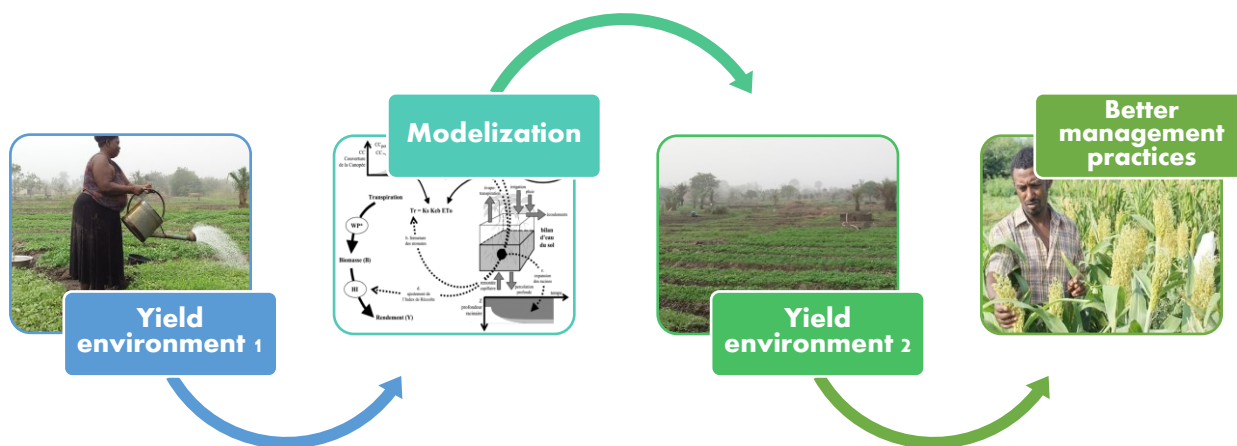




**Improving Agricultural Resilience to Salinity Through the Development and Promotion of Pro-Poor Technologies**

## **AquaCrop Model, Crop Modeling, and Management Decision Support Tool: Getting Started & Weather and Soil Data Collection**



# **AquaCrop Model, Crop Modeling, and Management Decision Support Tool: Getting Started**

## **& Weather and Soil Data Collection**

*Climate based on satellite data from “power.larc.nasa.gov/data”*

*Soil Water Characteristics software*

**Activity 4.3: Proposal of optimal irrigation and drainage allocation in irrigated areas  
based on soil-water-plant modeling and ground-truthing**

*Application of water allocation and management models*

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*Submitted September 2022*

**RESADE project**

**Activity 4.3: Proposal of optimal irrigation and drainage allocation in irrigated areas  
based on soil-water-plant modeling and ground-truthing**



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## 1. Introduction

The world food supply is affected by environmental stresses, which can cause up to 70% yield losses in food crops (Thakur et al., 2010; Nitin et al., 2012). Notably, in sub-Saharan Africa, we can confirm that seasonal water scarcity already affects food production. The climate is characterized by a unimodal rainfall distribution and two marked seasons: a rainy season and a dry season, in which rain is less than the quantity required for crop cultivation. In many locations, the current rainfall patterns do not provide enough rainfall that can adequately be used for agriculture. Therefore, despite the high water availability in some locations, most of the food requirements for sub-Saharan African countries are met through imports.

In some areas, water resources for irrigation, when available, are saline. Globally, salinity affects one-fifth of the world's irrigated lands. It is estimated that high salinity adversely damages large new irrigated lands (UNU-INWEH, 2014). The increasing economic penalties, which are about USD 27.3 billion per year, are largely explained by the decrease in crop yield (Qadir et al., 2014).

In sub-Saharan Africa (SSA), salinity affects 19.09 million hectares of land. Salinity in SSA is predominantly caused by inappropriate irrigation practices that result in waterlogging as well as by seawater intrusion into coastal farming areas because of the rising sea levels associated with climate change and over-pumping. In addition, the impacts of salinity are exacerbated by climate change mainly through the increase in global temperatures and decreased rainfall. Moreover, the expansion of area affected by salinity effectively diminishes the amount of arable land.

Because of this, it is imperative to introduce high-yielding, tolerant, and resilient crops, besides improving crop management practices to maintain a sustainable production system under marginal environments. The successful future development of agriculture in these environments mostly rests on

- ✓ Assessing new genetic resources.
- ✓ Developing and promoting the best farming practices, particularly water use requirements, fertilizer, and disease control for the new proposed crops.
- ✓ Better processing and marketing of products.

The Improving Agricultural Resilience to Salinity Through the Development and Promotion of Pro-Poor Technologies (RESADE) project is implemented by the International Center for Biosaline Agriculture (ICBA) in partnership with the International Fund for Agricultural Development (IFAD) and the Arab Bank for Economic Development in Africa (BADEA). The project will provide technical solutions in seven SSA countries in which salinization of agricultural land is a growing problem: The Gambia, Liberia, Sierra Leone, and Togo in Western Africa and Botswana, Mozambique, and Namibia in Southern Africa. The RESADE project aims to improve food security and diminish poverty among poor smallholder farmers, especially women, in areas affected by salinity in those seven countries. The objective is to increase agricultural productivity and income in agricultural areas affected by salinity by (i) introducing salt-tolerant crops and best agronomic management practices, (ii) developing value chains for the systems of crops introduced, and (iii) strengthening the capacities of farmers and extension agents in salinity-resistant and climate-smart agriculture in collaboration with the national agricultural research and extension systems (NARES).

The RESADE countries in West Africa have a tropical climate with a rainfall distribution pattern in two seasons, rainy and dry. They have an extensive hydrographic system that covers all their territory (Figure 1).

**Liberia** has six principal river basins, although smaller rivers and streams can be distinguished. These rivers empty into the Atlantic Ocean to the south, leading to frequent sea intrusion and salinization

of freshwater resources in coastal regions (LINC, 2013). Thus, Liberia has no shortage of water resources for agricultural development. Furthermore, although an estimated 600,000 hectares of land with irrigation potential exist, less than 1% of the land is under irrigation (LNRDS, 2012). Rice and cassava have for a while been the major staples. Although rice is highly consumed, it is imported on a large scale. Enhancing agricultural activities is possible given the fertile soil, good climatic conditions, adequate arable land, and abundant water resources. However, less than 5% of the land is under permanent cultivation and less than 1% is irrigated (Central Agricultural Research Institute).

**Togo** has an extensive hydrographic system that covers the whole country. The hydrographic system has three main basins: Volta, Mono, and Lac Togo. These three water basins cover the five administrative regions. Agriculture is the most critical sector in Togo and contributes 40% of GDP (Institut Togolais de Recherche Agronomique). It employs two-thirds of the active population, who work on small land areas (0.5 ha).

Food crops represent two-thirds of production and are mainly used for domestic consumption. Togo grows both cash crops and food crops. Indeed, 44% of the cultivated land is used for food crops, mainly maize, rice, millet, sorghum, yam, cassava, peanut, bean, and vegetable, cultivated during the rainy season. Meanwhile, 15% of the cultivated land is used for cash crops, mainly cotton, coffee, cocoa, and cashew.

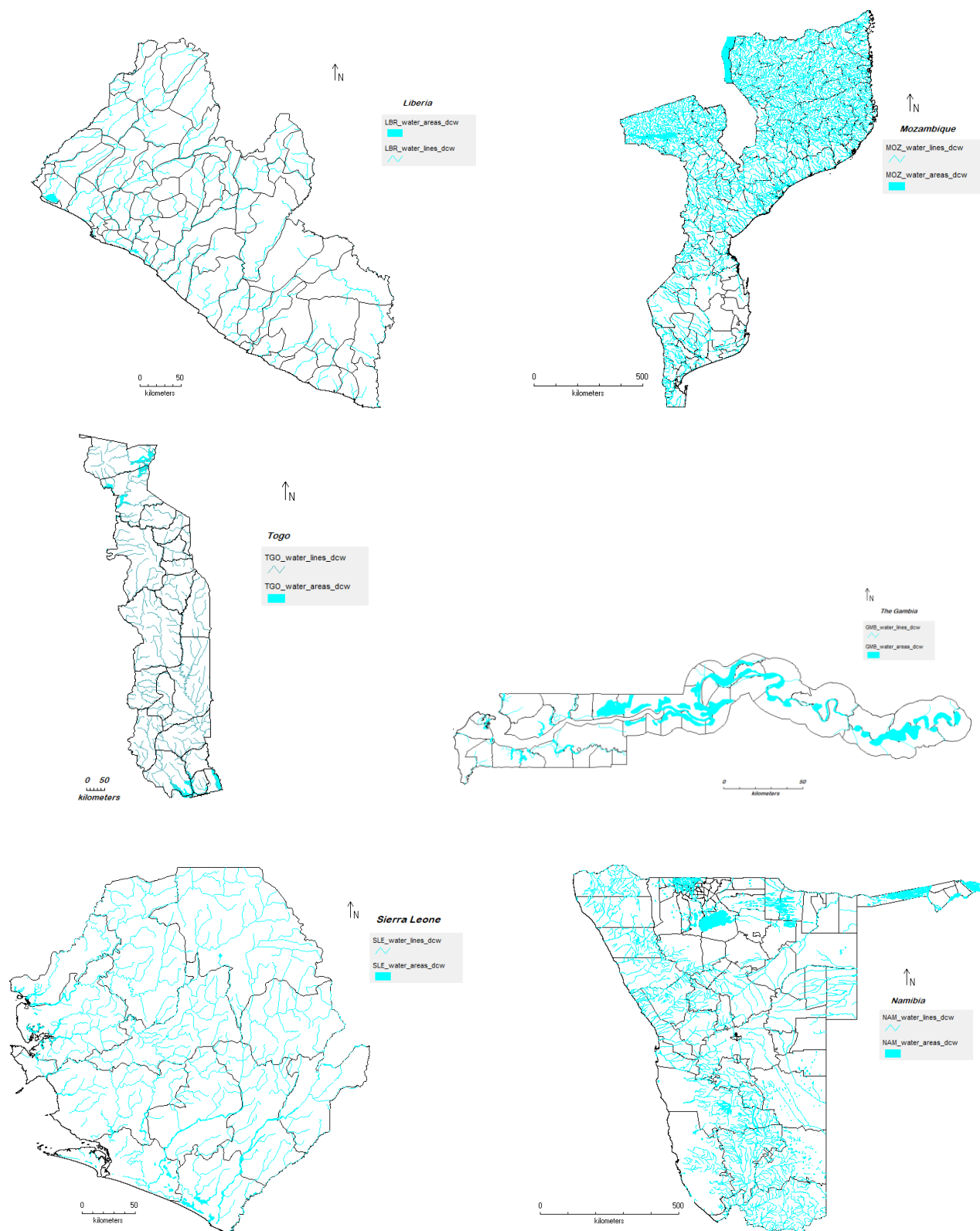
**Sierra Leone** is endowed with abundant rainfall, averaging 2,000 to 4,000 mm annually (Sierra Leone Agricultural Research Institute). Seven main rivers run across the country. These rivers cascade the country and give it huge potential for irrigation. Sierra Leone's irrigation potential was estimated at 807,000 ha in 1981 (FAO, 1990). The total river catchment area ranges from 720 km<sup>2</sup> to 14,140 km<sup>2</sup>. Despite the total water potential, only an estimated 0.3 km<sup>3</sup>/year is used mainly for agricultural activities (MAFFS-MFMR, 2004), given the absence of a national strategy to use surplus annual rainfall for extending the growing season.

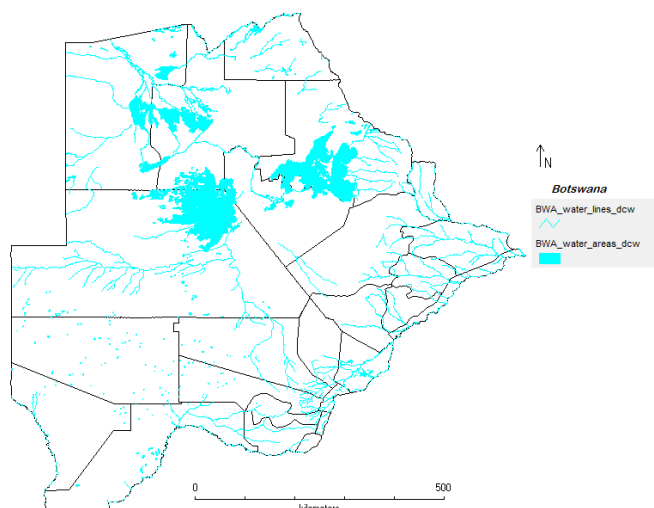
**Mozambique** has abundant water resources for irrigation development. Of the 3.3 million ha of land, only 50,000 ha are currently used because of limited water management infrastructure. Moreover, 60% of the irrigated land is used for the commercial production of sugarcane. The major food crops in Mozambique are maize, sorghum, millet, rice, cassava, vegetables, and fruits, and the major cash crops are sesame, cotton, tobacco, pigeon pea, tea, sugar, and cashew.

For **The Gambia**, the land area is approximately 400 km long and 30 km wide on both sides of Gambia's river. However, the river water resources are divided into fresh, brackish, and salty water, respectively, from inland to the Atlantic ocean (National Agricultural Research Institute). The Gambia's climate is semi-arid, with only one rainy season and the remaining dry period of 7 to 9 months.

**Botswana's** water sources consist primarily of surface water (in rivers, pans and dams of various sizes) and underground water in aquifers some of which are of a fossil nature with no recharge. Of the eight dams, Dikgatlong is the largest with a capacity of 400Mm<sup>3</sup>. All of Botswana's perennial rivers are shared with neighboring countries. The shared river-basins are Okavango, Zambezi, Orange-Senqu and Shashe-Limpopo. Botswana's storage capacity is one of the lowest in the region, owing to its flat topography (source: Water Policy Brief Reflecting on the Challenges of Attaining a ...<https://sustainabledevelopment.un.org>)

Botswana is one of the countries faced with water scarcity. The key geographical features of low rainfalls and semi-arid conditions contribute to the scarcity of water resources in the country (Tshabatau, M, 2020).





**Figure 1.** The hydrographic system: the geographic distribution of water area, lines, and rivers in Botswana, The Gambia, Liberia, Mozambique, Namibia, Sierra Leone, and Togo.

*DIVA-GIS software (version 7.5) obtained from the DIVA-GIS website (<http://www.diva-gis.org>) was used to create the maps.*

## 2. Soil-water-plant modeling

Crop simulation models are made up of mathematical algorithms that describe crop-soil interaction. They can be viewed in two ways. The first is that a crop model can be considered as a system of a set of equations that describe the dynamics of the crop-soil system. The second is that of the model that can be considered as a set of equations for answers of interest based on explanatory variables (Wallach et al., 2006).

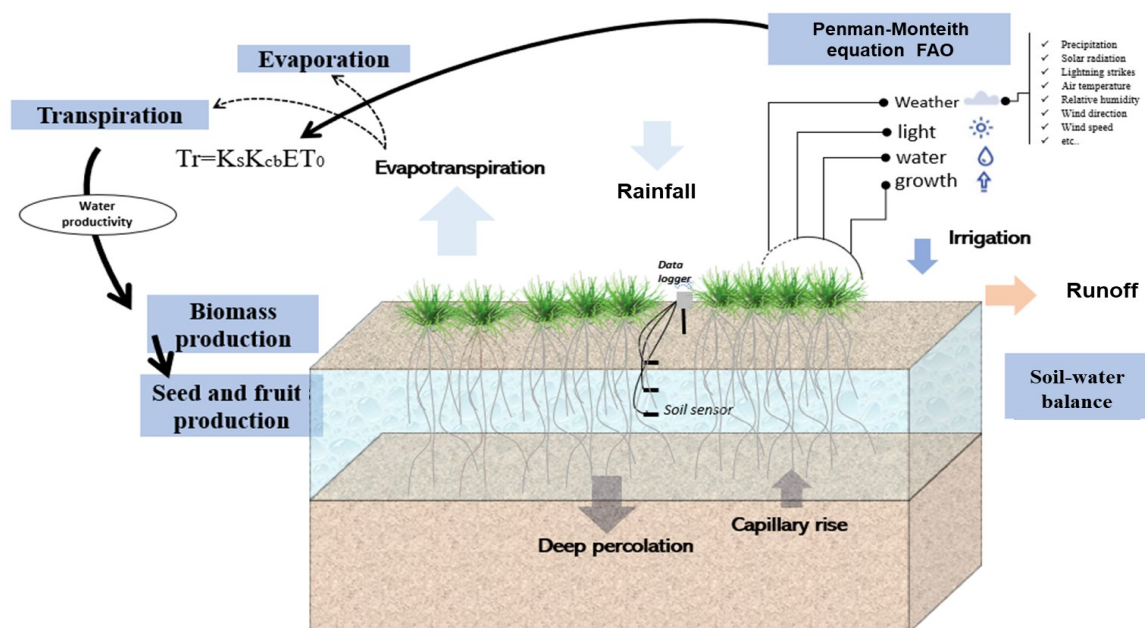
These types of dynamic models are widely used to represent agronomic or plant-breeding systems. Crop yield models are important in predicting crop yields and they assist in making decisions that optimize production even under changing climatic conditions (Adeboye et al., 2017).

Brisson et al. (1998) reported that the majority of crop models estimate crop response primarily to applied technical packages (e.g., water regime, mineral intake, and water quality), plant factors (e.g., species, varieties, and sensitivity of growth to stress), and the environment (e.g., climate, air pollution, soil texture, and climate change).

Several models were used to simulate the effect of salinity on the development and final yield of several crops as well as to estimate the crop water requirement. Verma et al. (2012) evaluated the SWAP model for simulation of the growth of wheat according to salinity profiles and root zone dynamics under various irrigation combinations with fresh water and saline solution (i.e., EC 6, 8, and 12 dS/m). The model was calibrated and validated from 2000 to 2003. The SWAP model observed and simulated values for relative yields ranging in absolute spreads from 4.2% to 9.7%. The validated model was then used to illustrate the consequences of long-term saltwater use on crop growth. The simulated results showed that more than 80% yield potential could be maintained by using saltwater up to 8 dS/m, which helps to overcome salt accumulation.

AquaCrop was selected because of its reliability and ability to estimate yield under saline stress (soil salinity). AquaCrop simulates crop yield responses to water and is particularly suitable for regions where water is the main limiting factor of agricultural production. The model evolved from the concepts of crop yield response to water developed by Doorenbos and Kassam (1979), with input variables requiring simple calculation methods (Steduto et al., 2009). Moreover, the model highlights the fundamental processes involved in crop productivity and responses to water deficits from both a

physiological and agronomic point of view. Crop growth and development simulations are run at daily intervals, using either thermal time (i.e., growth degree-days) or calendar days. Several researchers worldwide have tested AquaCrop's ability to simulate yields of different crops in diverse environments, and all have reported positive results, including, for example, barley (*Hordeum vulgare* L.) (Araya et al., 2010a), teff (*Eragrostis tef* L.) (Araya et al., 2010), cotton (*Gossypium hirsutum* L.) (Baumhardt et al., 2009), maize (*Zea mays* L.) (Heng et al., 2009), and wheat (*Triticum aestivum* L.) (Andarzian et al., 2011). Meanwhile, the application of AquaCrop to saline conditions is not yet well reported, although saline soils are prevalent in irrigated areas of semi-arid and arid environments. This document provides information on how to evaluate the model's performance, simulate crop production growth, and estimate crop water requirements and irrigation requirements under salinity conditions in different agroecosystems (Figure 2).



**Figure 2.** The soil-plant-atmosphere model considered in the present modeling exercise.

### 3. General introduction: AquaCrop model

AquaCrop can be used as a planning, research, or decision support tool for irrigated and rainfed agriculture. According to Raes et al. (2017), the model is beneficial for

- ✓ Developing irrigation strategies in normal and water-deficit conditions
- ✓ Irrigation scheduling
- ✓ Water productivity
- ✓ Studying the effect on yield of location, type of soil, and date of sowing
- ✓ Studying the effect of different land management techniques on yield
- ✓ Comparing the actual and optimal yield on a plot, perimeter, or region to identify constraints that limit crop production and water productivity
- ✓ Predicting the impacts of climate change on agricultural production
- ✓ Simulating scenarios for planning by economists, administrators, and water managers

AquaCrop is a simulation model for crop water productivity developed by FAO. It simulates the response of crop yields to water. Therefore, it is particularly suitable for regions where water is the main limiting factor in agricultural production. The model highlights the fundamental processes



involved in crop productivity and responses to water deficits from both a physiological and agronomic point of view. Furthermore, it considers simple methods for their calculation using a minimum of input variables (Hsiao et al., 2009; Steduto et al., 2009).

In addition, the solid predictability of the AquaCrop model under rainfed and irrigated conditions for different crops under various agro-climatic conditions has been observed by several researchers around the world (Heng et al., 2009; Iqbal et al., 2010; Abedinpour et al., 2012; Araya et al., 2010; Stricevic et al., 2011; Hsiao et al., 2009; Hussein et al., 2011; Sghaier, 2014) and some with a particular interest in arid and semi-arid areas (Salemi et al., 2011, El Mokh et al., 2016). Furthermore, the salinity module of the AquaCrop model (v4.0) was released in June 2012 to simulate crop growth and yield in a saline environment. Following this publication, several authors used the model to estimate yield under saline stress (Kumar et al., 2014; Mondal et al., 2015).

### 3.1. Description of the AquaCrop model

With AquaCrop, soil, crop, and atmosphere are considered as a continuum and processes that involve the water balance and plant growth, development, and yield processes, along with the atmosphere together with its thermal regime, precipitation, evaporation demand, and carbon dioxide (CO<sub>2</sub>) concentration. Aspects of crop management such as irrigation and soil fertilization are also considered. The AquaCrop model is based on the relationships between relative yield and relative evapotranspiration (Doorenbos and Kassam, 1979), as follows:

$$\frac{Y_x - Y_a}{Y_x} = K_y \left( \frac{ET_x - ET_a}{ET_x} \right)$$

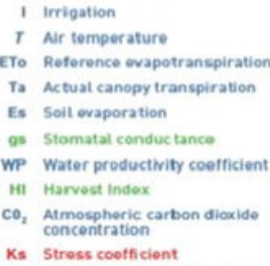
*In this formula,  $Y_x$  is the maximum yield and  $Y_a$  is the actual yield,  $ET_x$  is the maximum evapotranspiration,  $ET_a$  is the actual evapotranspiration, and  $K_y$  is the yield response factor between the relative decrease in yield and the relative decrease in evapotranspiration.*

The AquaCrop model simulates the water content of the soil in the rhizosphere based on the inlet and outlet of water. It is a tool for irrigation management and efficient water use (Raes et al., 2009). The concept, aspects, and basis of the model were described by Steduto et al. (2009) and the use of the model was explained by Raes et al. (2006).

The AquaCrop model avoids the confusion of the effect of unproductive water use on yield by separating evapotranspiration (ET) into crop transpiration (T) and soil evaporation I (Figure 3):

$$ET = E + Tr$$

*where ET is actual evapotranspiration, E is soil evaporation, and Tr represents actual transpiration of the crop.*



Abbreviations: *I* = irrigation; *T<sub>n</sub>* = minimum air temperature; *T<sub>x</sub>* = maximum air temperature; *E<sub>0</sub>* = reference evapotranspiration; *E* = soil evaporation; *T<sub>r</sub>* = transpiration of the canopy; *g<sub>s</sub>* = stomatal conductance; *WP* = water productivity; *HI* = harvest index; *CO<sub>2</sub>* = atmospheric concentration of carbon dioxide; (1), (2), (3), (4), water stress response functions on leaf expansion, senescence, stomatal conductance, and harvest index. Continuous lines indicate direct links between variables and processes. Broken lines indicate feedback.

$$B_i = WP^* \left( \frac{T_{ri}}{ET_{O_i}} \right)$$

The estimation and prediction of yield are based on the final biomass and harvest index (HI). This allows a clear distinction between the impact of stress on B and HI in response to the environmental conditions:

where  $Y$  = final yield,  $B$  = biomass, and  $HI$  = harvest index.

$$WP = \left[ \frac{Y}{\sum Tr} \right]$$

where  $Y$  is the yield expressed in kg/ha and  $Tr$  is the daily transpiration simulated by the model.

### 3.2. Summary of calculation structure

Figure 4 shows a calculation diagram for AquaCrop. With a daily time step, the model successively simulates the following processes:

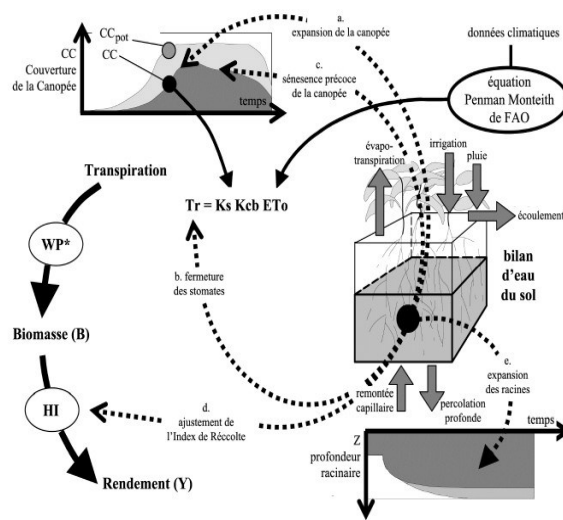
**Step 1:** Water balance of the soil

**Step 2:** Development of the green canopy (CC)

**Step 3:** Sweating of the crop

**Step 4:** The aboveground biomass (B)

**Step 5:** The conversion of aboveground biomass (B) into yield (Y)



**Figure 4.** AquaCrop calculation diagram showing (in dotted lines) the processes affected by stress (AquaCrop reference manual – Rael et al. 2017).

**Abbreviations:** CC = simulated canopy cover, CCp = potential canopy cover, Ks = water stress coefficient, Kcb = crop coefficient, ETo = reference evapotranspiration, WP\* = water productivity for a standardized crop, and HI = harvest index.

### 3.3. Crop response to soil salinity stress

The electrical conductivity of saturated soil paste extracts from the root zone (ECe) is commonly used as an indicator of the soil salinity stress used to determine the total reduction in biomass production, which determines the value for soil salinity stress coefficient ( $K_{s, \text{salt}}$ ).

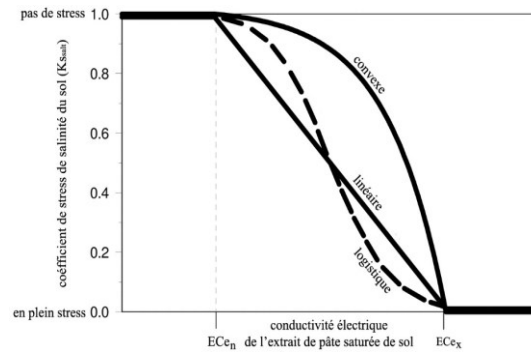
The coefficient of soil salinity stress ( $K_{s, \text{salt}}$ ) varied between 0 (full effect of soil salinity stress) and 1 (no effect). The following equation determined the reduction in biomass:

$$B_{\text{rel}} = 100 - 1 - K_{s, \text{salt}}$$

$B_{\text{rel}}$  represents the expected biomass production under given salinity stress relative to the biomass produced in the absence of salt stress. The coefficient is adjusted daily to the average ECe in the root zone.

It is well established that the reduction in biomass production due to salinity results from the closure of the stomata and poor development of the vegetation cover, which involve slow expansion of the canopy, low canopy cover, and a decline in canopy during the crop cycle.

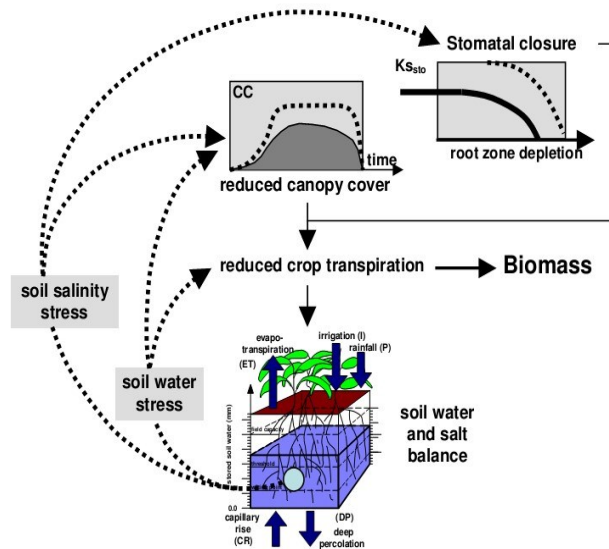
In AquaCrop, this total reduction in biomass is determined by a stress coefficient of the salinity of the soil ( $K_{s, \text{salt}}$ ), whose value depends on the average electrical conductivity of the extracts of the saturated paste of the soil (ECe) of the root zone. The stress coefficient of soil salinity ( $K_{s, \text{salt}}$ ) varies between 0 tbsp of the full effect of soil salinity stress and 1 tbsp (i.e., no effect of salinity; Figure 5).



**Figure 5.** The different shapes of the  $K_s$  curve (AquaCrop reference manual – Rael et al., 2017).

Soil salinity similarly influences the development of the green canopy (CC) and the productivity of biomass water (WP\*). It also directly influences crop transpiration by causing the stomata to close (Figure 6).

In AquaCrop, the effect of soil salinity stress on the crop can be specified by choosing a crop sensitivity class or by specifying the crop's threshold values for soil salinity in its root zone. The electrical conductivities of the saturated soil paste extracts (CEe) are given for thresholds and expressed in deciSiemens per meter (dS/m): the lower threshold (ECin) at which soil salinity stress begins to affect biomass production and the upper threshold (ECex) at which soil salinity stress has reached its maximum effect and stress becomes so severe that biomass production stops.



**Figure 6.** The effect of soil salinity and water stress on biomass production (AquaCrop reference manual – Rael et al., 2017).

### 3.4. Soil salinity estimation

AquaCrop adopts the calculation procedure presented in BUDGET to simulate the movement and retention of salt in the soil profile. After irrigation using saline water, salts enter the soil profile through capillary action, rising from a shallow groundwater table (vertical downward and upward salt movement). The average ECe in the compartments of the effective rooting depth determines the effects of soil salinity on biomass production.

To explain the movement and retention of soil water and salts in the soil profile, AquaCrop divides the soil profile into 2 to 11 soil compartments called “cells,” depending on the type of soil in each horizon (clay, sandy) and its saturated hydraulic conductivity ( $K_{sat}$  in mm/day). The salt diffusion between two adjacent cells (cell  $j$  and cell  $j + 1$ ) is determined by the differences in salt concentration and is expressed by the EC of the soil water.

AquaCrop determines the vertical salt movement in response to soil evaporation, considering the amount of water extracted from the soil profile by evaporation and the wetness of the upper soil layer. The relative soil water content of the topsoil layer determines the fraction of the dissolved salts that moves with the evaporating water.

AquaCrop determines the vertical salt movement because of capillary rise. Finally, the salt content of a cell is determined by

$$Salt_{cell} = 0.64 W_{cell} EC_{cell}$$

where  $Salt_{cell}$  is the salt content expressed in grams of salts per  $m^2$  soil surface,  $W_{cell}$  its volume expressed in liters per  $m^2$  ( $1\text{ mm} = 1\text{ L}/m^2$ ), and 0.64 a global conversion factor used in AquaCrop to convert dS/m to g/L.

The electrical conductivity of the soil water ( $EC_{sw}$ ) and of the saturated soil paste extract ( $EC_e$ ) at a particular soil depth (soil compartment) is calculated as

$$EC_{sw} = \frac{\sum_{j=1}^n Salt_{cell,j}}{0.64 (1000 \theta \Delta_z) \left\{ 1 - \frac{Vol\%_{gravel}}{100} \right\}}$$

$$EC_e = \frac{\sum_{j=1}^n Salt_{cell,j}}{0.64 (1000 \theta_{sat} \Delta_z) \left\{ 1 - \frac{Vol\%_{gravel}}{100} \right\}}$$

where  $n$  is the number of cells in each soil compartment,  $\theta$  is the soil water content ( $m^3/m^3$ ),  $\theta_{sat}$  is the soil water content ( $m^3/m^3$ ) at saturation,  $\Delta_z$  (m) is the thickness of the soil compartment, and Vol% gravel is the volume percentage of the gravel in the soil horizon of each compartment.

## 4. Installation of AquaCrop

### 4.1. Go to the FAO AquaCrop webpage:

<http://www.fao.org/aquacrop/software/aquacropstandardwindowsprogramme/en/>

**AquaCrop standard windows programme version 6.1**

Version 6.1 of AquaCrop standard windows programme is now available!

Version 6.1 of AquaCrop allows for language selection of the interface in English and French. The layout of some menus in this version has also been improved.

Just copy and paste the programme into your computer and run it!

**Download AquaCrop Version 6.1**

Download the installation guidelines for AquaCrop version 6.1

**Key Documents**

- Reference manual for AquaCrop version 6.0/6.1 - Chapter 1
- Reference manual for AquaCrop version 6.0/6.1 - Chapter 2
- Reference manual for AquaCrop version 6.0/6.1 - Chapter 3
- Reference manual for AquaCrop version 6.0/6.1 - Chapter 4
- Reference manual for AquaCrop version 6.0/6.1 - Chapter 5
- Reference manual for AquaCrop version 6.0/6.1 - Annexes
- Installation guidelines for AquaCrop version 6.1
- AquaCrop training handbooks. Book I: Understanding AquaCrop
- AquaCrop training handbooks. Book II: Running AquaCrop

### 4.2. To be able to download the software, you must fill out the proposed form.

**AquaCrop**

Please fill in the following fields to download your selected AquaCrop model. We will keep you updated on software updates and AquaCrop news.

Email \*  
z.hammami@biosaline.org.ae

First name \*  
zied

Last name \*  
hammami

Organization \*  
ICBA

Country \*  
United Arab Emirates

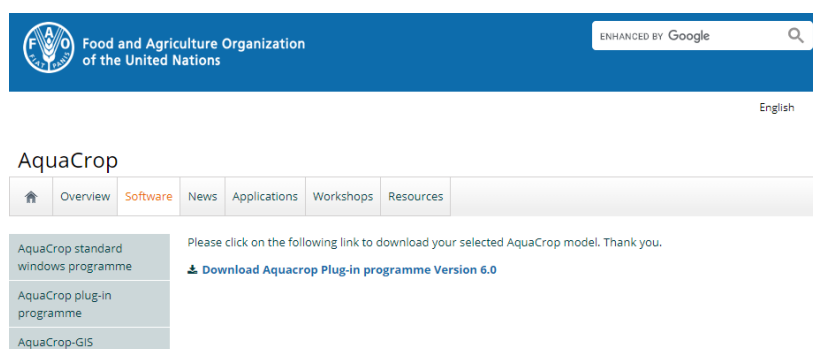
Save

### 4.3. Download the compressed file to install AquaCrop on your PC.

**AquaCrop**

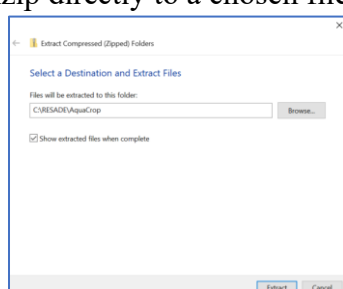
Please click on the following link to download your selected AquaCrop model. Thank you.

**Download AquaCrop Version 6.1**



4.4. Copy the compressed file “AquaCrop64bitV60NrXXXX2017.zip” to your PC.

Unzip directly to a chosen file, for example, "C:\RESADE\AquaCrop":



4.5. Copy the entire contents of the unzipped file (files and five directories with more files).

4.6. Paste the entire contents into a directory on your PC, for example "C:\RESADE\AquaCrop".

Note: The version is available in both English and French.



## 5. Getting started with AquaCrop

### Once installed

5.1. After AquaCrop is successfully installed, the AquaCrop folder should contain

- (i) The AquaCrop file.EXE (the executable file to launch the program) and
- (ii) Five subdirectories:
  - DATA (default subdirectory for input files);
  - IMPORT (default subdirectory for text files with climate data);
  - OBS (default subdirectory for field observation files);

- OUTF (default subdirectory for output files);
- SIMUL (subdirectory for simulation purposes), containing other files:
  - ✓ the MaunaLoa.CO2 file,
  - ✓ the file with the default project settings (\*.PAR), and
  - ✓ SOILS.DIR (a file with default values for soil characteristics).

5.2. For this exercise, a barley cultivation file was created. It is available in the training file given. The file name “barley\_icba. CRO. ”

Copy the file to the software folder C:\RESADE\AquaCrop \AquaCropV60Nr26042017\DATA.

5.3. Launch the software by clicking "AquaCrop.exe".

5.4. Get started with AquaCrop.

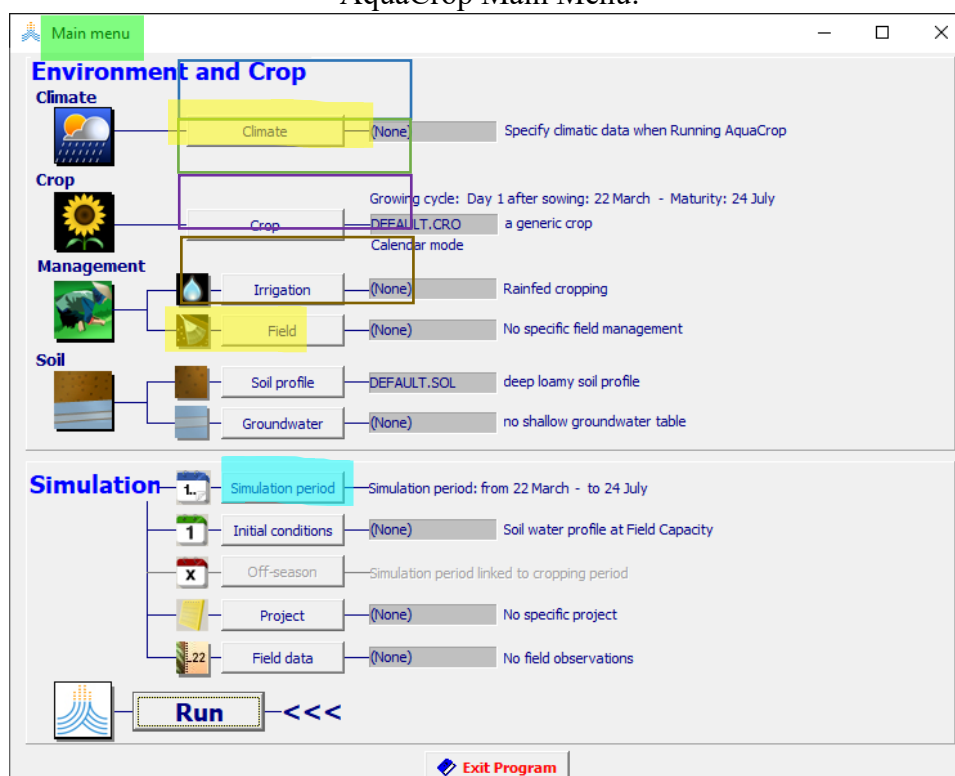
This part aims to familiarize you with the AquaCrop software, its input data, and its simulations to develop an irrigation program. For this, an example of barley installed in the pedoclimatic conditions of **BPH-Atti-Apedok-Togo** will be considered.

Once the program is launched, the software launch window opens.

Click **Start** to bring up the Main Menu.

The Main Menu contains two windows “Environment and culture” and “Simulation”

AquaCrop Main Menu:



## 6. Input data

Table 1 shows AquaCrop input parameters for climate, crops, soil, and management parameters for model simulation.

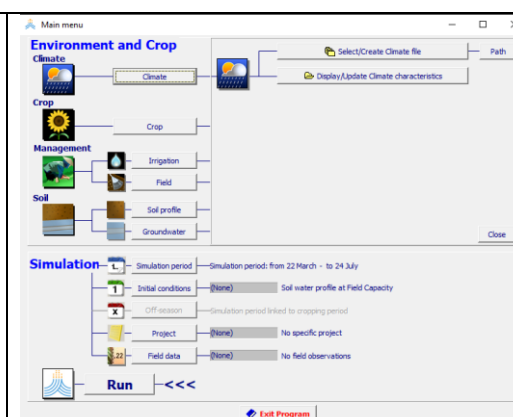


**Table 1.** Climate, soil, and crop management parameters used for simulation with the AquaCrop model.

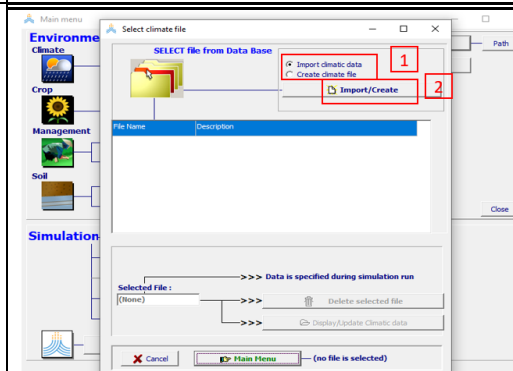
Climate		Daily rainfall, daily $ET_0$ , daily temperatures CO <sub>2</sub> concentration
Crop	Limited set	Crop development and production parameters, which include phenology and life cycle
	Crop parameters	Harvest index Root zone threshold at the end of canopy expansion Threshold root zone depletion for early senescence Time for maximum canopy cover Maximum vegetation Flowering time Initial vegetative cover Depletion threshold root zone for stomata closure Extraction of water
Soil	Field	Soil fertility, mulch Field practices (surface runoff presence, ground bond)
	Soil profile	Characteristics of soil horizon (no. of soil horizons, thickness, PWP, FC, SAT, $K_{sat}$ ); soil surface (runoff, evaporation); restrictive soil layer capillary rise
	Soil water and groundwater	Constant depth, variable depth, water quality

## 6.1. Climate

**To create “climate” file:**  
- Click on **Climate**.  
Then **Select/Create Climate file**.



Two options are available:  
Import climatic data and  
Create climatic file.  
Choose the first option and **Import climatic data**; then click on the command **Import/Create**.



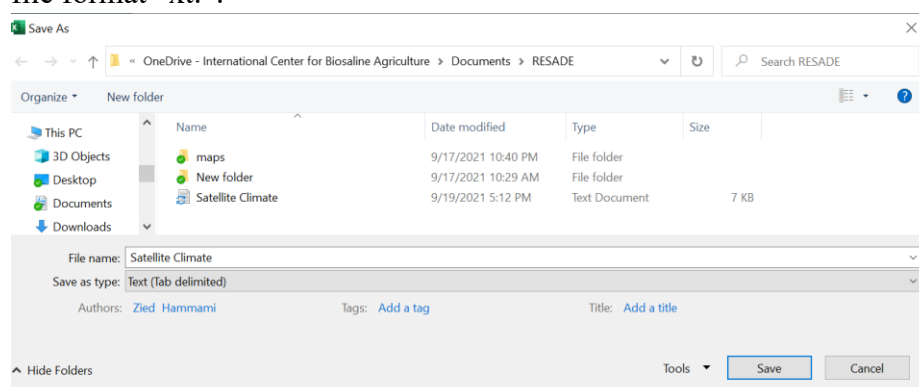
### First important remark

Regarding climate parameters, the AquaCrop software accepts only format ".xt".

The file must not contain dates or headers. Clear the first line headers and the date column.

	A	B	C	D	E	F	G
1	YEAR	DOY	T2M_MAX	T2M_MIN	RH2M	Rain	WS2M_MAX
2	2021	1	34.68	24.97	71.31	1	2.11
3	2021	2	31.79	25.4	79.88	0	2.34
4	2021	3	32.04	24.56	78.19	0	2.85
5	2021	4	32.95	24.52	75.62	0	2.04
6	2021	5	32.56	24.25	77.44	0	2.76
7	2021	6	31.87	24.65	74.38	0	3.23
8	2021	7	35.57	23.4	70.81	0	3
9	2021	8	32.15	24.41	78.19	0	2.73
10	2021	9	35.45	23.55	72.5	3	3.2
11	2021	10	34.9	23.92	71.81	0	2.59
12	2021	11	35.15	24.08	70.94	0	2.84
13	2021	12	36.11	23.59	65.69	0	2.34
14	2021	13	35.45	24.01	67.44	0	2.64
15	2021	14	36.06	23.58	65.12	0	2.34
16	2021	15	35.98	24.08	65.44	0	2.38
17	2021	16	34.23	24.15	69.25	0	2.79
18	2021	17	33.89	24.01	70.5	0	2.99

To be able to import climate data, you have to transform the Excel file "Satellite Climate.xlsx" in the file format ".xt".



Save the file "Satellite Climate.txt".

Check whether your file is successful; it will have to open with the block in the following format:

Satellite Climate - Notepad

File	Edit	Format	View	Help
34.68	24.97	71.31	1	2.11
31.79	25.4	79.88	0	2.34
32.04	24.56	78.19	0	2.85
32.95	24.52	75.62	0	2.04
32.56	24.25	77.44	0	2.76
31.87	24.65	74.38	0	3.23
35.57	23.4	70.81	0	3
32.15	24.41	78.19	0	2.73
35.45	23.55	72.5	3	3.2
34.9	23.92	71.81	0	2.59
35.15	24.08	70.94	0	2.84
36.11	23.59	65.69	0	2.34
35.45	24.01	67.44	0	2.64
36.06	23.58	65.12	0	2.34
35.98	24.08	65.44	0	2.38
34.23	24.15	69.25	0	2.79
33.89	24.01	70.5	0	2.99
35.37	24.24	67	0	2.32
36.41	24.17	64.06	3	2.36
36.77	24.14	64.81	0	2.19
35.39	24.22	65.25	0	2.81

### Second important remark

The separator format decimal configuration in the computer can be ("," or ".")

Be sure to change the separator in the you file to "."

A window "Import climatic Data" opens with five tabs:

Select file

Time range

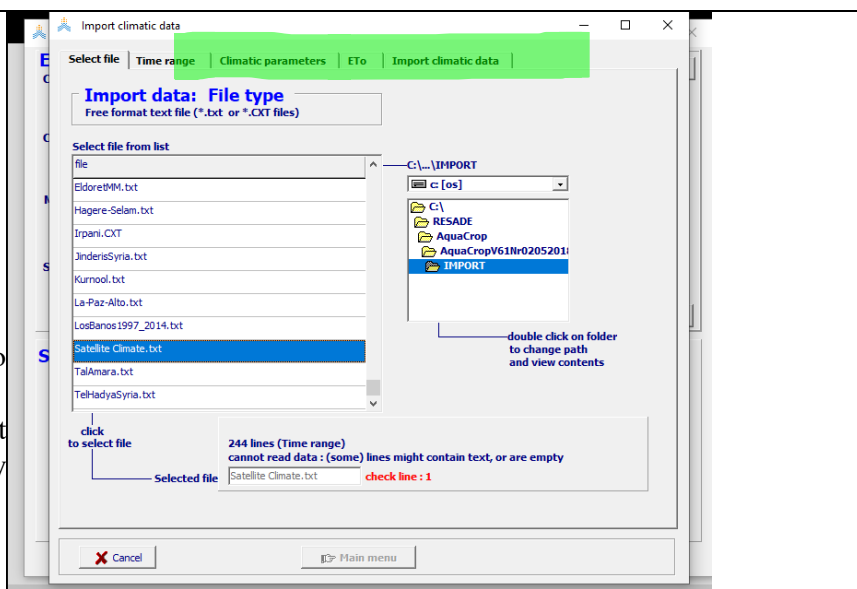
Climatic parameters

ETo

- Import climatic data

You have to move from one tab to another.

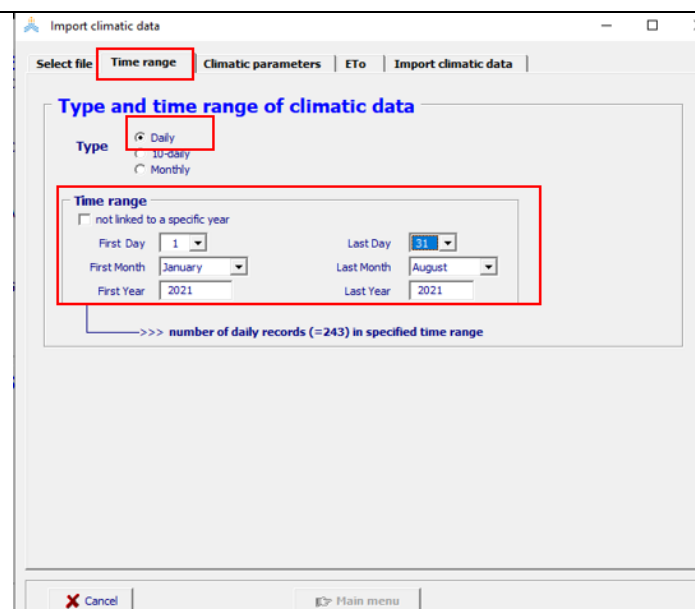
Note: Start with the Select file tab, select the training folder, and then the recently created Climat\_Medenine.txt file.



Skip to the next tab, "Time range."

As we have daily data, we must select the type "Daily" For the time interval, select the first date of 01/09/2012 and the last date of 30/06/2013.

Enter the year 2013 in **last year** and then the year 2012 in **first year** and then the other data (day and month).



Skip to the next tab: Climatic parameters.  
Each column of data must be defined.  
Remember that, in your file, column 1 corresponds to Tmax, column 2 to Tmin, and column 3 to rain.

Start by selecting column 1 by clicking on 1.  
A list of climatic parameters with several tabs appears.  
For column 1, select Tmax in °C.  
For column 2, select Tmin in °C.

Code	Symbol	Unit	Description
101	Tmax	°C	maximum air temperature
102	Tmean	°C	mean air temperature
103	Tmin	°C	minimum air temperature
111	Tmax	°F	maximum air temperature
112	Tmean	°F	mean air temperature
113	Tmin	°F	minimum air temperature

For the third column, select the Humidity tab.

For the fourth column, select the Rain tab and then the Rain parameter in mm.  
Etc.

Code	Symbol	Unit	Description
200	Rhmax	%	maximum relative humidity
202	Rhmean	%	mean relative humidity
203	Rhmin	%	minimum relative humidity
210	Tdew	°C	dewpoint temperature
211	Tdew	°F	dewpoint temperature
221	e(act)	kPa	actual vapour pressure
222	e(act)	hPa (mbar)	actual vapour pressure
223	e(act)	psi	actual vapour pressure
224	e(act)	atm	actual vapour pressure
225	e(act)	mmHg	actual vapour pressure
231	Tdry	°C	temperature of dry bulb
232	Twet	°C	temperature of wet bulb
233	Tdry	°F	temperature of dry bulb
234	Twet	°F	temperature of wet bulb

It is possible to check the data entered looking at the min and max intervals shown in the figure.

**Import climatic data**

Select file | Time range | Climatic parameters | ETo | Import climatic data

**Climatic parameters**

Column: 1 2 3  
 << click in cell to select parameter >>

Symbol	Tmax	Tmin	Rain
Unit	°C	°C	mm
Code	101	103	601

**Missing data**

Undefined Value: -999.000

Missing: none none none

**Data range**

Column Max	Column Min	Column Avg
40.5	12.6	27.0
27.0	3.1	23.9
23.9	0.0	0.0

**Program limits (Data Range)**

Upper limit	Column Max	Column Min	Column Avg
45.0	45.0	300.0	300.0
-15.0	-15.0	0.0	0.0

>>> Update Data Range

Cancel Main menu

*ETo can be calculated in the ETo tab from climatic data using Penman-Monteith equation. Then, the calculated ETo can be exported directly to the climatic file.*

Skip to the ETo tab.  
 Enter station coordinate data  
 as follows: Altitude: 97.8  
 m.  
 Latitude: 6.44663

**Import climatic data**

Select file | Time range | Climatic parameters | **ETo** | Import climatic data

**Coordinates of Meteorological station**

Station: Satellite Climate

Altitude: 97.8 meter above sea level (m.a.s.l.)

Latitude: 6.44663 decimal degrees North

specified in: ☐ Degrees and Minutes ☒ Decimal degrees

**ETo calculation (FAO Penman-Monteith method)**

considered:

- Air temperature: Maximum (Tmax) and minimum (Tmin) air temperature (available)
- Air humidity: Actual vapour pressure (estimée de Tmin) - estimated
- Radiation: Net radiation (solar radiation estimated from (Tmax - Tmin) difference) - estimated
- Wind speed: Wind speed (available)

Coefficients: check coefficients for required estimates

**ETo calculator**

**ETo**

Reference evapotranspiration (evaporating power of the atmosphere)

calculated with estimates for:

- air humidity
- net radiation

Cancel Main menu

Approximations shall be applied for the ETo calculation in the absence of humidity and/or radiation and/or wind speed data. To do this, click “n

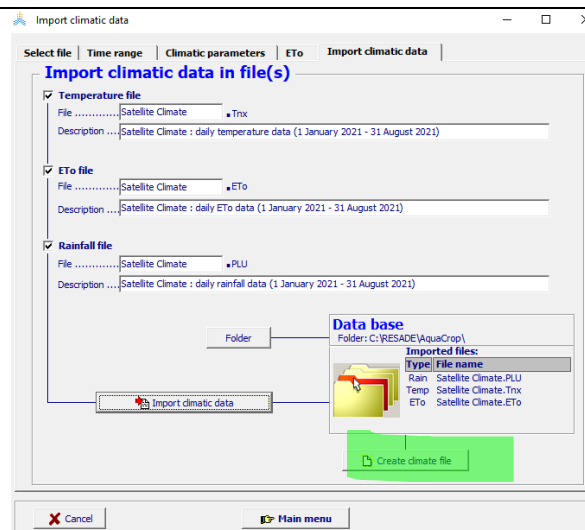
coefficients” and then select the average climatic conditions that best correspond to your study area.

For example, in the case of the region of PBH, these conditions can be

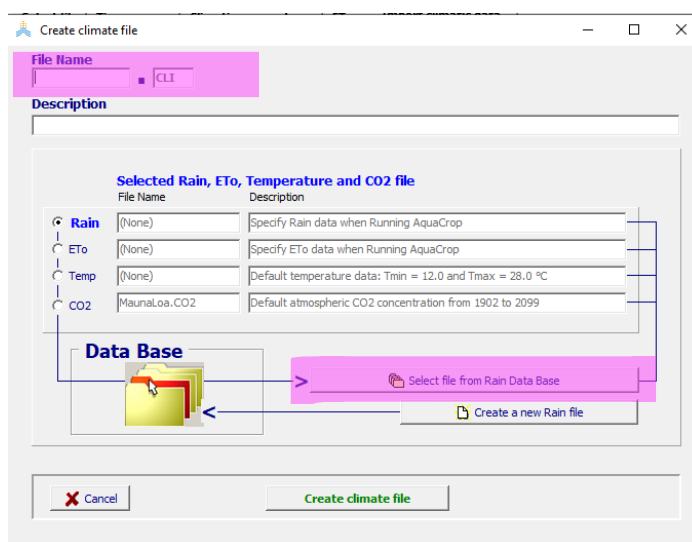
- at the coast
- light to moderate winds
- in semi-humid or humid area

Go to the Import climatic data tab. Make sure that the three parameters are checked and then click on **Import climatic data**.

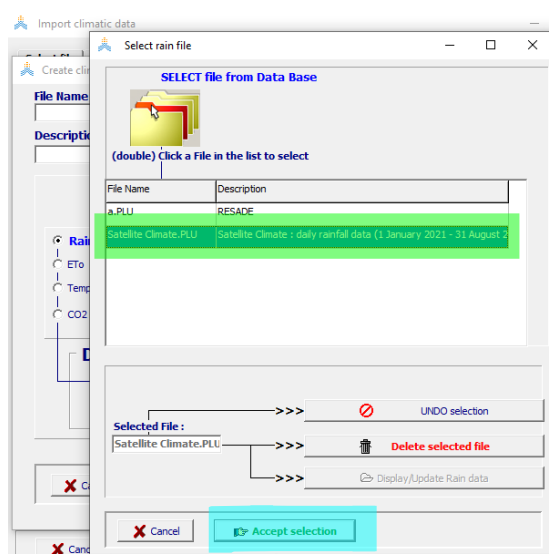
Three new files will appear in the database area "Climat\_Togo.PLU"  
 "Climat\_Togo.Tnx"  
 "Climat\_Togo.Eto"  
 Click on **Create climate file**.



The **Create climate file** window appears.  
 Name the file  
 Climat\_Togo.CLI.  
 For rain, you have to select the Rain  
 parameter and click on  
 "Select file from Data Base"

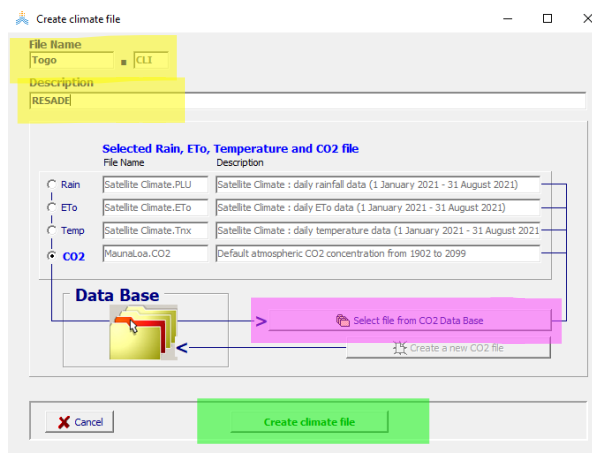


In the Select file from Data Base  
 window that opens,  
 select Climat\_Togo and then click on  
**Accept selection**.  
 Repeat this procedure for all climatic  
 parameters, including ETo.

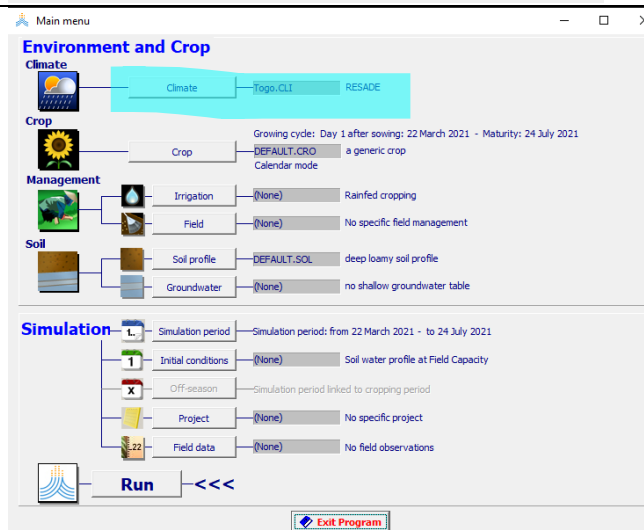


Once the different files of the different climatic parameters are selected, they must appear as in the figure.

Click on **Create**.

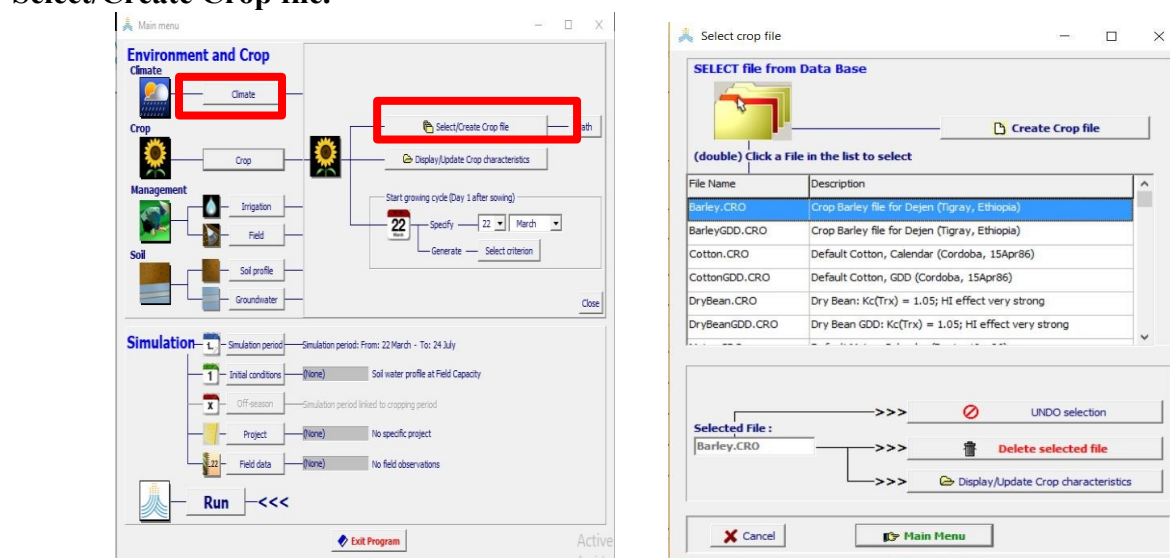


The software returns to the Main Menu and the created climate file is preselected.



## 6.2. Crop

The AquaCrop software contains a crop database accessible when you click on **Crop** and then **Select/Create Crop file**.





Two options are available:

- **Select crop file** a-d - Create crop file.

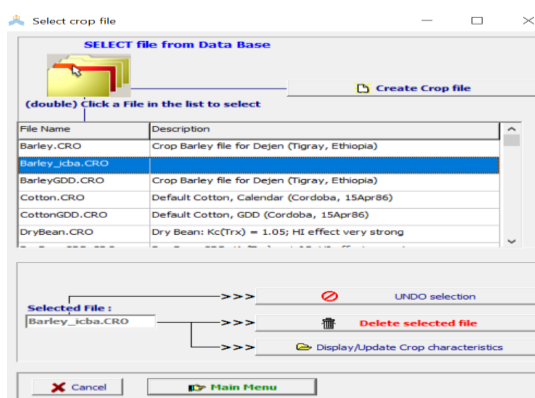
Choose the first option and **select** the type of crop. Many crops are available (e.g., quinoa, sorghum, soybean, cotton, barley, etc.).

Note: The ICBA team can collaborate later with RESADE members to calibrate the model for any crops and/or genotypes.

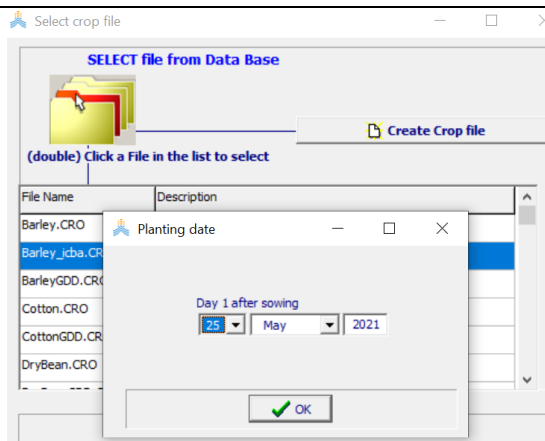
For this exercise:

Choose **Barley\_icba.CRO** and click on the command

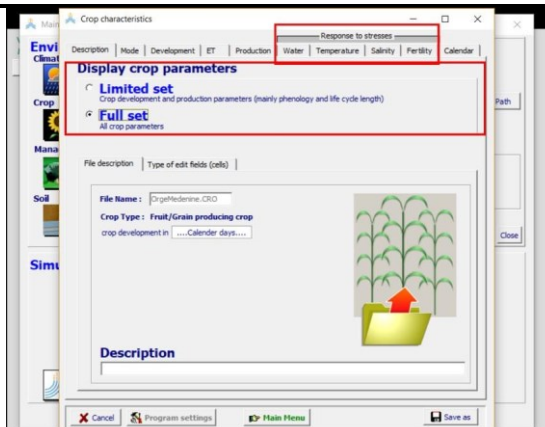
**Display/Update Crop characteristics** to view or modify the characteristics of your genotype.



A planting date window appears. Select the date of May 25.



In the **Crop characteristics** window that opens, check the "Full set" option to be able to display the stress response parameters

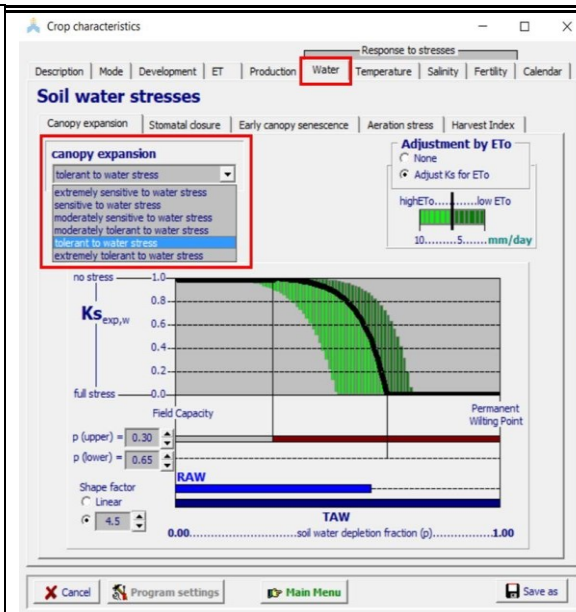


Go to the **response to stresses** window and then the Water tab and choose the tolerance threshold of your crop.

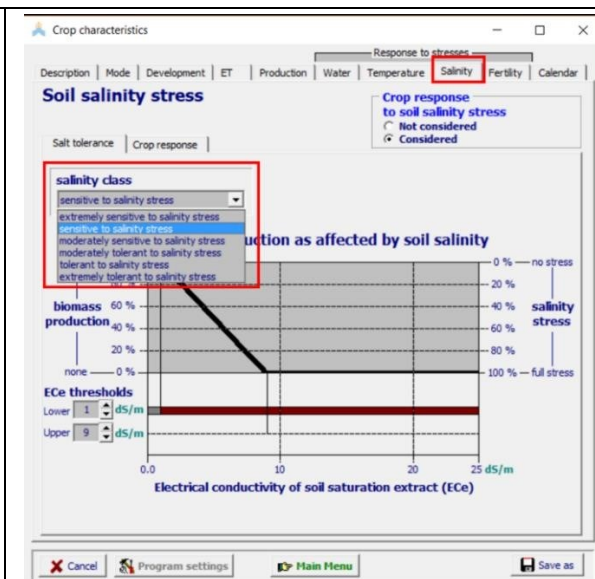
For example:

Barley genotype

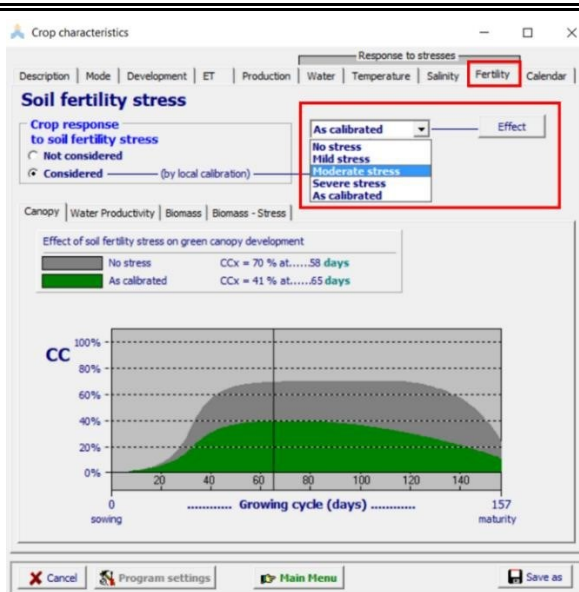
**Tolerant of water stress**



Go to the Salinity tab and choose the tolerance threshold of your barley genotype (**Tolerant of salinity stress**).

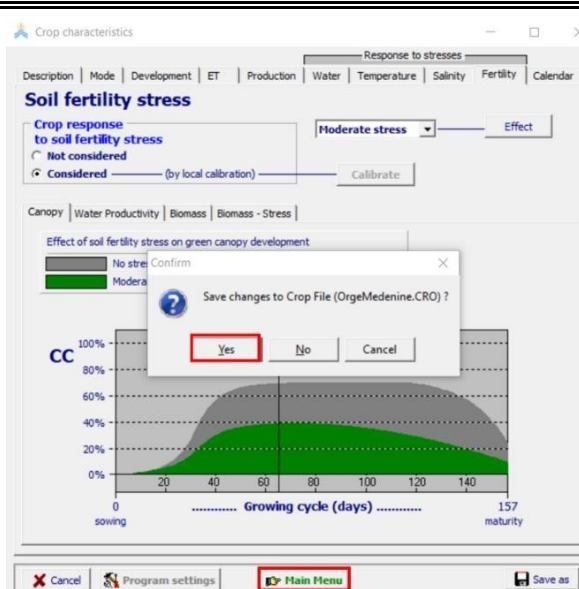


Go to the Fertility tab and choose the tolerance threshold of your crop.



Once the settings are changed, click on **Main Menu**.

A window appears asking if you want to save the changes to the crop. Click **Yes**.



### Remark:

Several crop parameters can be adapted to the real conditions of the crops in the area. They can be conservative and species-specific or depend on the variety (varietal effect).

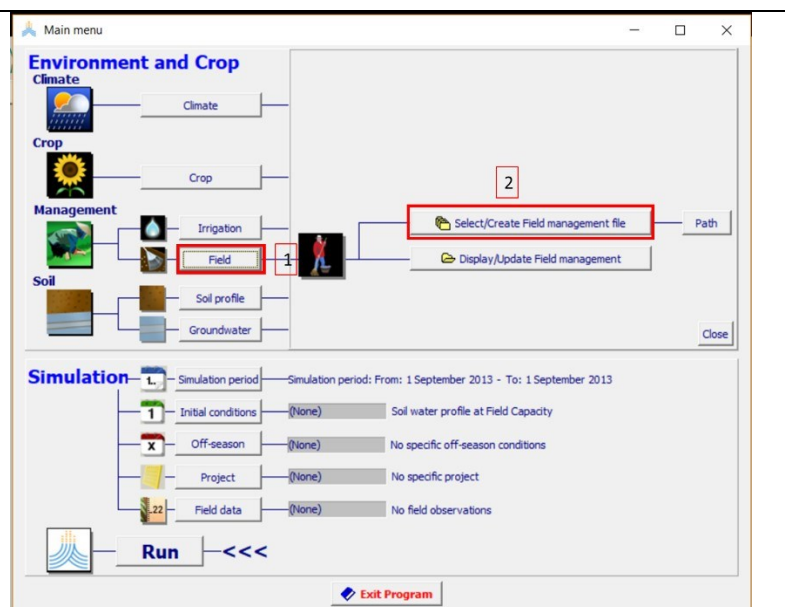
**Table 2.** The values of different model input parameters obtained after calibration for barley genotypes (Hammami et al., 2020).

Crop input parameters	Remarks
Base temperature (°C)	Conservative
Upper temperature (°C)	Conservative
Initial canopy cover, CC0 (%)	Conservative
Canopy cover per seeding (cm <sup>2</sup> /plant)	Conservative
Maximum coefficient for transpiration, KcTr,x	Conservative
Maximum coefficient for soil evaporation, Kex	Conservative
Upper threshold for canopy expansion, Pexp,upper	Varietal effect

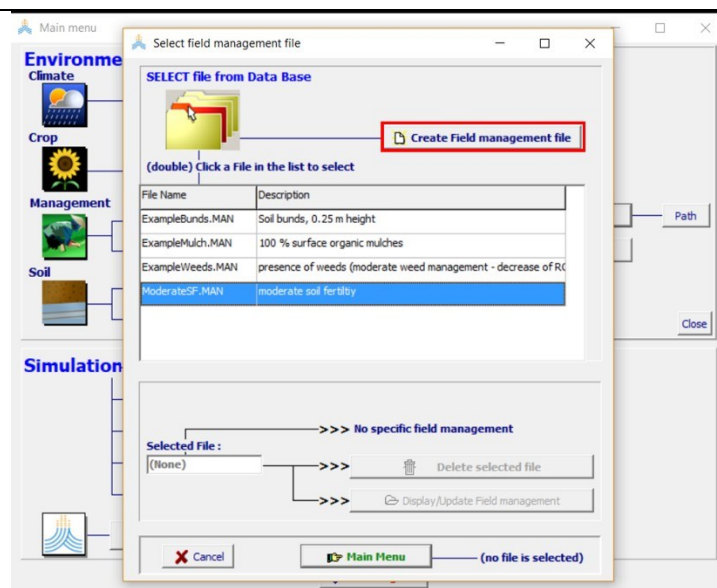
Lower threshold for canopy expansion, Pexp,lower	Varietal effect
Leaf expansion stress coefficient curve shape	Conservative
Upper threshold for stomatal closure, Psto,upper	Varietal effect
Leaf expansion stress coefficient curve shape	Conservative
Canopy senescence stress coefficient, Psen, upper	Varietal effect and environment effect for the sensitive genotypes
Senescence stress coefficient curve shape	Conservative
Reference harvest index, HI0 (%)	Varietal and salt stress effect
Normalized crop water productivity, WP* (g/m <sup>2</sup> )	Conservative
Time from sowing to emergence (days)	Conservative
Time from sowing to maximum CC (days)	Varietal and salt stress effect
Time from sowing to maximum CC (days)	Conservative
Time from sowing to maturity (days)	Varietal and salt stress effect
Maximum canopy cover, CCx (%)	Varietal and salt stress effect
Canopy growth coefficient, CGC (%/day)	Varietal effect
Canopy decline coefficient, CDC (%/day)	Conservative
Maximum effective rooting depth, Zx (m)	Site effect
Salinity stress, lower threshold, ECen (dS/m)	Varietal effect
Salinity stress, upper threshold, ECex (dS/m)	Varietal effect
Shape factor for salinity stress coefficient curve	Conservative

### 6.3. Field management

In the Main Menu, select **Field** to enter the plot management criteria. Then, **Select/Create Field management file**.



Click on **Create Field Management file.**



Name the file  
"Togo BPH"

Add the field or plot characteristics:

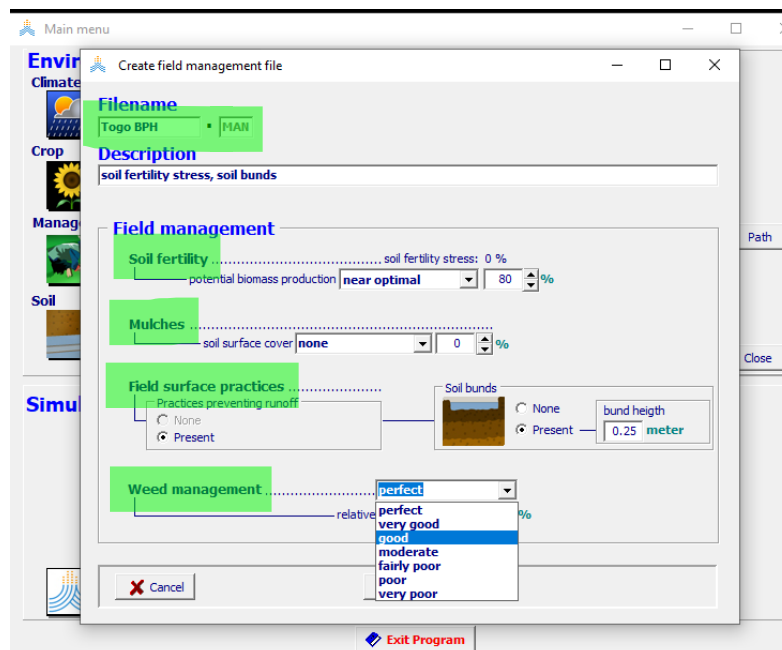
- *Soil fertility*
- *Mulches*
- *Field surface practices*
- *Weed management*

For example:

For Soil fertility, choose "**near optimal**".

For mulches, "**none**".

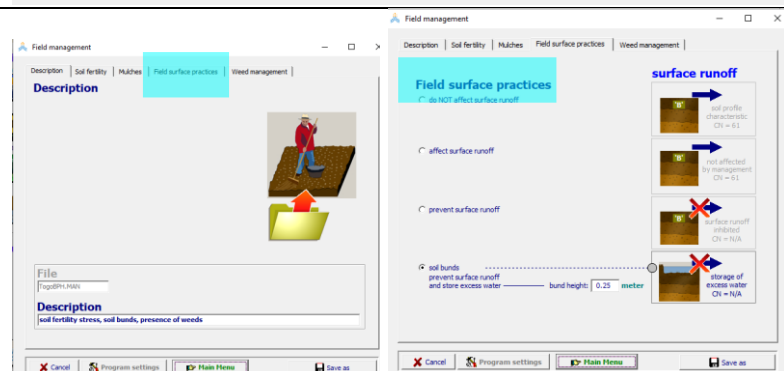
For Field surface practices at **25 cm** depth, "**good**" for Weed management.



Click on **Create.**

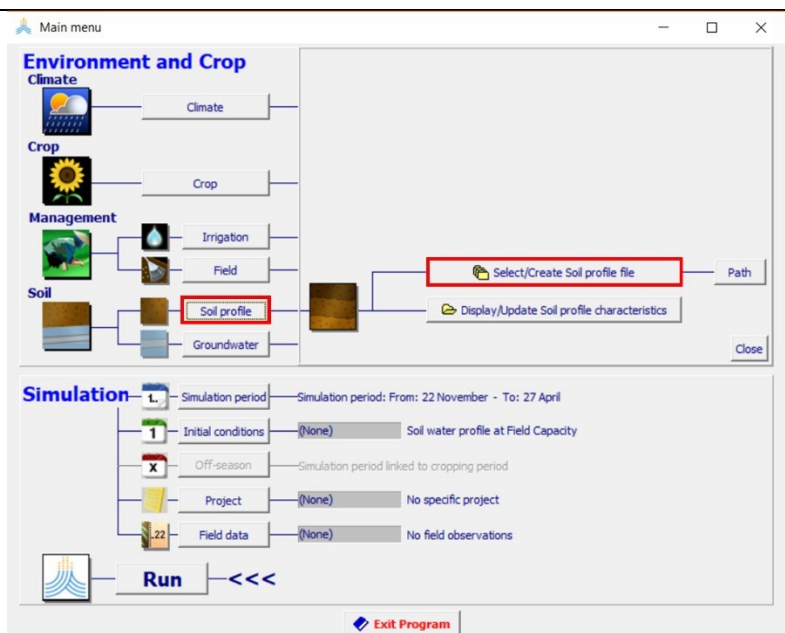
A window appears, which defines the different management characteristics of the plot.

Click **Main Menu** to return to the Main Menu.

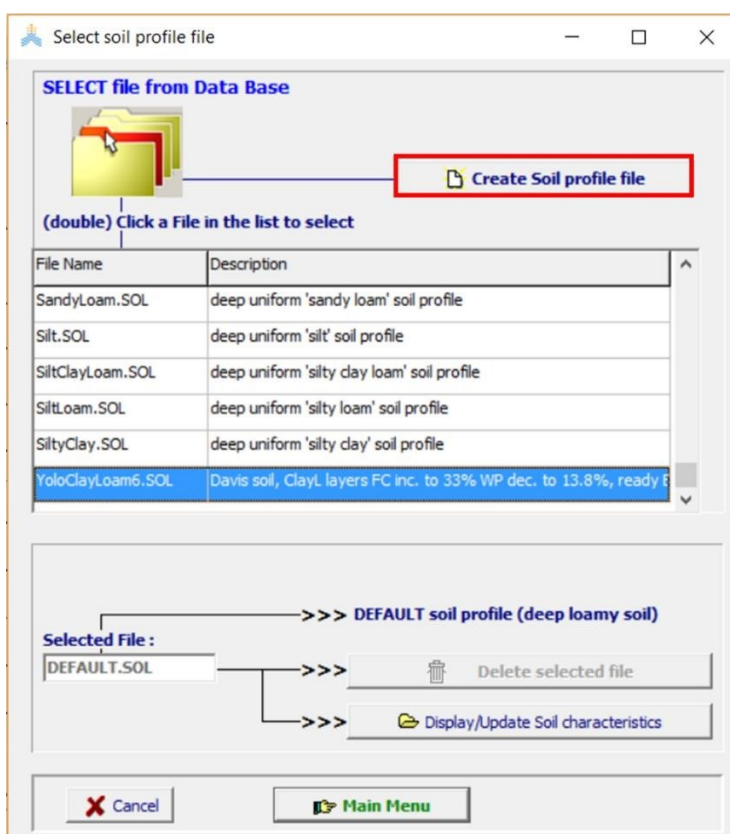


## 6.4. Soil

As with other input data, to edit or add a soil, on the Main Menu, click on **Soil profile** and then **Select/Create Soil profile file**.



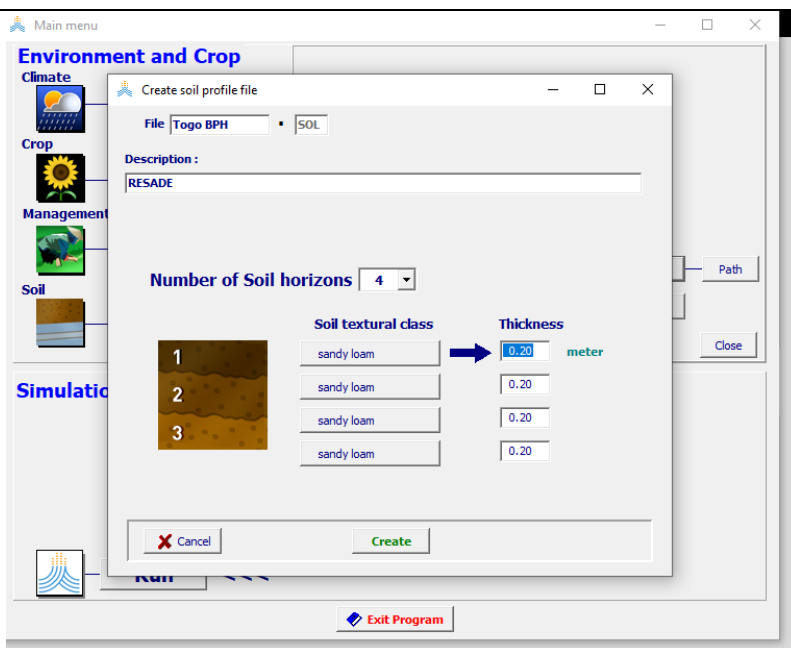
Select **Create Soil profile file**.



Name the **Sol** file  
**Togo.SOL**.  
Select the number of  
horizons (**4**) and the  
thickness (**0.20 m each**).

**Press Create.**

**Note:** AquaCrop can  
consider soils with more  
than one horizon with each  
a different thickness.

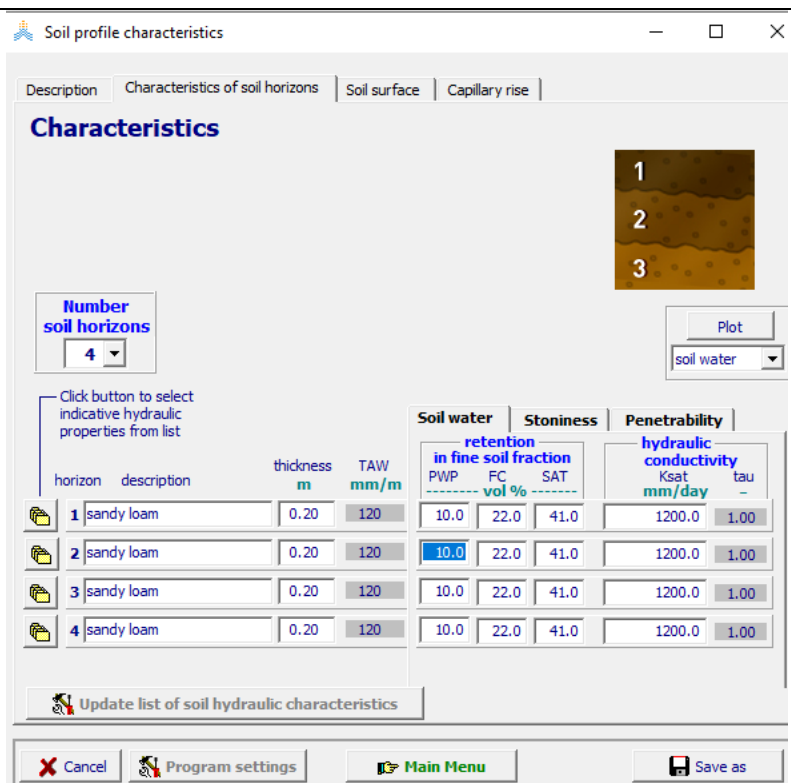


In the **Soil profile characteristics** window that opens, select the **Characteristics of soil horizons** tab and then click



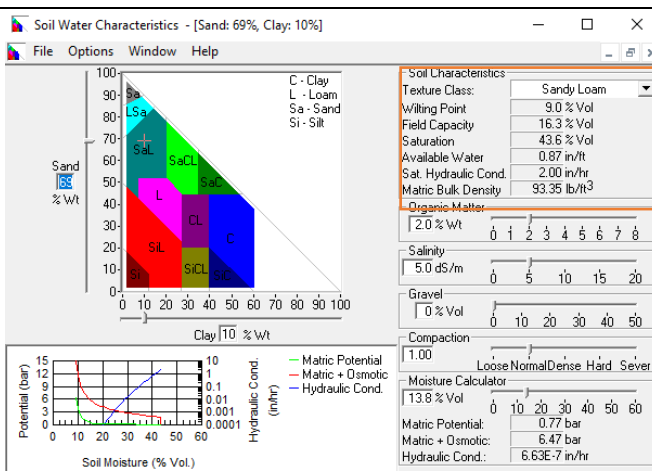
on the button

The soil water and hydraulics can be adjusted using **SPAW Hydrology software** described in section 8.5.

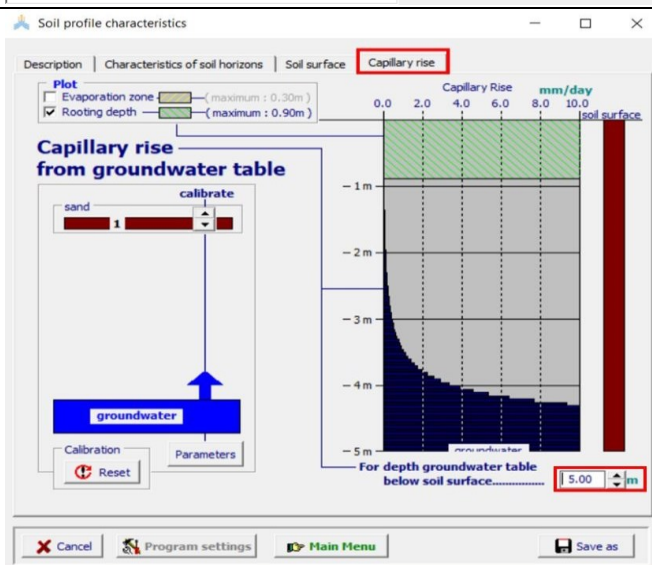




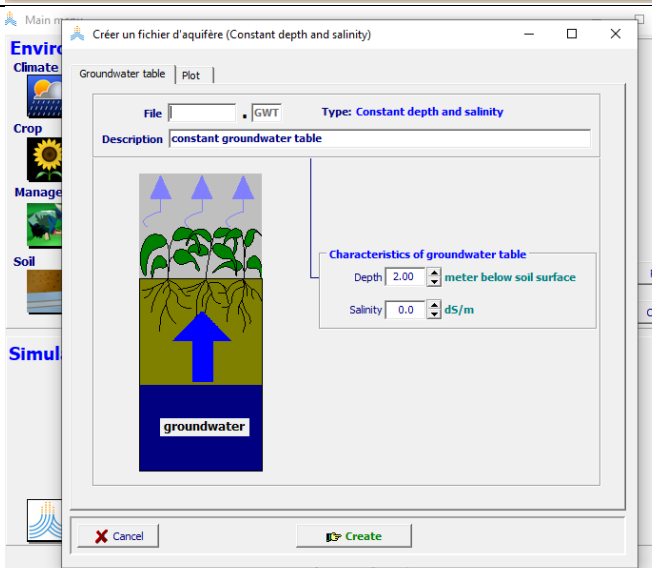
Select for soil  
Sandy Loam.  
Click **OK**.



With the tab **Capillary rise**,  
select the depth of the  
groundwater table at **5 m** and  
**less** if there is capillary rise  
from the groundwater table.



Return to the Main Menu and  
save the file.  
Then go to the groundwater  
window and add any  
information available about  
your groundwater table.

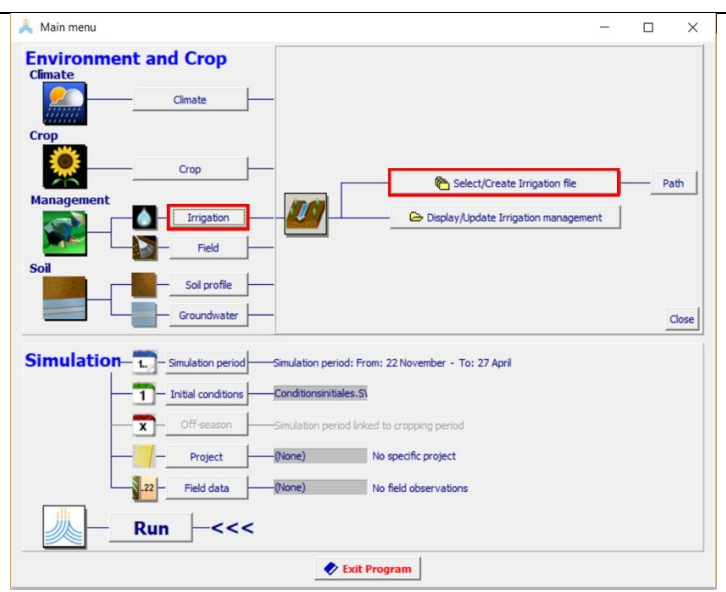




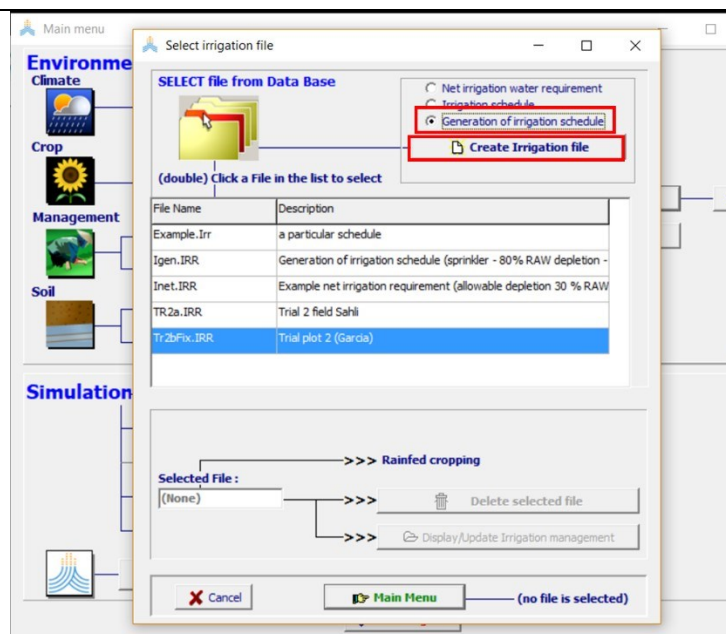
## 6.5. Irrigation

As with other input data, to modify or add an irrigation program, in the Main Menu, click on **Irrigation** and then on **Select/Create Irrigation file**.

*With this option, you will be responsible for entering the irrigation quantity and timing as you wish.*

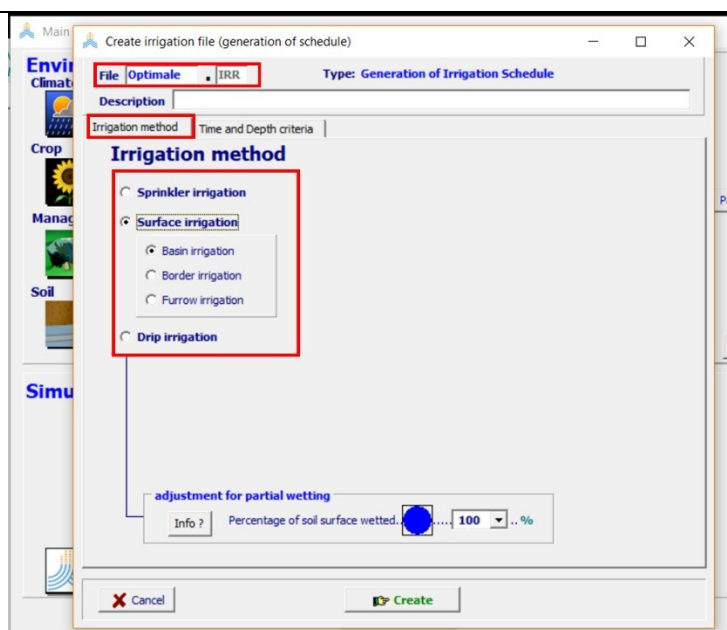


Select **Generation of irrigation schedule** and click on **Create irrigation file**.



Name the file "**Optimal**".

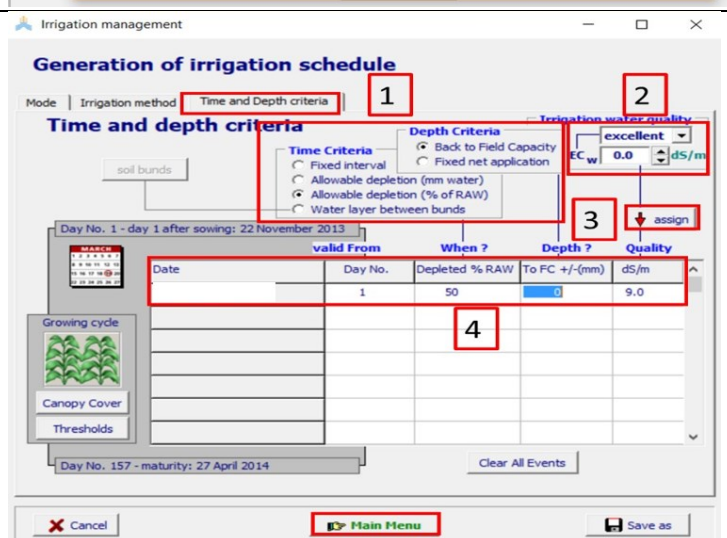
With the Irrigation method tab, select the irrigation mode as **Surface irrigation** and then **Basin irrigation**.



With the Time and Depth criteria tab, for **Time criteria**, select **Allowable depletion (% of RAW)** and in the table fill in the value **50%**.

For **Depth criteria**, select **Back to Field Capacity**.

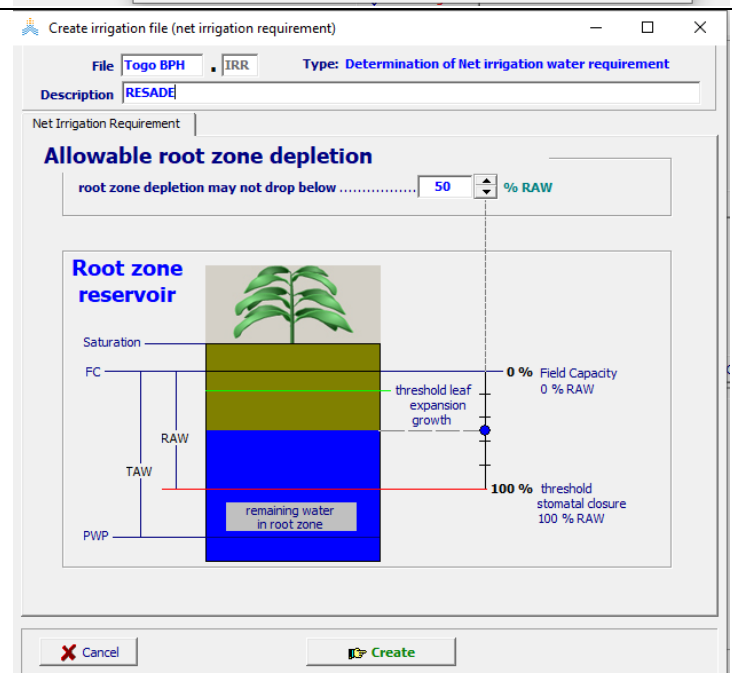
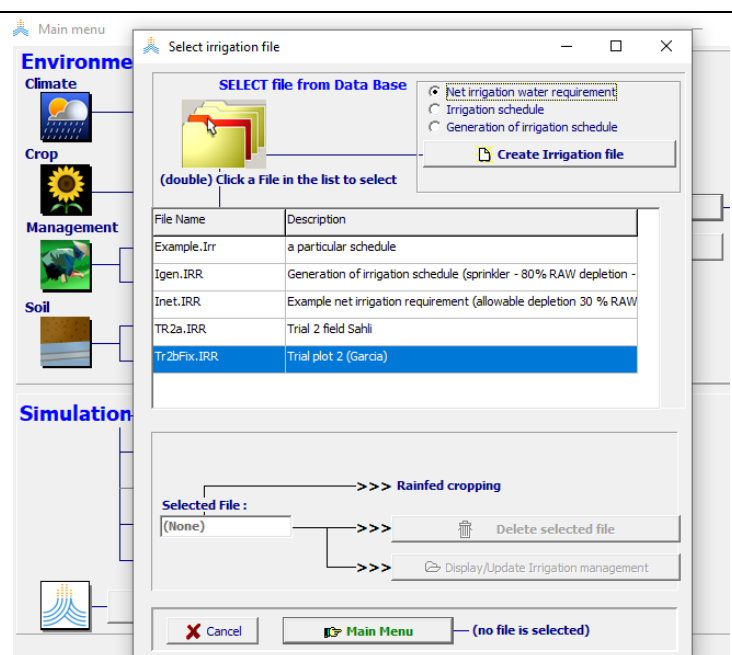
For **Irrigation water quality**, select **Very poor** and  $EC_w = 9.0$  dS/m and click on **Assign**. Then click on **Create**.



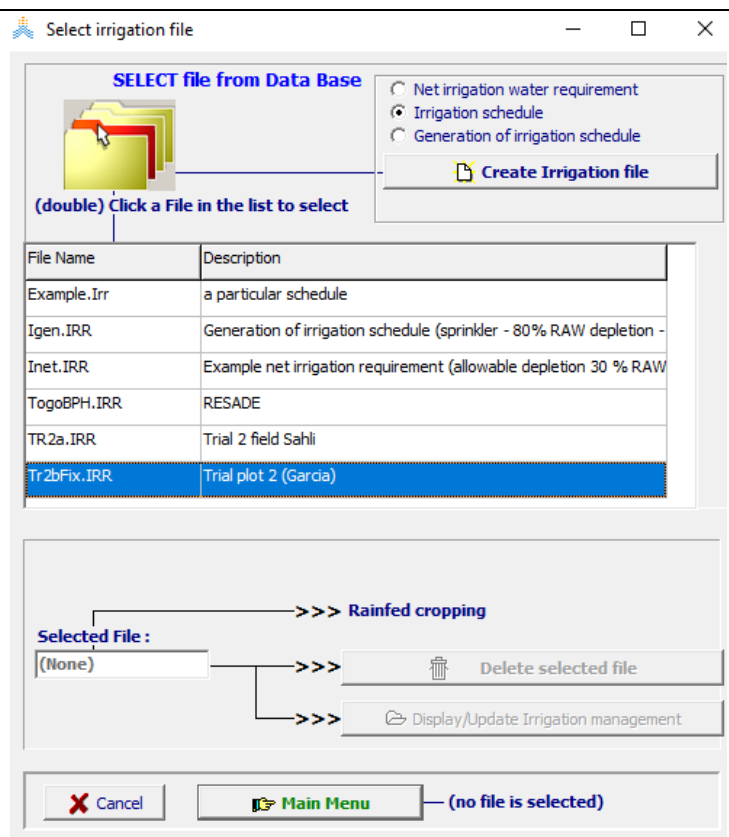
## Irrigation Option 2

Select irrigation file and then click on **Net irrigation water requirement**.

*With this option, AquaCrop will provide the irrigation quantity and timing as per the crop's water requirement according to the soil and weather data.*

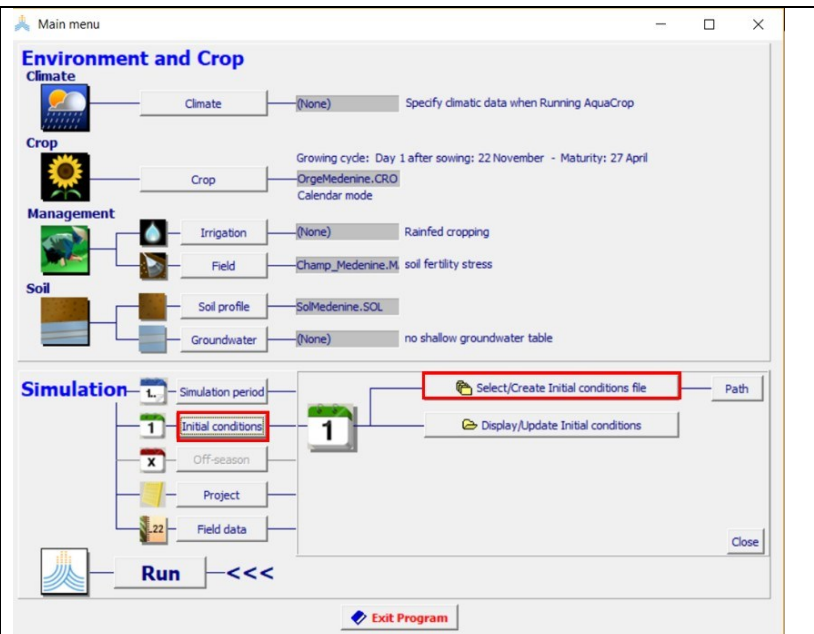


You can also choose the **Irrigation schedule** option.

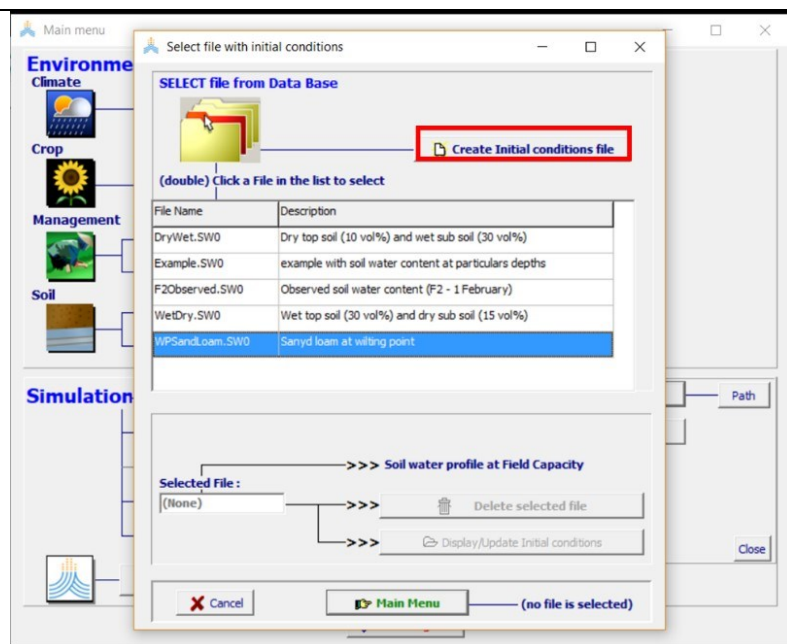


## 6.6. Simulations

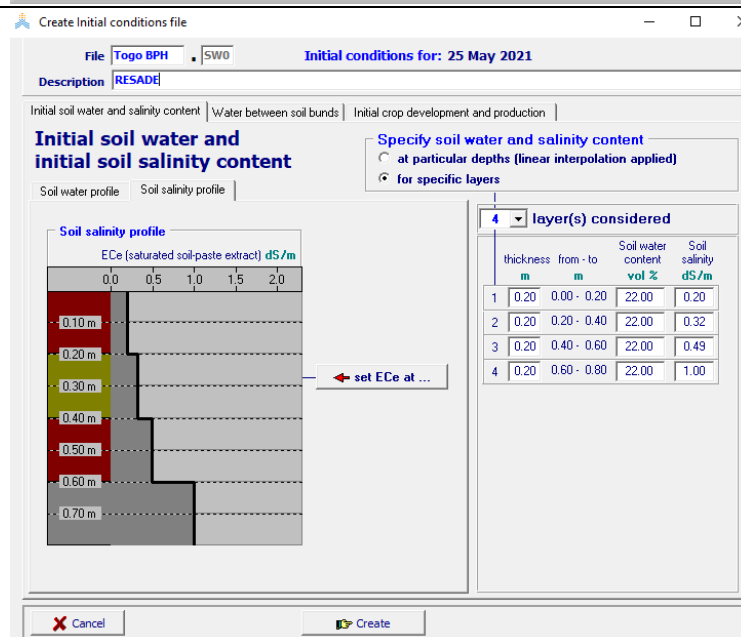
Before launching the simulation, it is necessary to set the initial conditions, mainly the water content in the soil and salinity of the soil. From the Main Menu, click on **Initial conditions** and choose **Select/Create Initial conditions file**.



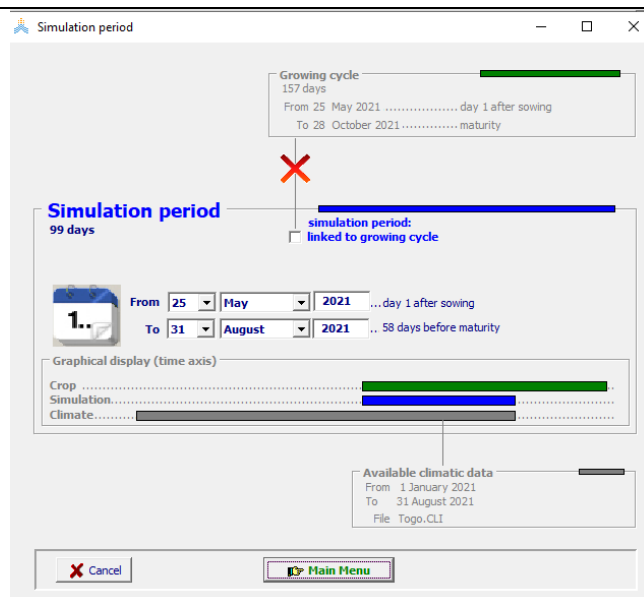
Click on **Create Initial conditions file.**



In the **Initial Conditions** file, for the value Soil water content, set 10%. For Soil salinity, set the value as described in the table of Togo BPH soil proprieties. Click on **Create**.

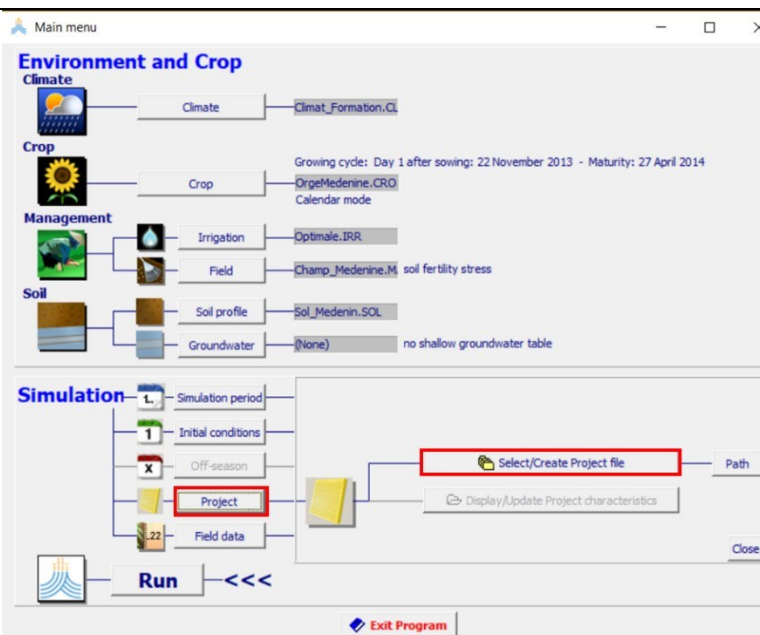


You can select the simulation period or the model will be set automatically according to the available weather data.

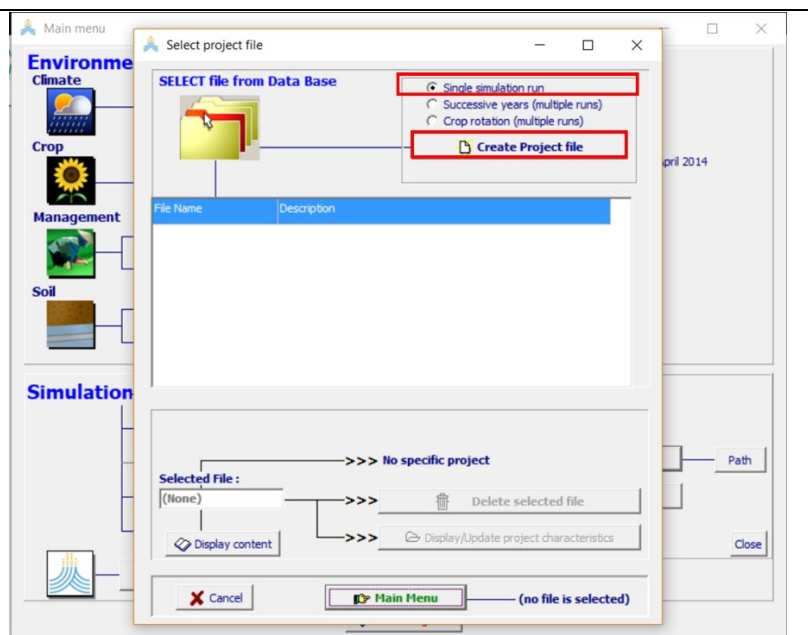


## 6.7. Project registration

To save the project, click on **Project** and then **Select/Create Project file**.

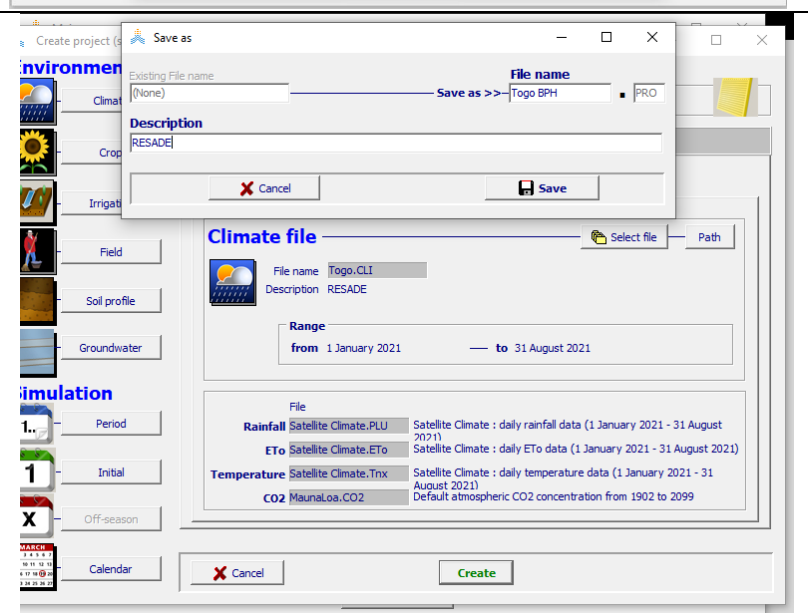


Select **Single simulation run**.



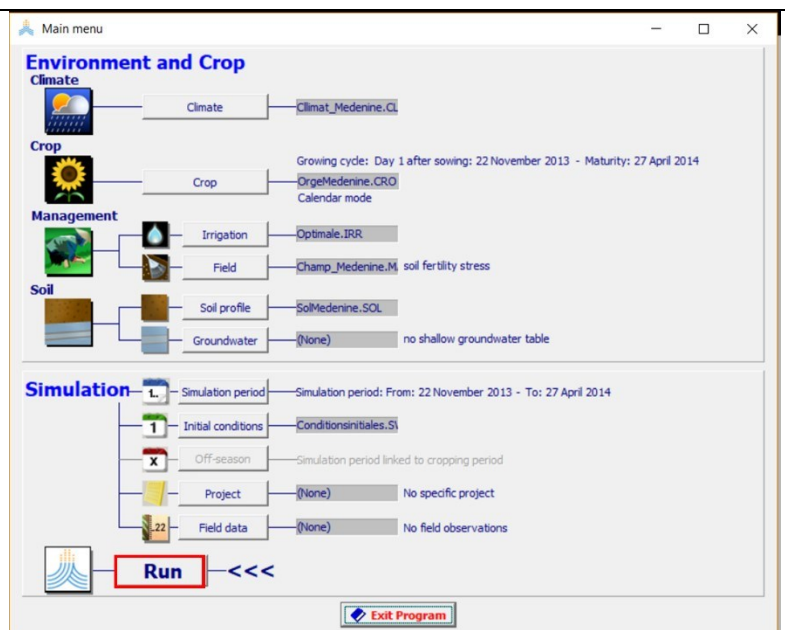
You can check whether the different input parameters have been entered into the software.

Save the project as **Togo BPH.PRO**.

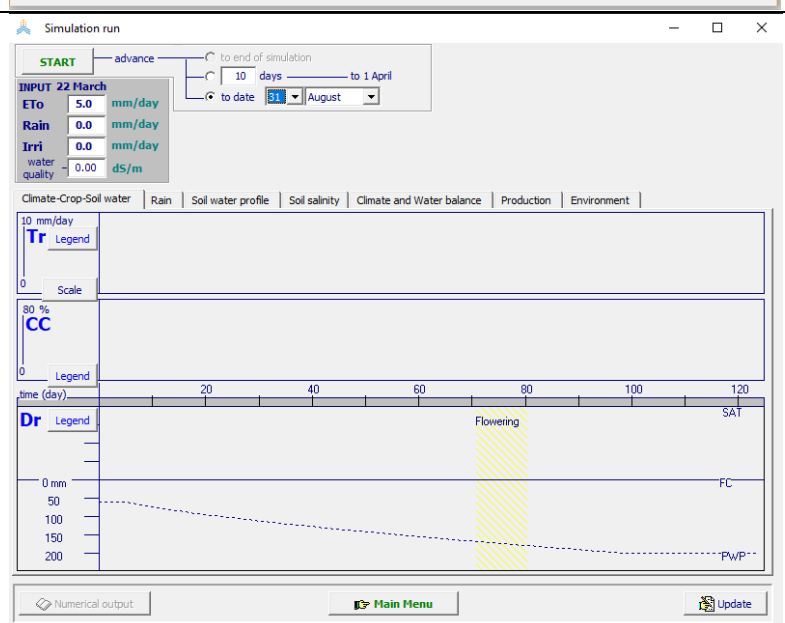


## 6.8. Run the model

To run the simulation, in the Main Menu, click on **Run**.



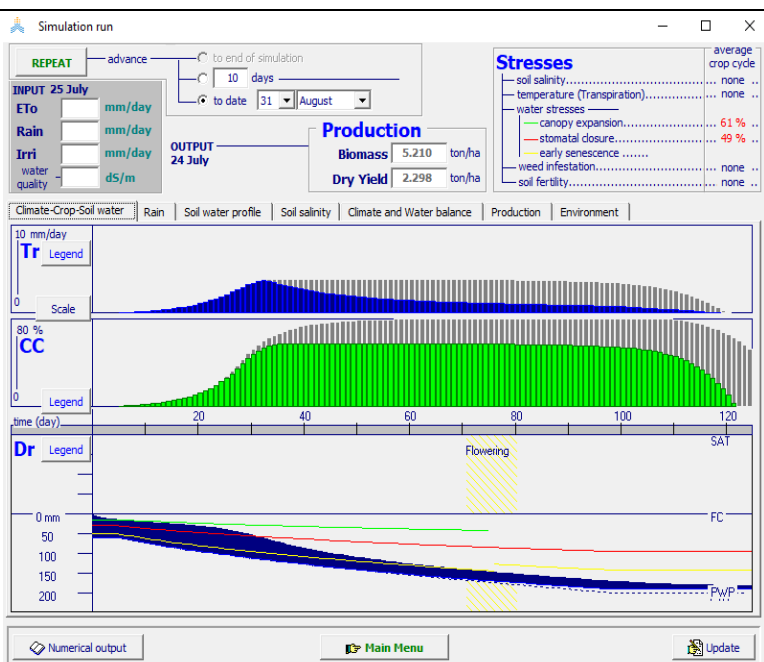
In the simulation window, click on **Start**.





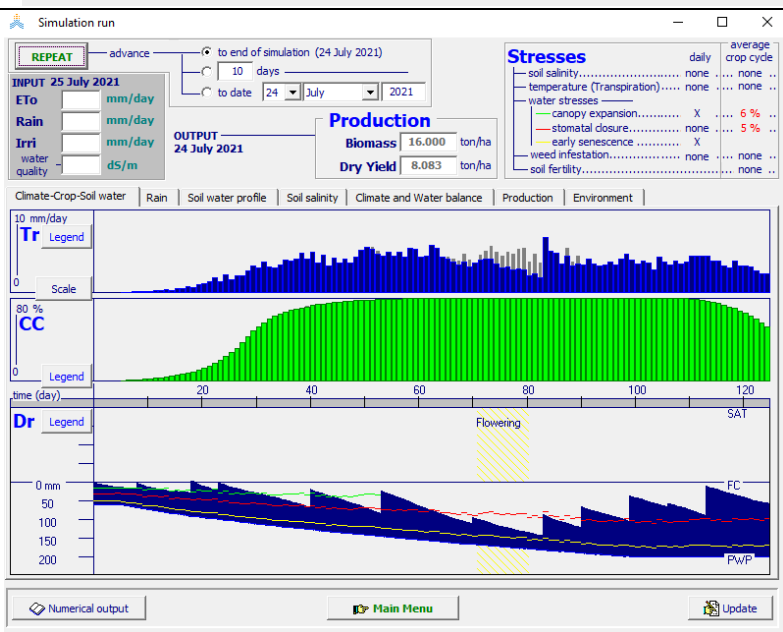
Check production values as well as stresses on the crop.

*Result of simulation without rain.*



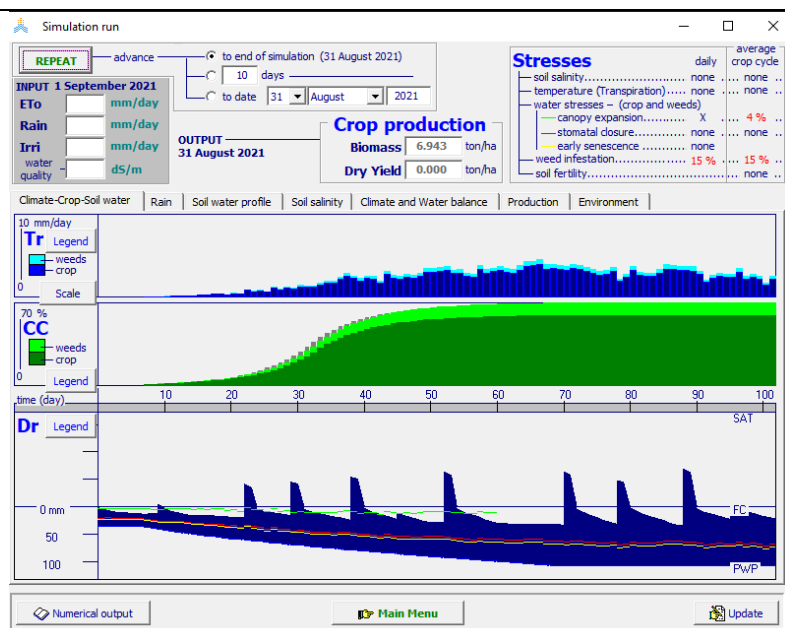
Check production values as well as stresses on the crop.

*Result of simulation with rain.*

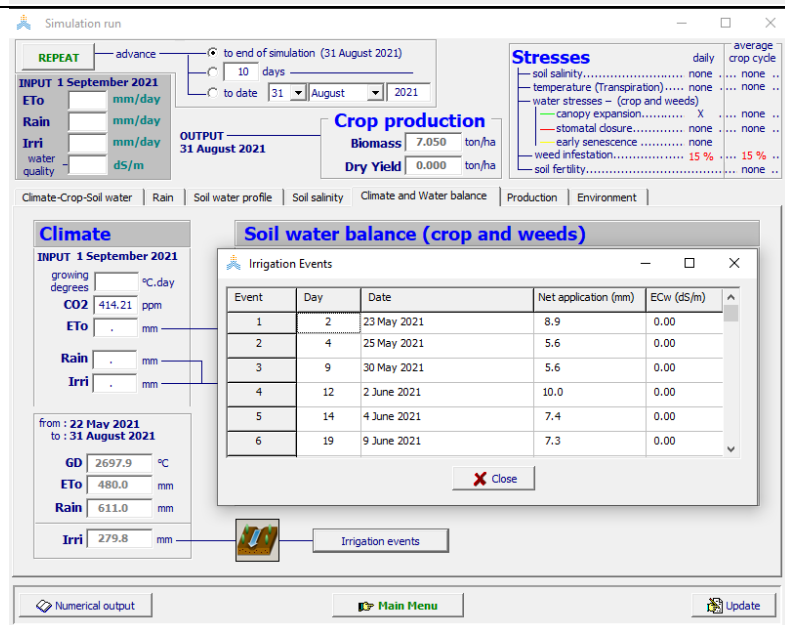


Check production values as well as stresses on the crop.

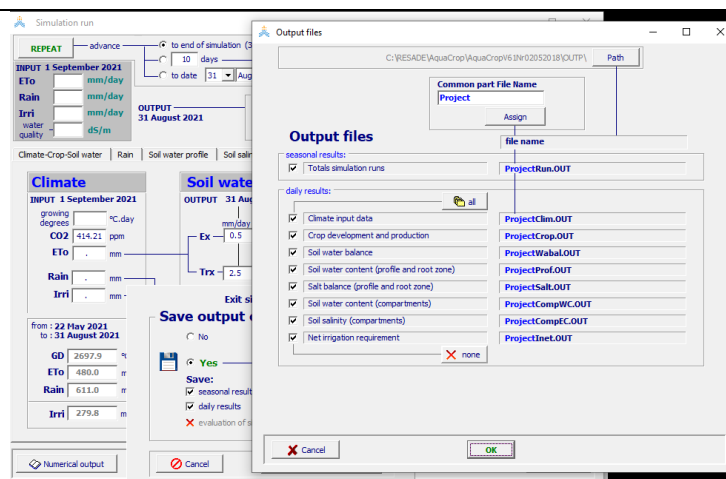
*Result of simulation using the real available data.  
The harvest: not yet.*



To see the proposed irrigation scheduling by AquaCrop according to the input data, go to the tab Climate and Water balance; then click on **Irrigation events**.

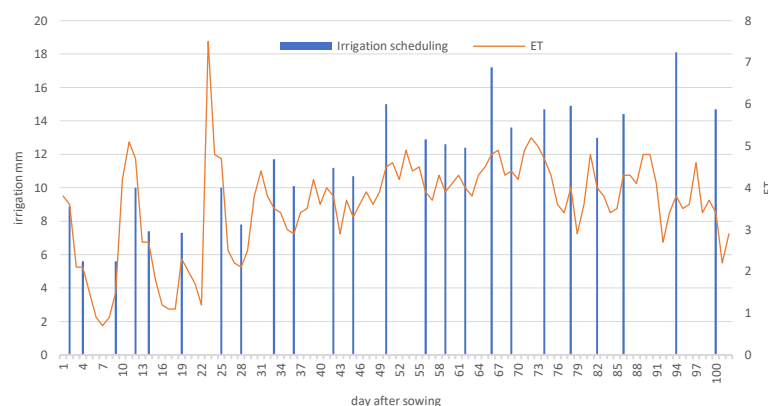


To export the results, in the menu simulation, click on **Main Menu**. A window opens and asks if you want to save the outputs. Select **Yes** and click on **Output files**. In the window that opens, check all the results and click **OK**. The output files are located in AquaCrop/OUTP.



*Irrigation scheduling proposed by AquaCrop according to the input data.*

*Please note that the precipitation data used in this exercise were not accurate.*



## 7. Creation of different scenarios using the model

This part will be developed during training according to the available data.

The proposed different scenarios are related to

- ✓ Effects of field conditions on irrigation scheduling and water productivity
- ✓ Generation of irrigation schedules
- ✓ Salinity: water and soil
- ✓ Genotype effect
- ✓ Temperature effect

## 8. Effects of crop conditions on irrigation planning and water productivity

This part aims to see the effects of changes in crop conditions on irrigation scheduling in the plot.

Thus, based on the parameters of the test plot considered in the previous part, "Getting started with AquaCrop," the following scenarios of operating conditions will be tested:

- Climatic conditions
- Irrigation mode
- Irrigation alert criteria (when and how much)

- Irrigation water quality
- Soil type
- Soil fertility
- Sensitivity of the genotype to salinity

The aim is to examine their impacts on irrigation planning and water productivity.

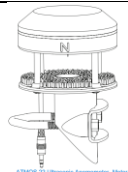
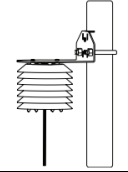

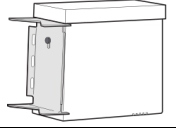

## 9. Methods of characterizing pedoclimatic data to be used in the model in case no field data are available

### 9.1. Sensors planned to be installed by RESADE in each BPH

Data on the variables necessary for the AquaCrop model and irrigation management are the following:

- Atmospheric data (aboveground) to estimate atmospheric evaporative demand, including air temperature, humidity, wind speed, and solar radiation, and water provided as precipitation.
- Belowground data to measure water availability to meet crop water requirements, including soil water content and potential, soil water salinity, soil temperature, and water movement within and below the root zone.

For the atmospheric data, the RESADE project planned to install a weather station that incorporates different weather sensors (precipitation; barometric pressure; maximum wind gust; solar radiation; vapor pressure; air temperature; relative humidity; wind direction; wind speed). Weather data from these sensors can be available in real time on a specific platform. For soil sensors, we will install TEROS-12 sensors from METER group (USA).

Sensors from METER Group	Photo
<b>ATMOS 22 Ultrasonic Anemometer</b> <ul style="list-style-type: none"> <li>• Horizontal wind speed</li> <li>• Wind direction</li> <li>• Wind gust</li> </ul>	
<b>ATMOS 14</b> <ul style="list-style-type: none"> <li>• Temperature sensor</li> <li>• Relative humidity (RH) sensor</li> </ul>	
<b>PYRANOMETER</b> Radiation	
<b>ECRN-50</b> Rain gauge	
<b>TEROS 12</b> The TEROS-12 sensors are precise tools for measuring <ul style="list-style-type: none"> <li>• Volumetric water content (VWC), temperature in the soil and soil-less substrates</li> <li>• Electrical conductivity. It has a maximum EC threshold of 20 dS/m.</li> </ul>	

- Soil temperature

**ZL6 DATA LOGGER**

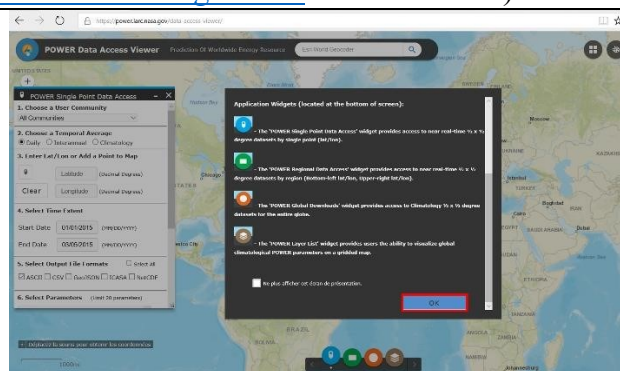
For data storage and download

**9.2. Climate based on satellite data*****Downloading climate data***

In the absence of measured climate data, it is possible to download climate parameters from satellite models that offer good concordance. We propose the site developed by the Worldwide Energy Resource (POWER) Project for this training. POWER is funded through the National Aeronautics and Space Administration (NASA) Applied Sciences Program within the Earth Science Division of the Science Mission Directorate ([website https://power.larc.nasa.gov/data-access-viewer/](https://power.larc.nasa.gov/data-access-viewer/)).

First, go to the [website https://power.larc.nasa.gov/data-access-viewer/](https://power.larc.nasa.gov/data-access-viewer/).

Click **OK**.



The control panel on the left allows you to select:

The user community (Renewable energy, Construction sustainable, and Agroclimatology).

The time step of the data to download.

The coordinates of the point (latitude and longitude).

The time extent of the data to be downloaded.

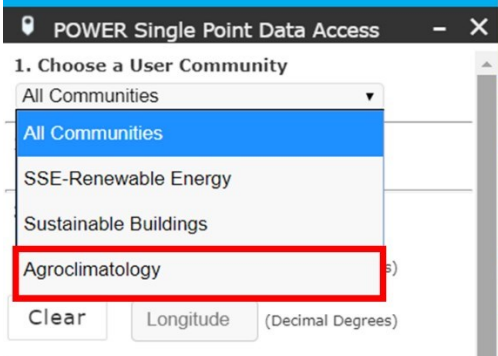
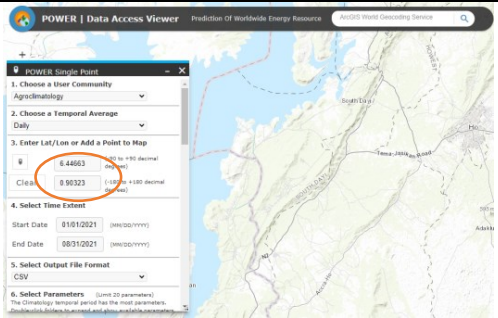
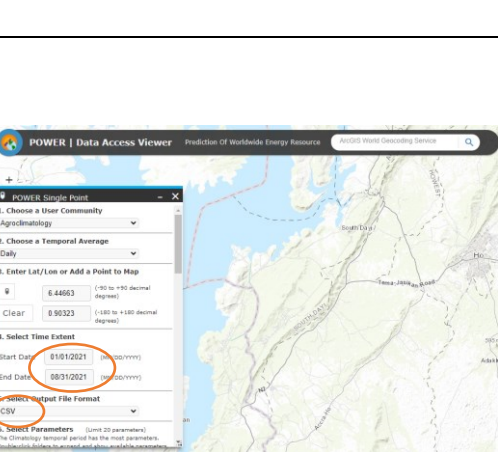
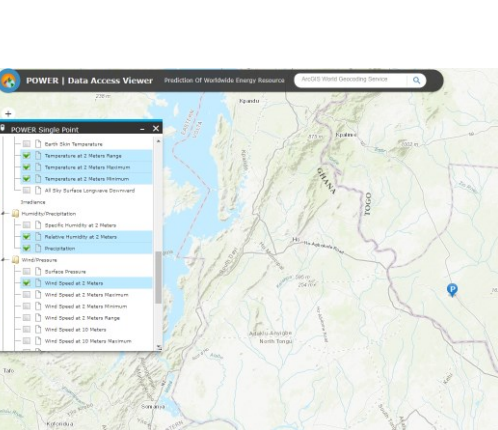
The format to export.

Settings to download.

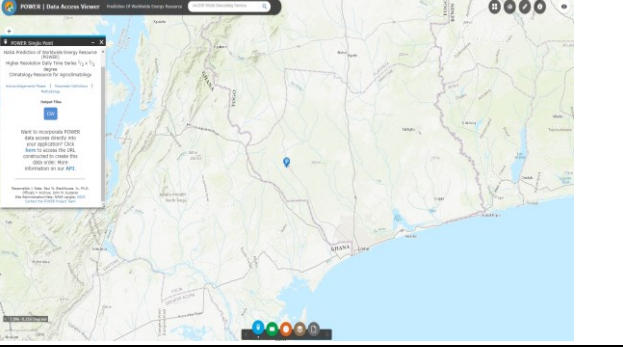
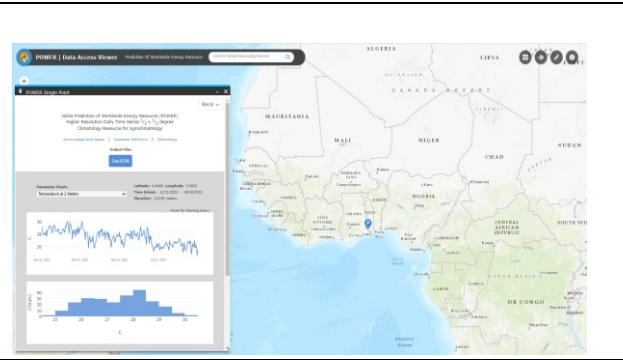
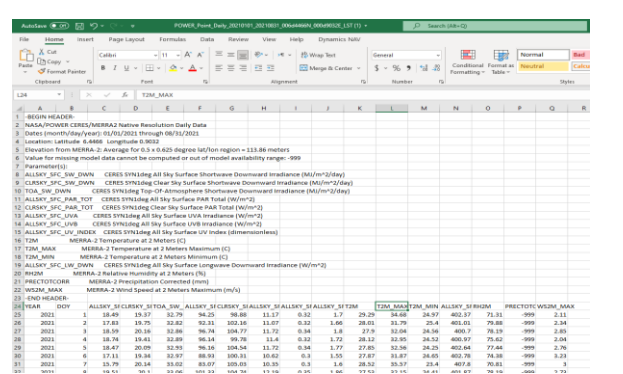
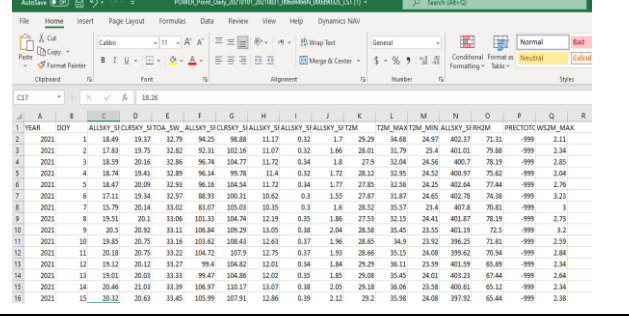
Then submit the download request.

**POWER Single Point Data Access**

- Choose a User Community**  
All Communities
- Choose a Temporal Average**  
☒ Daily ☐ Interannual ☐ Climatology
- Enter Lat/Lon or Add a Point to Map**  
Latitude (Decimal Degrees)  
Clear Longitude (Decimal Degrees)
- Select Time Extent**  
Start Date: 01/01/2015 (MM/DD/YYYY)  
End Date: 03/05/2015 (MM/DD/YYYY)
- Select Output File Formats** ☐ Select All  
☒ ASCII ☐ CSV ☐ GeoJSON ☐ ICASA ☐ NetCDF

<p>1. Selection of the user community: Select Community: Agroclimatology.</p>	
<p>2. Select the Daily 3 time step. Enter the required information for the desired location (e.g., BPH site): Example: Atti-Apédok, Togo Latitude: 6.44652 Longitude: 0.90319</p>	
<p>3. Selection of the period for the data needed to be downloaded. For our exercise, the period selected is from 01/01/2021 to 08/31/2021. <b>Important note:</b> The American system, unlike the French system, considers the months before the days in the dates, so the dates will be displayed as "Month/Day/Year."</p>	
<p>4. For the export format, select <b>CSV format</b>.</p> <p>5. The parameters to be selected are</p> <ul style="list-style-type: none"> <li>- Downward longwave radiative flux: Flux of t in MJ/m<sup>2</sup>/day</li> <li>- Precipitation: Rain in mm</li> <li>- Relative humidity at 2 m: Relative humidity at 2 m in %</li> <li>- Maximum temperature at 2 m: Maximum temperature at 2 m in °C</li> <li>- Minimum temperature at 2 m: Minimum temperature at 2 m in °C</li> <li>- Wind speed at 2 m: Wind speed at 2 m</li> </ul>	



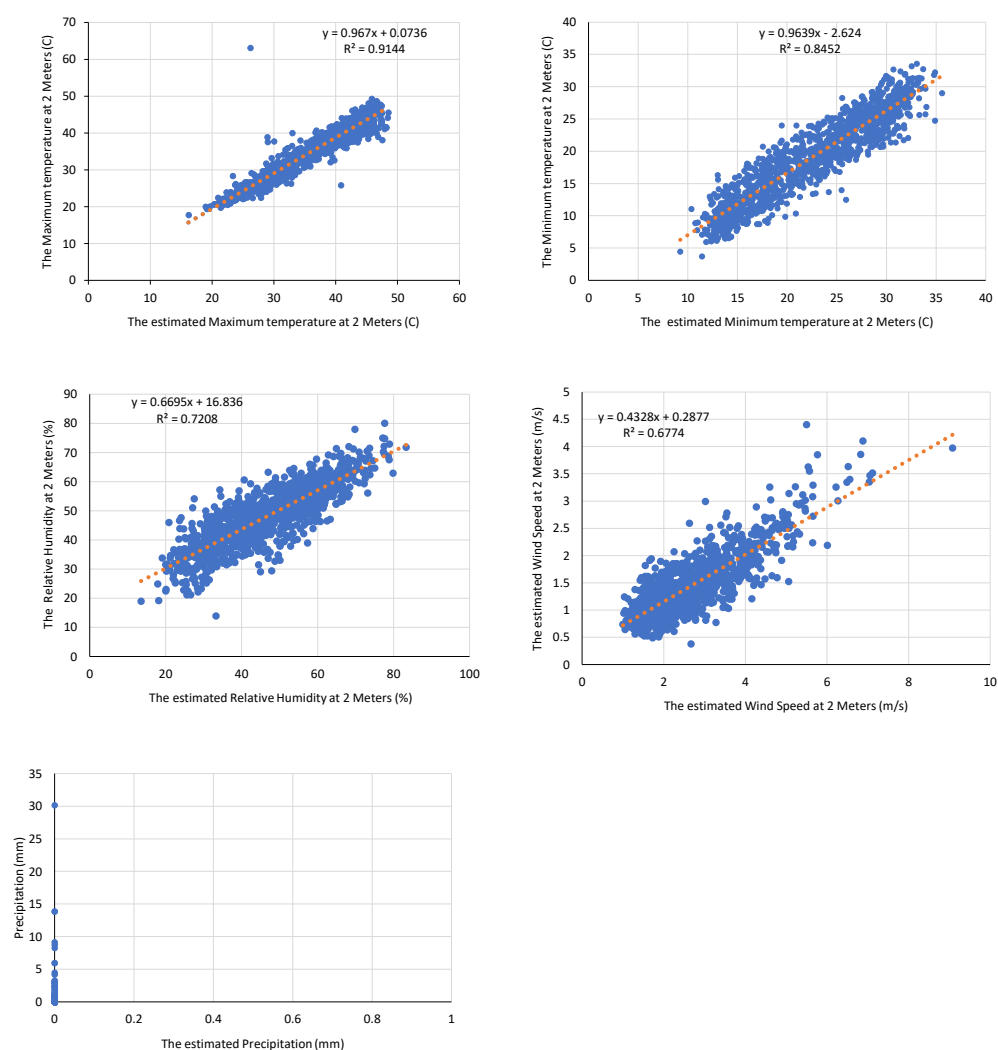
<p>6. Click <b>Submit</b>.</p>	<p>Some parameters unavailable in selected temporal average.  <a href="#">Parameter Definitions</a>   <a href="#">Methodology</a></p> <p><b>7. Submit and Process</b></p> <p><b>Submit</b></p>
<p>7. The data are available in CSV format (Excel).</p>	
<p>8. It is possible to view the parameters to download. Select the parameter to display from the drop-down list and the graph will be drawn automatically. For that, click on <b>GeoJSON</b> instead of <b>CSV</b>.</p>	
<p>10. Open the downloaded file in Excel. Its name will be a code representing the selected period and location GPS. Our example is <b>POWER_Point_Daily_20210101_20210831_006d45N_000d90E_LS T.</b> Once opened, the data are displayed as follows.</p>	
<p>The table should be displayed as follows. You can save the file as "Satellite Climate.xlsx".</p>	

### 9.3 Reliability of uploaded climate data

To check the reliability of uploaded climate data, we compare the satellite values of Tmax, Tmin, average relative humidity, wind speed, and rain with those from data collected from a local weather station for 1,189 consecutive days (Figure 7).

For this exercise, we used the data from a weather station (LiCor 1200, LiCor Inc., Lincoln, Nebraska 68504-5000, USA) located at the research station of the International Center for Biosaline Agriculture (ICBA) (25.09°N; 55.39°E; 48) near Dubai.

You can compare the satellite values of Tmax, Tmin, average relative humidity, wind speed, and rain to the available local weather data in your country.



**Figure 7.** Correlation between the estimated data for the different weather parameters and the collected data from the local weather station for 1,189 days.

This comparison shows that the satellite maximum and minimum temperature data correlate well with those measured at the station. On the other hand, data on relative humidity and wind speed are only acceptable. However, rainfall data are weakly correlated. Therefore, it is advisable to use satellite



climate data with great care. Except for rain, we recommend using a rain gauge with no expensive component. Again, it is advisable to use satellite climate data with great care.

#### 9.4 Soil texture testing

Soil texture testing is quite easy. Other than the possibility of sending the samples to the laboratory to test them, approaching and dealing with your soil is considered an effective solution to obtain sufficient data about the type of soil used in the irrigation process.

Two simple methods can be used. The first, the jar method, is the most common method used for gardening. It is not complicated, but it does require some arithmetic skill to do the job.

This method requires a clear, straight-sided jar with a lid. A pasta sauce or mason jar will work. Remove any bigger pebbles and bits of organic matter. Also have a measuring tape or ruler handy. For more details, please visit the website

<https://www.the-compost-gardener.com/soil-texture-testing.html>.

The second method, texture of the soil by the feel or ribbon method, is not complicated, but, due to ignorance of its details, it is considered for experts only. But it can be considered easier and faster than the jar method (<https://www.the-compost-gardener.com/soil-texture-testing.html>). For more details, please visit <https://www.youtube.com/watch?v=GWZwbVJCNe>.

Here is the USDA key for this section of soil texture testing by feel (Figure 8).

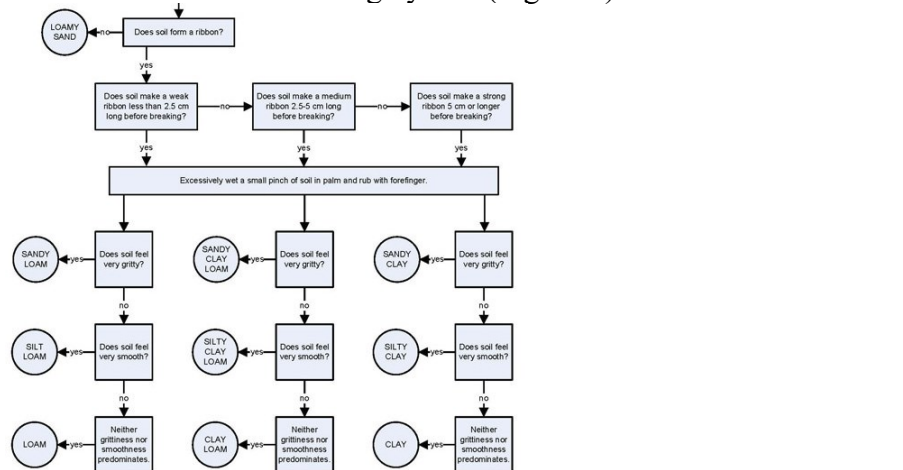


Figure 8. USDA soil texture by feel key.

#### 9.5 Soil water properties from the Soil Water Characteristics software

In the absence of data on water content characteristics of the soil (namely,  $\theta_{sat}$ ,  $\theta_{cc}$ , and  $\theta_{pfp}$ ), it is possible to estimate these values from the results of the soil particle size analysis based on pedotransfer functions. This is one of the most-used functions developed by Saxton et al. (1986 and 2005). The SPAW software developed by USDA is based on these pedotransfer functions.

SPAW Hydrology software can be downloaded from the following site:

<https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/drainage/?cid=stelprdb1045331>.

Otherwise, the installable SPAW Hydrology Setup (6.02.70).exe is provided during the workshop.

For the following exercise, we used data from the laboratory soil analysis done at ICBA for soil samples collected from the PBH site in Togo and Liberia.

**Table 2.** Soil physical properties for BPH-Atti-Apedok-Togo, laboratory results.

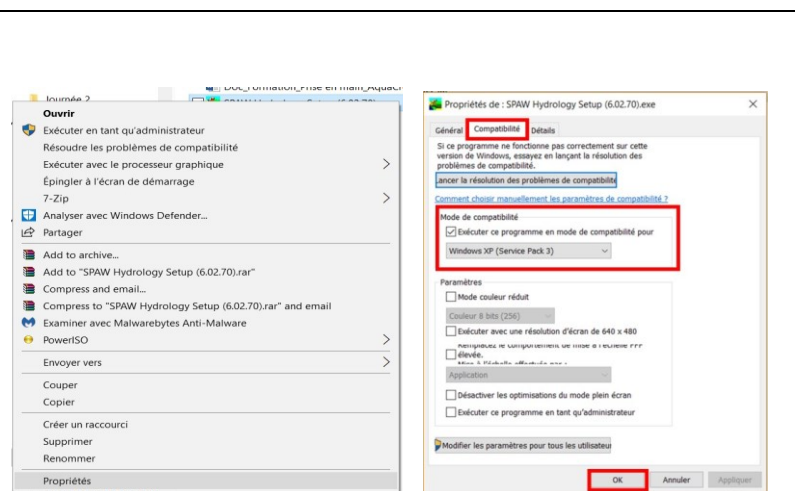
Sample	Depth (cm)	pH 1:1	EC 1:1 ms/cm	Clay (%)	Silt (%)	Sand (%)	% OM	% C
Togo1	0-20	5.14	0.243	8.352	22.6	69.048	2.02	1.17
Togo1	20-40	5.54	0.325	10.072	25.32	64.608	1.67	0.97
Togo1	40-60	5.63	0.494	15.992	21.12	62.888	2.46	1.43
Togo1	60-80	5.54	0.700	17.992	16.80	65.208	2.63	1.53
Togo1	80-100	5.18	1.016	24.672	16.48	58.848	3.50	2.03
Togo2	0-20	5.20	0.192	9.032	13.76	77.208	2.76	1.60
Togo2	20-40	5.50	0.088	8.192	11.60	80.208	1.62	0.94
Togo2	40-60	5.92	0.059	4.552	11.28	84.168	0.79	0.46
Togo2	60-80	5.96	0.094	17.232	9.52	73.248	2.60	1.51
Togo2	80-100	5.83	0.180	28.032	8.72	63.248	3.92	2.27

**Table 3.** Soil physical properties for BPH-Liberia, laboratory results.

Sample	Depth (cm)	pH 1:1	EC 1:1 ms/cm	Clay (%)	Silt (%)	Sand (%)	% OM	% C
Liberia	0-20	4.05	0.041	1.35	6.64	92.008	2.51	1.46
Liberia	20-40	4.01	0.037	1.91	5.60	92.488	2.53	1.47
Liberia	40-60	4.19	0.030	4.19	7.44	88.368	3.15	1.83
Liberia	60-80	4.00	0.022	12.11	6.72	81.168	2.92	1.69
Liberia	80-100	3.96	0.021	13.07	5.48	81.448	2.57	1.49

For the detailed soil chemical proprieties (Ca Mg, Cl, Na, available K, P, and N), please see Annex 1.

In case of installation problems, right-click on **Installable SPAW Hydrology Setup (6.02.70).exe**. Go to **properties**. On the **Compatibility** tab, check the compatibility mode to run this program in **compatibility mode for Windows XP (Service pack 3)**. Click **OK**. Start the installation.

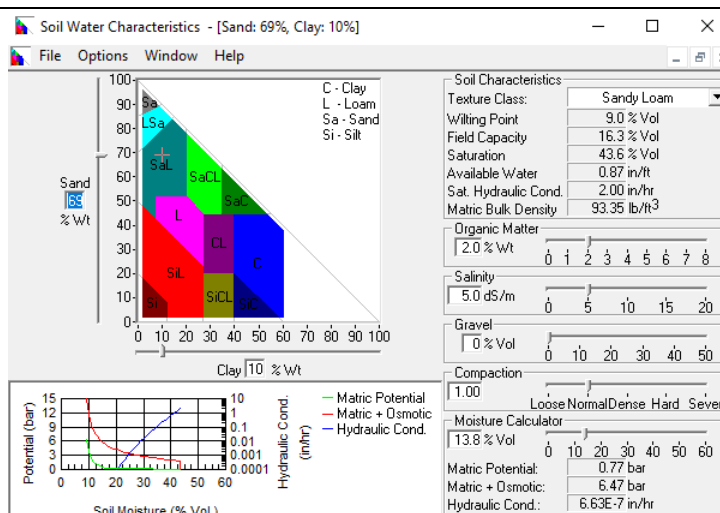


Once installed, launch the program:

### Soil Water Characteristics

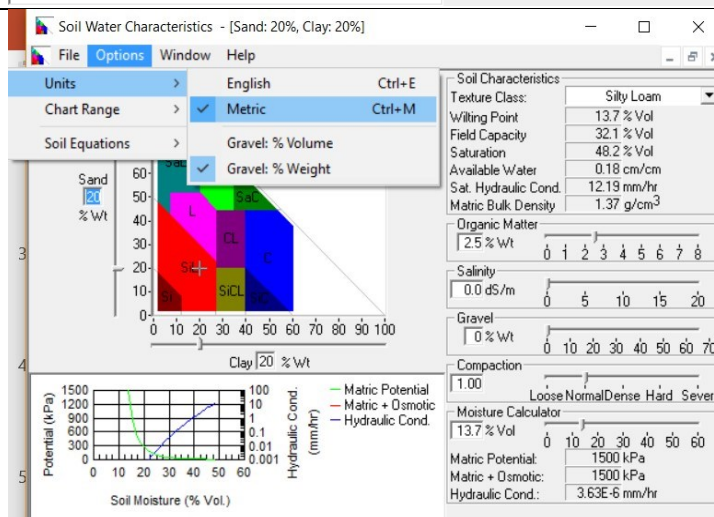


Under the SPAW Hydrology tab,



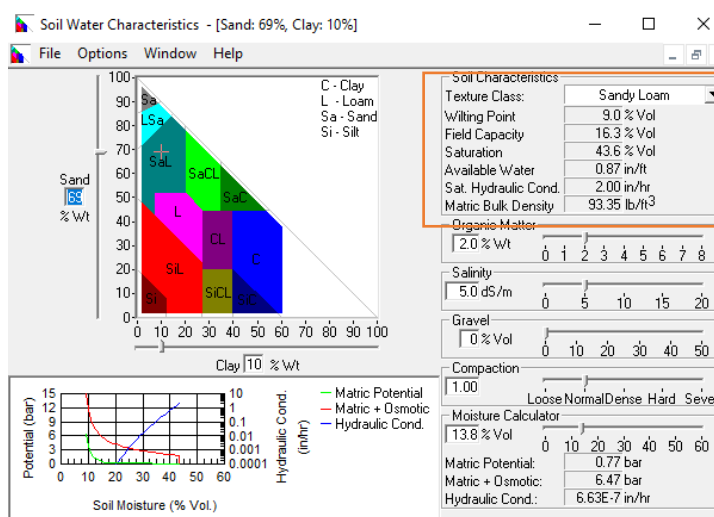
first of all, you have to change the system of units.

Go to **Options, Units**, and select **Metric** and then **Gravel: %Weight**.



To determine the characteristic water content of the soil ( $\theta_{sat}$ ,  $\theta_{cc}$ , and  $\theta_{pfp}$ ), it is sufficient to introduce the % of clay and sand at the level of the textural triangle.

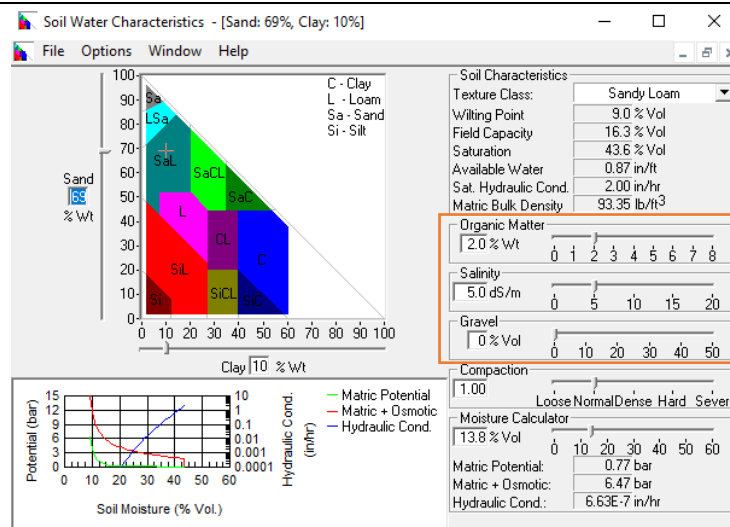
The textural class of the sample as well as the values of  $\theta_{pfp}$ ,  $\theta_{cc}$ ,  $\theta_{sat}$ , useful reserve, hydraulic conductivity at saturation, and bulk density will be automatically displayed at the top right.



The entry **Soil Water Characteristics** also allows you to examine the influence of the richness of the soil in

- organic matter,
- soil salinity,
- the % of stone, and

compaction on these characteristic parameters.



These estimated results can be entered directly into the AquaCrop software for better water management, such as for irrigation scheduling.

## Annex 1

**Table 1.** Soil chemical properties: Ca Mg, Cl, Na, available K, P, and N.

Sample	Depth (cm)	Ca (meq/L)	Mg (meq/L)	Cl (meq/L)	Na (mg/L)	Na (meq/L)	K (mg/L)	K (meq/L)	P (mg/kg)	N (ppm)
Togo1	0-40	2.82	2.10	72.00	174.20	7.57	1.19	0.03	1.87	3.64
Togo1	40-80	3.44	2.02	118.50	323.84	14.08	1.19	0.03	0.62	2.80
Togo1	80-100	3.92	11.56	169.50	441.03	19.18	1.78	0.05	10.27	4.34
Togo 2	0-40	1.48	6.70	10.50	50.99	2.22	0.86	0.02	3.11	2.66
Togo 2	40-80	0.56	0.90	19.00	59.12	2.57	0.86	0.02	1.25	1.82
Togo 2	80-100	0.74	0.64	13.50	63.81	2.77	0.86	0.02	14.32	1.96
Liberia 1	0-40	0.56	0.66	12.50	19.75	0.86	0.86	0.02	2.18	1.68
Liberia 2	40-100	0.82	1.04	11.00	23.93	1.04	0.42	0.01	1.25	1.82