columns A through N with data for 8 rows. The bottom screenshot shows columns O through V with data for 8 rows.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	WSTA	SOIL_0	SOIL_1	CROP_0	CROP_1	WEATHER_0	FIRST_I_0	FIRST_I_1	FIRST_D_0	FIRST_D_1	INITIAL_0	INITIAL_1	IRRIGATION_0	IRRIGATION_1
2	101	0	1	0	1	ria0_1.xlsx	19_03	16_04	20_03	17_04	0	1	1	2
3	102	0	1	0	1	ria0_1.xlsx	19_03	16_04	20_03	17_04	0	1	1	2
4	103	0	1	0	1	ria0_1.xlsx	19_03	16_04	20_03	17_04	0	1	1	2
5	104	0	1	0	1	ria0_1.xlsx	19_03	16_04	20_03	17_04	0	1	1	2
6	105	0	1	0	1	ria0_1.xlsx	19_03	16_04	20_03	17_04	0	1	1	2
7	106	0	1	0	1	ria0_1.xlsx	19_03	16_04	20_03	17_04	0	1	1	2
8	107	0	1	0	1	ria0_1.xlsx	19_03	16_04	20_03	17_04	0	1	1	2

	O	P	Q	R	S	T	U	V
1	GDD_0	GDD_1	GDD_2	MAN_0	GWT_0			
2	1	2	3	1	0			
3	1	2	3	2	0			
4	1	2	3	1	0			
5	1	2	3	2	0			
6	1	2	3	1	1			
7	1	2	3	2	1			
8	1	2	3	1	1			

Fig. 8. Example of batch.xlsx file

For all input types at least one column must be included in the batch file. Finally, the order of the names cannot be changed from the original batch.xlsx file.

The content of each column is described in detail below:

- **WSTA:** Indicates the identification code of each field. This value will be used for the connection of the alphanumeric database with the Geographic Information System. This code must be unique for each field.
- **SOIL_S (where S is the simulation code):** Indicates for each field the soil type described in the *soils.xlsx* file (for example 0 indicates that the soil type is that described in the column S0 in the *soils.xlsx* file).
- **CROP_S (where S is the simulation code):** Indicates for each field the crop described in the *crops.xlsx* file (for example, 0 indicates that the crop is the one described in the column C0 in the *crops.xlsx* file).
- **INITIAL_S (where S is the simulation code):** Indicates for each field the initial conditions described in the *initials.xlsx* file (for example 0 indicates that the initial conditions are those described in the column I0 in the *initials.xlsx* file).
- **MAN_S (where S is the simulation code):** Indicates for each field the management described in the *management.xlsx* file (for example 0 indicates that the management is the one described in the column MAN_0 in the *management.xlsx* file).
- **GWT_S (where S is the simulation code):** Indicates for each field the groundwater conditions described in the *groundwater.xlsx* file (for example 0 indicates that the

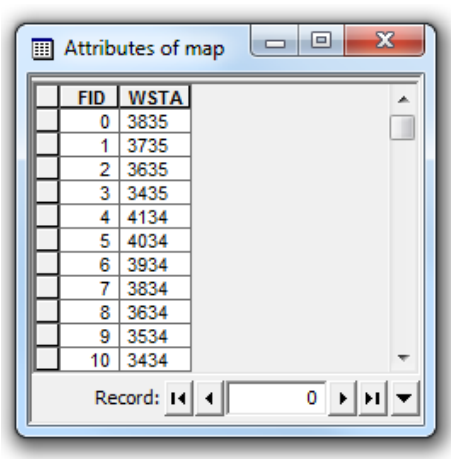
groundwater conditions are those described in the column GWT_0 in the groundwater.xlsx file).

- WEATHER_S (where S is the simulation code): For each field, the weather file used (including the .xlsx extension) is included here. The filename is not case sensitive.
- FIRST_I_S (where S is the simulation code): Uses the format dd_mm (day and month), the date when AquaCrop initializes the simulation period, ie. the first day of the simulation period, is indicated.
- FIRST_D_S (where S is the simulation code): Uses the format dd_mm (day and month), the date when AquaCrop initializes the crop, ie. the first day of the crop cycle or sowing date, is indicated.
- IRRIGATION_S (where S is the simulation code): For each field the file describing the irrigation management is indicated here. If 0 is included here, it implies that this field is not irrigated (rainfed conditions). A number higher than 0 indicates the name of the irrigation file, i.e. AquaCrop-GISN.IRR where N is the number indicated for each field). For example, if number 2 is written, AquaCrop-GIS2.IRR irrigation file will be considered.

3.2. Graphical information (Shape files)

The Geographic Information System (GIS) is composed by three files (.shp file, .shx file and dbf file). The graphical information must be stored in a ShapeFile (.shp) named *map.shp* and located in the “Data” folder (for example C:\AquaCrop-GIS\Data\). This file must follow the WGS 1984 standard with geographic coordinates (EPSG code 4326).

In order to associate each polygon with the alphanumerical inputs (see previous sections) a common column with the batch.xlsx file is required. That column is named WSTA and that information must be included in a file called map.dbf and located in the “Data” folder. The values included in this column (WSTA) should not be repeated. This file could include additional information (columns) but WSTA is mandatory.



FID	WSTA
0	3835
1	3735
2	3635
3	3435
4	4134
5	4034
6	3934
7	3834
8	3634
9	3534
10	3434

Record: 0

Fig. 9. Example of Dbf file indicating the WSTA code for each field.

AquaCrop-GIS does not require the GIS files to generate the simulations indicated in the batch.xlsx file. In these cases the GIS option will not be available.

4. Using AquaCrop-GIS

4.1. Running requisites

Before executing AquaCrop-GIS, one must ensure that all input files are closed. Executing AquaCrop-GIS without closing all the files will generate an execution error.

4.2. Introduction

A welcome screen will appear when AquaCrop-GIS is open. In the *About* screen, information is available about the authors and some bibliography on AquaCrop and AquaCrop-GIS. From this page the user can decide to continue with AquaCrop-GIS or exit.

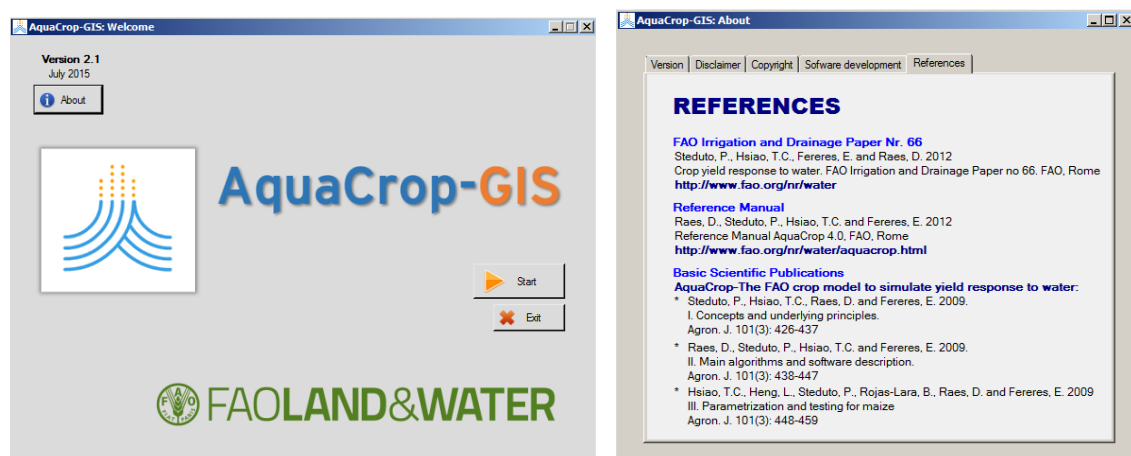


Fig. 10. Initial page of AquaCrop-GIS and page with references for information on AquaCrop and AquaCrop-GIS

4.3. Main window

The main window (Fig. 11) indicate the simulations that AquaCrop-GIS will carry out and is based on the batch.xlsx file previously described. All the columns included in this file, will appear in the main window of AquaCrop-GIS. In this window, all the available options for the user are described as:

Batch ID: AquaCrop-GIS allows carrying out different simulations. To identify them in this field, an identification of the current simulation can be added. This specific identification will be included in all the results obtained by AquaCrop-GIS, allowing to analyze and to compare the results provided by different simulations.

From – to: Here the period of simulation is included. The years refer to the beginning of the simulation period, not to the harvest year (that could be the same or not). AquaCrop-GIS analyzes the weather files indicated in the batch.xlsx file and extracts the available years to do the simulations. Thus, AquaCrop-GIS updates the default years in both fields, although these could be easily modified by the user.

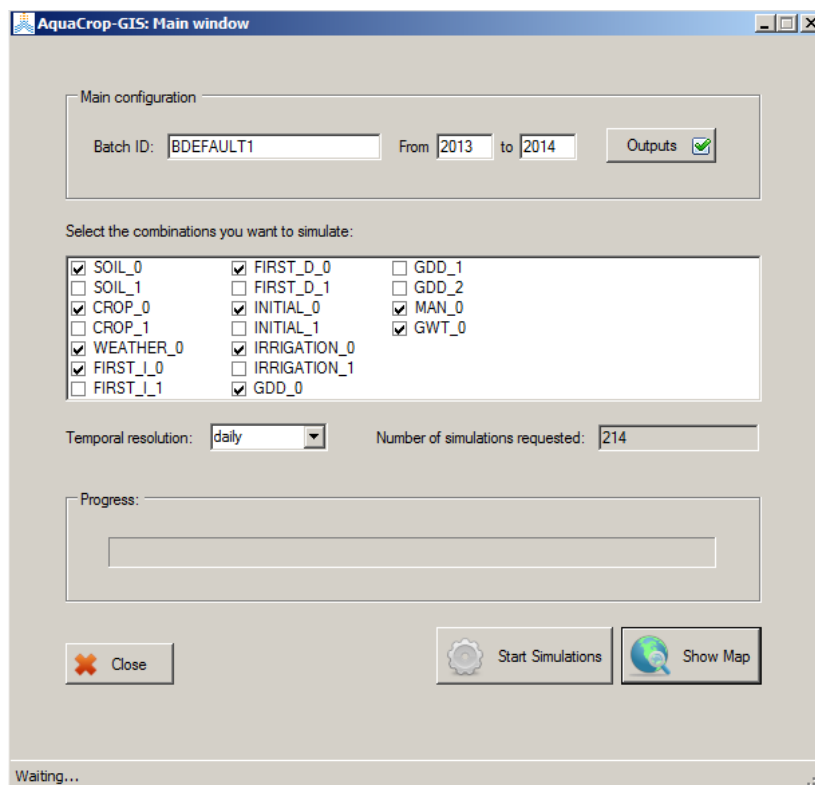


Fig. 11. Main window of AquaCrop-GIS, indicating the available combinations based on batch.xlsx file (see Fig. 8).

Outputs: With this option, the user can determine those output files that AquaCrop-GIS will generate. Fig. 12 shows the windows with the outputs configuration tool.

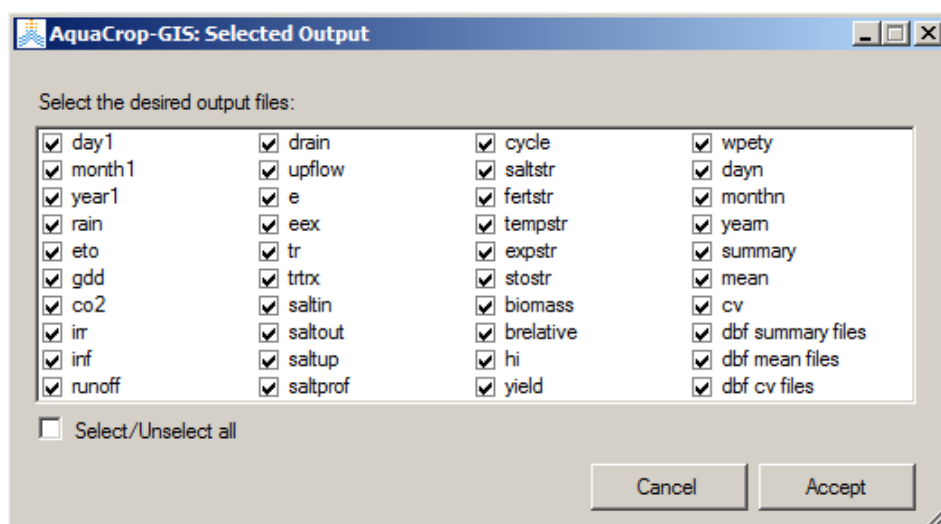


Fig. 12. Selection of output files

In this window the user can check or uncheck any result file (except summary, mean and cv –the coefficient of variation- that are mandatory), in order to indicate to AquaCrop-GIS if the output files will be generated or not. When the number of required simulations is very high, unchecking those files that are not necessary reduces significantly the computation time required by AquaCrop-GIS.

Any change done in the configuration window is stored for future executions of the program (this option can be undone by restoring the configuration or by deleting the file *selected_output.txt* in the “Data” folder).

Selected combinations: With this box, the user can choose which combinations, from those previously included at *batch.xlsx*, will be simulated using AquaCrop-GIS. By default, only the first combination (*_0) for each component is checked although the selected combinations are editable by the user. Thus, for example in Fig. 11 all the combinations included in the *batch.xlsx* file (Fig. 8) are available for simulation.

As a result of the selected combinations, AquaCrop-GIS calculates the total number of simulations that will be carried out.

Temporal resolution: AquaCrop provides the simulation outputs at daily scale or with different level of aggregation (annual, monthly, and 10-daily). In this section the user can select the temporal resolution of the outputs: daily, 10-daily and monthly. The daily scale is taken as the default option in the current version of AquaCrop-GIS.

Progress bar: This indicator describes the evolution of the different processing steps carry out by AquaCrop-GIS

Start simulations: Prior to starting the simulation process, AquaCrop-GIS evaluates that all the files and dates are correct. If everything is correct, AquaCrop-GIS launches the selected simulations.

Show Map: A Geographic Information System with the results obtained by AquaCrop-GIS is displayed in this window. The visualization tool is described in the following sections. The graphical information is the one added by the user through the GIS files (map.shp, map.shx and map.dbf). This button will only be enabled when some results are available.

Status bar: In this section the status of the program is shown, indicating the action that AquaCrop-GIS is currently performing. If there are some errors or misconfigurations in the simulation process, warning messages will be reported here.

4.4. Simulation process

When the *Start Simulations* button is pressed, input files will be read, simulation files will be prepared and the progress bar will indicate the development of several steps (simulation progress and results creation progress). If everything is correct, in the process bar “the *Process completed!*” message will be displayed. All the results (outputs) are stored in the “Results” folder (for example C:\AquaCrop-GIS\Results\) and the visualization tool is enabled.

If some errors are detected, warning messages are displayed at the information bar, and the simulation would be stopped. For example, if erroneous data are found, a warning message such as “*Erroneous data (tmax) at: ria0_1.xlsx (line 14)*” will be displayed.

AquaCrop-GIS is programmed to detect also processing errors of AquaCrop model. Some examples of these errors are displayed here:

- AquaCrop could display errors in external windows such as “*Floating point division by zero.*” or “*Invalid floating point operation.*”. In these cases AquaCrop-GIS close these windows, the specific simulation affected by the error is skipped and the process will continue. An example of an error window can be seen at Fig. 13.

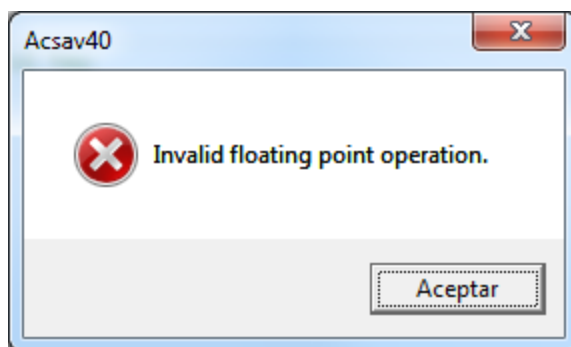


Fig. 13. External window generated by AquaCrop

- In other cases unknown errors could happen and then AquaCrop-GIS waits 5 seconds to check if AquaCrop is simulating, and if not, the specific simulation is skipped and the simulation continues.

The management and configuration of the AquaCrop-GIS / AquaCrop processing errors are included in the file *skip_errors.txt* located at the “Data” folder. An example of this file is shown here:

```
CLOSE_WHEN=Message from the window to close.
WAITING_SECONDS=3
```

To modify the *skip_errors.txt* will change the AquaCrop-GIS behaviour when a processing errors in detected. If an error window appears and shows the message described at the line “*CLOSE_WHEN*”, it will be automatically closed without waiting. If an unknown error window appears, AquaCrop-GIS will wait time indicated in the line “*WAITING_SECONDS*” instead of the default of 5 seconds. The *skip_errors.txt* file can describe the two variables or just one.

After dealing with any of those errors, AquaCrop-GIS will continue the execution ignoring the erroneous simulations. This situation will be indicated with a message as “*Process completed with some errors. View BDEFAULT1_warnings.txt*”. Those warnings files will be stored in the “Results” folder containing information about the skipped simulations.

4.5. Viewer of the Geographic Information System

When the viewer of the Geographic Information System developed by AquaCrop-GIS is open, the map included in the *maps.shp* file will be displayed (Fig. 14).

In order to indicate which information (results) will be displayed (on the map previously described), a menu has been created. The menu is located on the first row and is labeled as “Source”:

- **ID:** Indicates the simulation results that the user wants to display. The available names coincide with previous simulations (See *batch_ID* in Fig. 11).
- **Soil / Crop / Weath / FirstI / FirstD / Initial / Irrig. / GDD / Man / Gwt:** The user select the previously simulated combinations (indicated in the main window previously described in Fig. 11) for Soil, Crop, Weather, Initial simulation date, Initial cropping date, Initials conditions, Irrigation, Management and Groundwater characteristics respectively. The “*Selected column combination*” box (located just below the source line) will summarize the selected combinations that will be displayed.
- **Info:** Indicates the results obtained for a specific year, the mean results and variability (using the coefficient of variation; cv) results.
- **Field:** Indicates the variable that user wants to display.

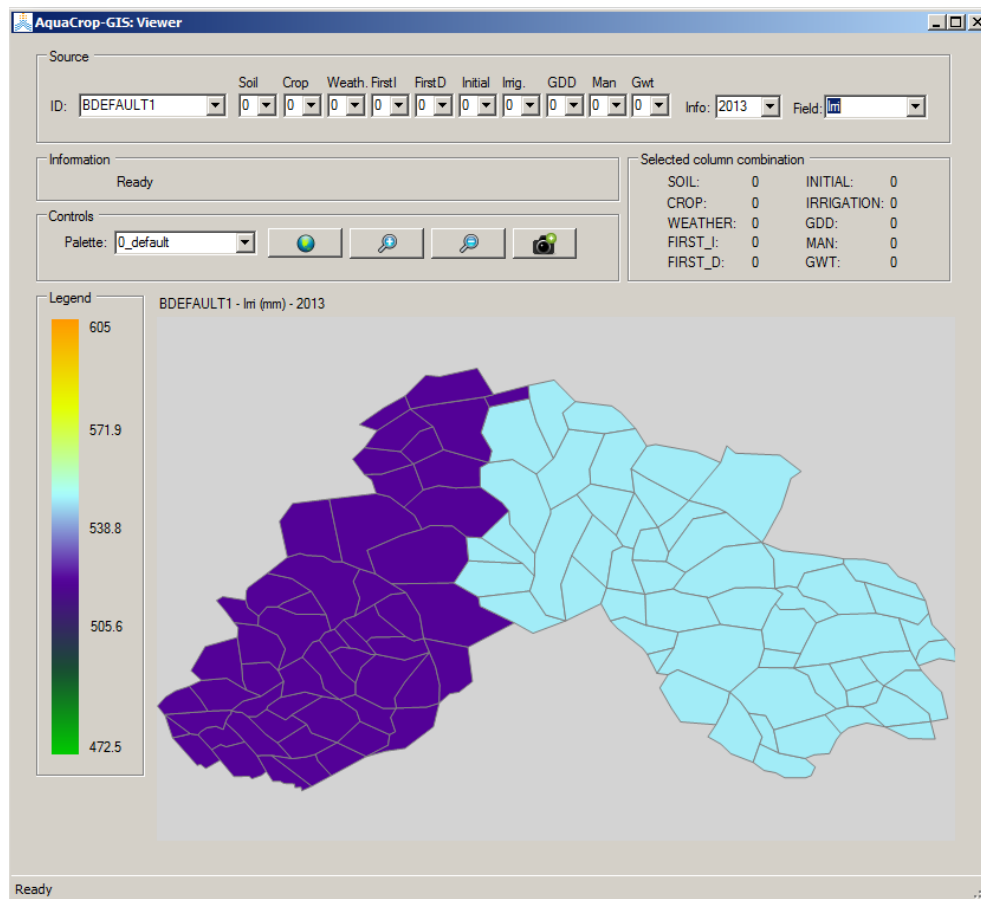





Fig. 14. Example of viewer showing the GIS

The Information box is located below Source line and will display several information messages.


In the Control box some tools for visualization are included:

 It will fit the figure to the screen.

 Zoom in.

 Zoom out.

The two previous actions can be also done with the mouse wheel when placing the cursor over the map. The mouse may be used for also dragging the map. In addition, when the mouse is pressed the longitude and latitude will be shown.

 A picture with the most important information showed in the screen will be generated. This picture will be saved at the "Print folder".

Finally, the colors describing the results in the GIS can be selected by a palette. AquaCrop-GIS will load all the palettes available in the “*Palettes*” folder. The user can remove, add or create new palettes. An example of a palette is shown in Fig. 15.

The first column indicates the percentage of the data value range that will be associated with the color indicated by the other three columns (Red, Green, Blue with values between 0 and 100). The rest of percentages are interpolated automatically by AquaCrop-GIS. A minimum of two rows is required (0 and 100 %) and there is no maximum number of rows.

0.0	80.0	0.0	100.0
10.0	30.0	20.0	100.0
33.0	0.0	60.0	30.0
66.0	100.0	100.0	0.0
90.0	100.0	0.0	0.0
100.0	60.0	0.0	0.0

Fig. 15. Content of a palette file

4.6. AquaCrop outputs files (*.xlsx files)

In addition to using the previously described GIS to explore and analyze the simulation results, all the generated results are stored in spreadsheet files located in the “*Results*” folder. The name of the output files is: “*BATCH_ID*” + variable or info + “.xlsx”.

For every simulation, “*BATCH_ID*” + mean.xlsx, “*BATCH_ID*” + cv.xlsx and “*BATCH_ID*” + summary.xlsx will be created. If the selected aggregation is different than *none*, then files for each selected variable (see main window section) will be created.

The structure of any Result file is shown in Fig. 16.

	A	B	C	D	E	F	G	H	I	
1	DAY	MONTH	P101S1C1	P102S1C1	P103S1C1	P104S1C1	P105S1C1	P106S1C1	P107S1C1	P108S1C1
2	19	3	100	100	100	100	100	100	100	100
3	20	3	90	90	90	90	90	90	90	90
4	21	3	99	99	99	99	99	99	99	99
5	22	3	86	86	86	86	86	86	86	86
6	23	3	85	85	85	85	85	85	85	85
7	24	3	87	87	87	87	87	87	87	87
8	25	3	100	100	100	100	100	100	100	100
9	26	3	92	92	92	92	92	92	92	92
10	27	3	91	91	91	91	91	91	91	91
11	28	3	71	71	71	71	71	71	71	71
12	29	3	61	61	61	61	61	61	61	61

Fig. 16. Example of an output file

In the output files each column represents a simulation, identified by its header indicating the selected soil, crop, etc. Each row represents a time slice depending on the selected aggregation (daily, every 10 days or monthly).

4.7. AquaCrop-GIS graphical outputs

AquaCrop-GIS generates graphical outputs of the results using dBase files to be displayed into a GIS environment. For each simulation, dBase files (mean, CV and summary data) will be generated and stored in the “Database” folder (within the “Results” folder). In order to use this information with an external GIS, the user has to follow these instructions:

- Choose a folder
- Copy the original map.shp and map.shx files (located in the “Data” folder) to the selected folder
- Copy the generated map.dbf file to the selected folder
- Open the map with your GIS tool

4.8. Cleaning up

If the user wants to reset the AquaCrop-GIS by removing everything done before, a script called *delete_files.bat* is provided. This script will erase any result of previous simulations and configurations.

The user must use this option carefully as all the results located in the indicated folders will be deleted and this operation cannot be undone.

5. References

Lorite IJ, García-Vila M, Santos C, Ruiz-Ramos M, Fereres E (2013) AquaData and AquaCrop-GIS: Two computer utilities for temporal and spatial simulations of water-limited yield with AquaCrop. *Computers and Electronics in Agriculture* 96: 227-237.