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AQUACROP WATERPRODUCTIVITY MODEL SIMULATION FOR MAIZE USING DIFFERENT METHODS OF CALCULATING EVAPOTRANSPIRATION

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Abstract

Maize is a drought-resistant plant, a feature ensured by low water consumption, the highly developed and deep root system, and has the ability of the plant to adapt to drought conditions by reducing the perspiration surface. In this paper, the water productivity model simulation Aquacrop was used for maize crop. AquaCrop is a crop water productivity model developed by the Land and Water Division of FAO to address food security and to assess the effect of environment and management on crop production. AquaCrop simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. There were analyzed climatic, water, soil and crop parameters from April 1st to August 31 for the years 2014-2017 for maize crop. In the Aquacrop model we used two different methods for evaluate the evapotranspiration: simulated Evapotranspiration with ETo Calculator module and calculated Evapotranspiration using Penman-Monteith. Constantly monitoring and observation the risk/stress phenomena, lead to the most effective measures to prevent and mitigate the effects on the obtained agricultural productions.

***Key words**: agrometeorology, evapotranspiration, maize, productivity, water stress.*

INTRODUCTION

There is an urgent need to increase the efficiency and productivity of agricultural water use in response to growing pressures on finite water resources worldwide (Schewe et al., 2014; Taylor, 2014; Richey et al., 2015). Critically, tackling this challenge will require a sound understanding of the biophysical response of crop yield to water (Steduto et al., 2012). The relationship between crop yield and water supply traditionally has been based on empirical production functions (Doorenbos and Kassam, 1979), which cannot be extrapolated reliably beyond the location for which they were developed.

Irrigations are measures of agricultural technique that consist in the directed supply of the soil with additional volumes of water, compared to those naturally received from rainfall and from the groundwater, with the purpose of intensifying agricultural production and stabilizing crops. Associated with the administration of fertilizers, with the use of varieties and hybrids with great productive potential, with the use of different cultivation technologies, under the conditions of a good work organization, irrigation determines a substantial increase in the yield of agricultural crops.

Population growth, land use change, climate change, and increasing demand in non-agricultural sectors profoundly affect the availability and quality of water resources for irrigated agriculture. Amid increasing concerns that water scarcity and food security are among the main problems to be faced by many societies in the 21st century, a global challenge for the agricultural sector is to produce more food with less water (Greaves et al., 2016).

It is important to realize that several crop models are already available in literature to simulate yield response to water. They are used mostly by scientists, graduate students, and advanced users in highly commercial farming. However, it is also important to recognize that these models present substantial complexity and are rarely used by the majority of FAO target users, such as extension personnel, water user associations, consulting engineers, irrigation and farm managers, planners and economists. Furthermore, these models require an extended number of variables and input parameters not easily available for the diverse range of crops and sites around the world. Some of these variables are much more familiar to scientists than to end users (e.g., leaf area index -LAI- or leaf water potential –ψl-). Lastly, the insufficient transparency and simplicity of model structure for the end user were considered strong constraints for their adoption (Reference Manual, Chapter 1 - AquaCrop, 2011).

Maize is one of the most important crops known to humankind, accounting for nearly 30% of the total global grain production. The crop is cultivated on more than 197 million ha of land worldwide, producing over 1.134 million of grain (FAO, 2017).

The objective of this work was to analyze the maize productivity using soil, meteorological and groundwater as input parameters required for the AquaCrop water balance model, in order to obtain biomass and grain yield data of a rainfed-simulated corn crop, for 2014-2017 in Calarasi region.

AquaCrop is a crop water productivity model developed by the Land and Water Division of FAO to address food security and to assess the effect of environment and management on crop production.

AquaCrop simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. AquaCrop uses only a relatively small number of explicit parameters and mostly-intuitive input-variables requiring simple methods for their determination. The calculation procedures are grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system. AquaCrop is designed to be widely applicable under different climate and soil conditions, without the need for local calibration, once it has been properly parameterized for a particular crop species. To this end the model is constructed with parameters falling into two groups. One group is considered conservative, in that the parameters should remain basically constant under different growing conditions and water regimes. The other group encompasses parameters that are dependent on location, crop cultivar, and management practices, and must be specified by the user (Figure 1).

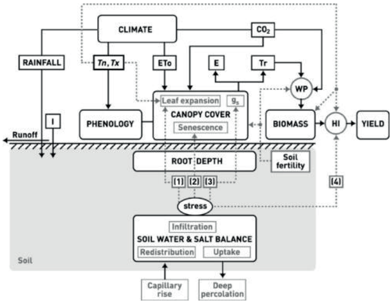


Figure 1. Chart of AquaCrop indicating the main components of the soil-plant-atmosphere continuum and the parameters driving phenology, canopy cover, transpiration, biomass production, and final yield (Reference Manual, Chapter 1 - AquaCrop, 2011)

A critical stipulation for many of the conservative parameters is that their values are based on data obtained from modern high-yielding cultivars grown with optimal soil fertility without limitation by any mineral nutrient, particularly nitrogen.

MATERIALS AND METHODS

The analysis of the thermal and water resources implies the identification of the parameters and the critical thresholds on specific calendar intervals that correspond to the process of growth and development of the maize plants during the vegetation period.

Real evapotranspiration (ETR) represents the amount of water actually lost depending on atmospheric parameters, soil and plant status. It is understood that the real evapotranspiration, in the case of a cultivated or uncultivated vegetable cover, can reach potential values only under the conditions of unlimited water supply from the soil. The intensity of water loss by evaporation from the soil or by evapotranspiration from the leaf surface, is largely determined by the vapor pressure gradient from the leaf or soil surface and from the atmosphere.

For the accomplishment of this work, the climatic data from April 1st to August 31st for the years 2014-2017 were processed in the analysis of the vegetation period of the maize crop. Also, these data were compiled within the AquaCrop model in order to highlight the agricultural potential of the study area when using an irrigation method.

AquaCrop simulates in daily time steps because plant responses to water status are highly dynamic and cannot be easily represented as weekly or 10-day means. The model runs with 10-day or monthly mean temperature and evapotranspiration (ETo) files, through interpolations. The results are, however, obviously approximations, and should not be used to calibrate or validate the model except as the last resort. ETo is a key input for AquaCrop as the model calculates daily crop transpiration (Tr) and soil evaporation (E) using daily ETo values. ETo was calculated using the *FAO **Penman-Monteith*** equation from full daily weather data sets, as described by Allen et al. (1998). In this paper we also used a simulation program to do this calculation, named ***ETo Calculator*** (FAO, 2009) available on the FAO website, Allen et al. (1998).

ETo was obtained from the data recorded at the weather stations through the FAO Penman-Monteith equation and also through the ETo Calculator application. In the ETo Calculator application, data from a weather station can be specified in a wide variety of units, meteorological data can be imported, and procedures for estimating missing climate data are available. Climate files (*ETo and *TMP) can be exported to AquaCrop.

ETo represents the evapotranspiration rate on a reference surface, without water. The reference surface is considered worldwide as a large, flat surface covered with grass. The culture covers the whole soil, is well watered and develops under optimum vegetation conditions.

The rougher the approximation of ETo, the less reliable would be the simulated results and derived AquaCrop parameters.

The climatic indicators used in the simulations performed by *ETo Calculator* and the Aquacrop model were:

- The cumulative precipitation quantities during the April-September 2014, 2015, 2016 and 2017 periods;
- The average monthly temperatures recorded between April-September 2014, 2015, 2016 and 2017.

The ETo Calculator application evaluates the potential reference evapotranspiration from the weather data through the FAO Penman-Monteith equation. This method was chosen by FAO because it accurately approximates the potential evapotranspiration in the analyzed perimeter, is physically based and explicitly incorporates both physiological and aerodynamic parameters.

The meteorological data needed for calculating the ETo using the *FAO **Penman-Monteith*** equation: the actual duration of sunshine in a day - n (hour/day), the minimum and maximum air temperature (°C) and the rainfall (mm) between April 1st to August 31st for period 2014-2017.

The AquaCrop program can manage daily, decadal and monthly climate data. The data can be exported to several units of measurement and are data from commonly used climatic parameters. By selecting the minimum and maximum limits of the weather data, the program applies a quality check when specifying or importing data. The specified and derived climate data, including ETo, can be exported to text files compatible with AquaCrop or graphically represented in different user-specified modes.

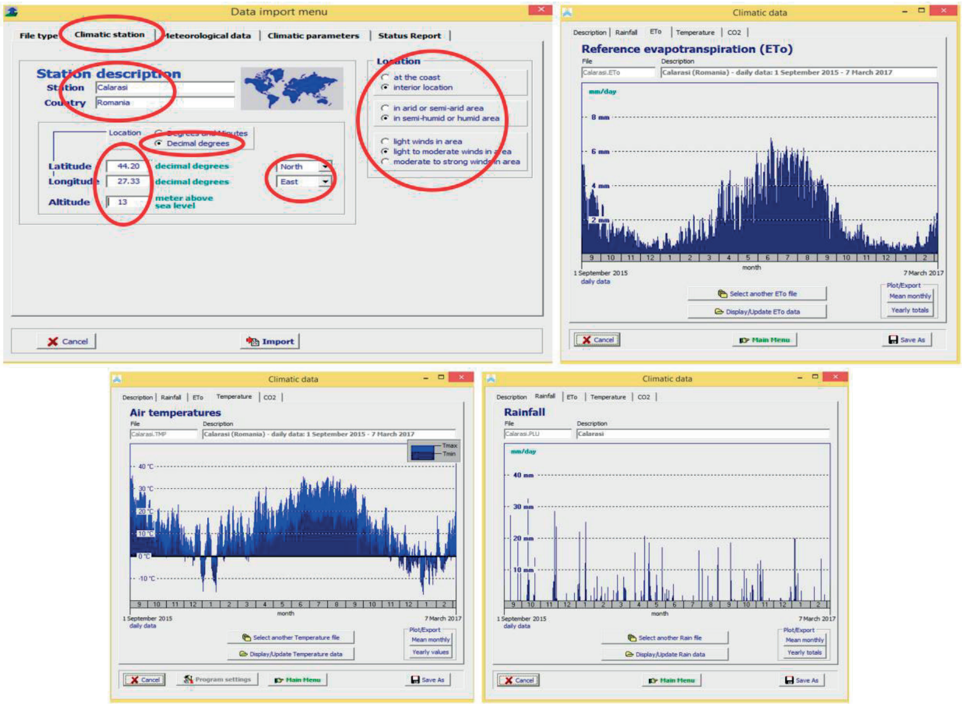
RESULTS AND DISCUSSIONS

In order to simultate AquaCrop response of crop production to water, were gathered daily meteorological parameters for one station, namely Călărași (NMA National Meteo Network), for the following period April 1st to August 31st for period 2014-2017.

AQUACROP model input includes different types of data: climate (meteorological), maize crop, soil, groundwater and irrigation data.

The weather data were needed to calculate the reference evapotranspiration (ETo - calculated according to FAO standards) using the ETo Calculator application (software developed by the FAO Department of Land and Water).

The meteorological data were uploaded: the actual duration of sunshine in a day - n (hour/day), the minimum and maximum air temperature (°C) and the rainfall (mm). In addition, there are the climatic station details to take into account, such as latitude, longitude, altitude and the location of the station, Figure 2.



Station description

Station: Calarasi

Country: Romania

Location: ○ Degrees and Minutes ● Decimal degrees

Latitude: 44.20 decimal degrees North

Longitude: 27.33 decimal degrees East

Altitude: 13 meter above sea level

Location: ○ at the coast ● interior location

○ in arid or semi-arid area ● in semi-humid or humid area

○ light winds in area ● light to moderate winds in area ○ moderate to strong winds in area

Reference evapotranspiration (ETo)

File: Calarasi.ETo

Description: Calarasi (Romania) - daily data: 1 September 2015 - 7 March 2017

Air temperatures

File: Calarasi.TMP

Description: Calarasi (Romania) - daily data: 1 September 2015 - 7 March 2017

Rainfall

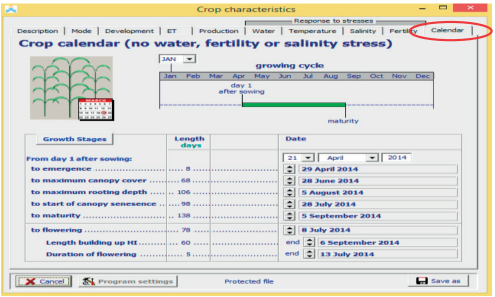
File: Calarasi.PLU

Description: Calarasi

Figure 2. The climatic data for Călărași station

Maize crop data
FAO calibrated the agricultural parameters for the main crops and provided them as predefined values in this model. However, the user has the option to change these values so as to return the crop specificity according to area, climate, soil, etc. In this paper, for the characteristics of the crop were introduced data regarding the date of sowing, the method of sowing, average time intervals specific to the period of vegetation of maize, the thermal thresholds that can affect the development of the plants. For maize crop simulation, the following vegetative data were necessary (Figure 3):

- the sowing date;
- the initial canopy cover (%);
- the type of planting method, seedling (cm^2/plant);
- from day 1 after sowing to: emergence, maximum canopy cover, start of canopy senescence, maturity, flowering, maximum rooting depth (days);
- the length building up to harvest index (days);
- the duration of flowering (days);
- the threshold temperatures for crop development (minimum and maximum air temperature - °C).



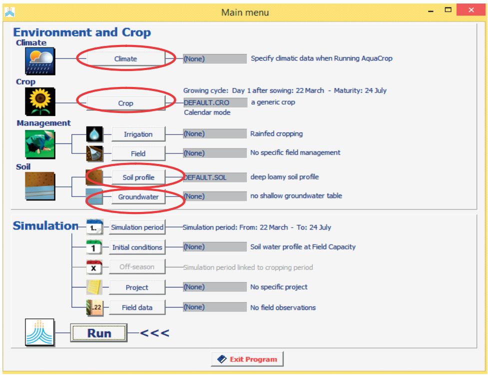
Crop calendar (no water, fertility or salinity stress)

Growth Stages	Length days	Date
From day 1 after sowing:		21 April 2014
to emergence	8	29 April 2014
to maximum canopy cover	68	28 June 2014
to maximum rooting depth	106	5 August 2014
to start of canopy senesence	98	28 July 2014
to maturity	138	5 September 2014
to flowering	78	8 July 2014
Length building up HI	60	end 6 September 2014
Duration of flowering	5	end 13 July 2014

Figure 3. AquaCrop - crop data

Soil characteristics for AquaCrop simulation includes soil type, number of layers, thickness for each layer (m), curve number and readily evaporable water (mm); and the groundwater data: if the depth is constant or not, water quality, depth at which the groundwater is present (meters bellow the soil surface), salinity (dS/m).
All the previously mention data are necessary in order to create the following AquaCrop files (Figure 4):

- 1 climate file;
- 2 crop files, for wheat and maize;
- 1 soil profile file;
- 1 groundwater file.



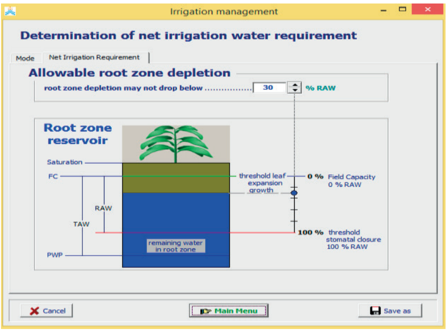
Climate: (None) Specify climatic data when Running AquaCrop
Crop: Growing cycle: Day 1 after sowing: 22 March - Maturity: 24 July
DEFAULT.CRO a generic crop
Calendar mode
Irrigation: (None) Rainfed cropping
Field: (None) No specific field management
Soil profile: DEFAULT.SOL deep loamy soil profile
Groundwater: (None) no shallow groundwater table
Simulation period: Simulation period: From: 22 March - To: 24 July
Initial conditions: (None) Soil water profile at Field Capacity
Off-season: Simulation period linked to cropping period
Project: (None) No specific project
Field data: (None) No field observations

Figure 4. The AquaCrop menu and each file type created (NMA, 2018)

As for the irrigation file, the user has the option of determining whether the water needed to develop the crop comes strictly from rainfall or if a irrigation method is applied. If the land is irrigated, the irrigation method can be chosen, the watered surface, for each watering, the quality of the water is specified, the time at which it will be irrigated and the amount of water related. Also, it is possible to establish the net irrigation requirement and a program of application of the watering rules according to time and depth. Since the criteria may change during the vegetation period, the program may apply, depending on the phenological phase in progress, certain quantities of water. In this paper, the method of irrigation through furrows was chosen, ensuring an application on the whole cultivated area and requiring that the water supply available to the plants at the root level should not fall below 70% (Figure 5).

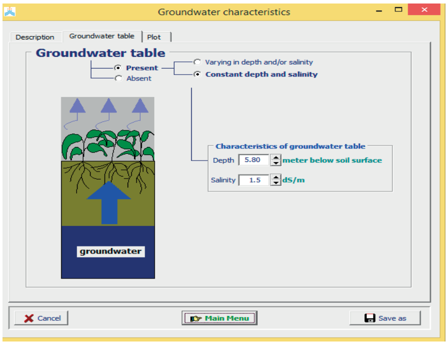
The characteristics of the groundwater considered by the model are its depth and salinity. The average depth of the groundwater in the study area is 5.8 meters, and the salinity is 1.5 dS/m (Figure 6).

For maize, precipitation registered in the summer months have a decisive influence on the final yield, and their uniform distribution is more important than the total amount of rainfall.



root zone depletion may not drop below .... 30 % RAW

Figure 5. AquaCrop - irrigation data



● Present
○ Absent
○ Varying in depth and/or salinity
● Constant depth and salinity
Depth 5.80 meter below soil surface
Salinity 1.5 dS/m

Figure 6. AquaCrop - groundwater data

It can be observed that **2014** is the **rainiest period** from those analyzed and that **2015** is the period in which the **precipitation deficit** was more pronounced (Figure 7).

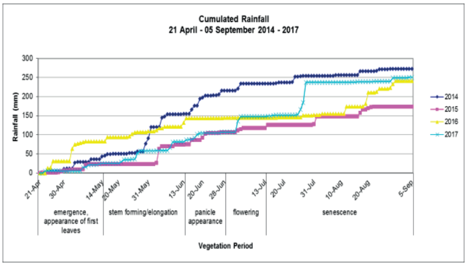


Figure 7. Cumulated rainfall, April-September, 2014-2017, Giurgiu meteorological station (NMA, 2019)

The *maximum air temperature* varies in the vegetation period, but more important are the values above 32°C registered in June 1- August 31, this being a biological threshold for resistance for the agricultural crops, affecting the growth and development processes and production in terms of quantity and quality. In accordance, in the 4 years analyzed, the number of days with the maximum air temperature which exceeds 32°C (June 1-August 31) ranges between 25 (2014) and 46 (2015), out of a total of 92 days (Figure 8).

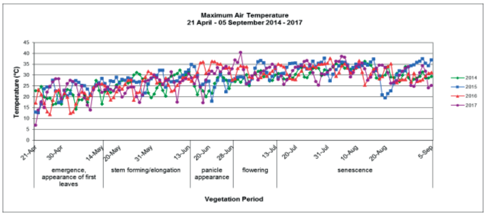


Figure 8. Maximum air temperature, April-September, 2014-2017, Giurgiu meteorological station (NMA, 2019)

In a second step, were calculated daily evapotranspiration database, based on the *Penman-Monteith equation* (ETP).

The comparison between the two parameters of evapotranspiration, simulated with *ETo Calculator* (ETo) and calculated by *Penman-Monteith* (ETP), is presented below.

The evapotranspiration were obtained by two different methods: simulated ETo Calculator module (FAO, 2017) and calculated Evapotranspiration using Penman-Monteith (Figure 9).

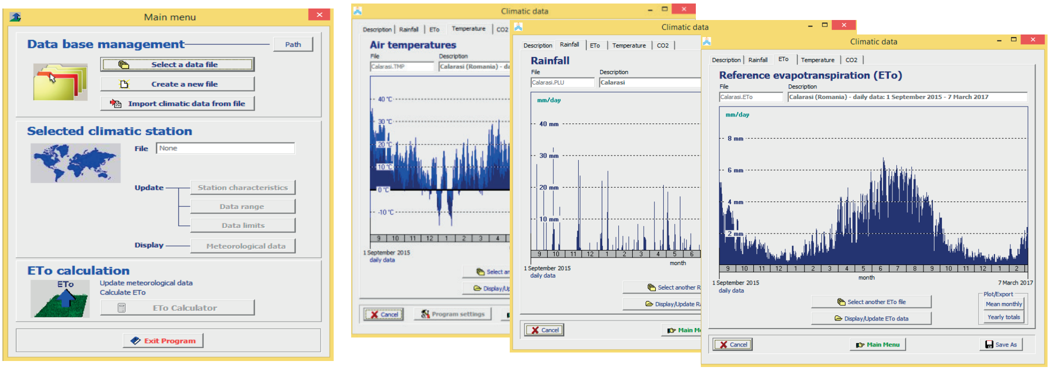


Figure 9. ETo Calculator: rainfall, reference evapotranspiration and temperature plots

Between April 21-September 5, 2014, which corresponds to the vegetation period in maize, the ETo values simulated using the ETo Calculator application are generally similar to the ETP data by the Penman-Monteith method. Deviations are between -1.4 mm/day, recorded on September 5th, in the maturity phase (milk/wax/full) and 1.0 mm on June 28, in the panicle phase, as well as on August 02, also in the maturity phase of the maize crop (Figure 10).

The estimation of the evolution of evapotranspiration (ETo) during the vegetation period active in maize cultivation in 2015 using the *ETo Calculator* application indicates values of this parameter between 1.8 mm and 7.0 mm. The potential evapotranspiration values calculated on the basis of the weather data using the *Penman-Monteith* equation for the same studied interval are between 1.6 mm and 5.8 mm/day.

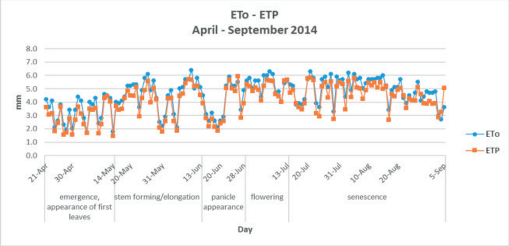


Figure 10. Dinamics of the potential evapotranspiration values between April 21 and September 5, 2014

It turns out that the differences between the two ways of estimation of the potential evapotranspiration analyzed during the whole season of maize vegetation are very small. The analysis of the values by vegetation phases indicates differences generally recorded in the canopy/first leaves (May 04) and maturity (July 7-August 10th) phases, ranging from -0.9 mm to 1.4 mm/day (Figure 11).

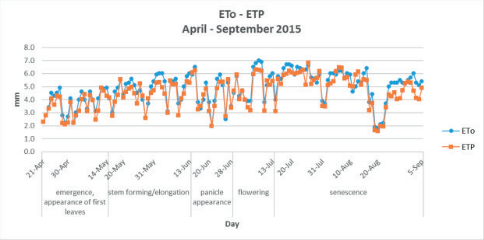


Figure 11. Comparisons of the potential and the reference evapotranspiration period April 21-September 05, 2015

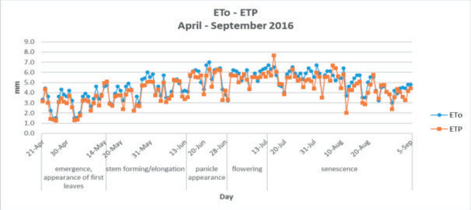


Figure 12. Comparisons of the values of potential evapotranspiration and of the reference evapotranspiration period April 21-September 05, 2016

In the agricultural year 2017, in the maize crop, the obtained values from the comparison between ETo and ETP indicate that during the whole vegetation season (April 21-September 05, 2017) the differences between the two methods of calculating the evapotranspiration they are small and have the range from -1.2 mm/day to 1.1 mm/day. The months of June, July and August are the months in which these maximum differences are recorded and correspond to the phases of panic emergence, panicle flowering and maturity in the maize crop (Figure 13).

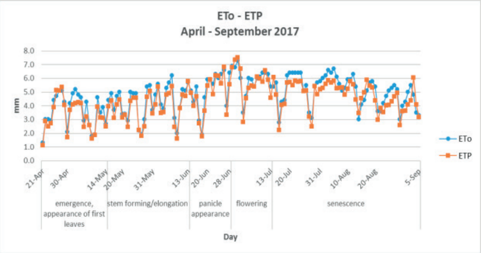
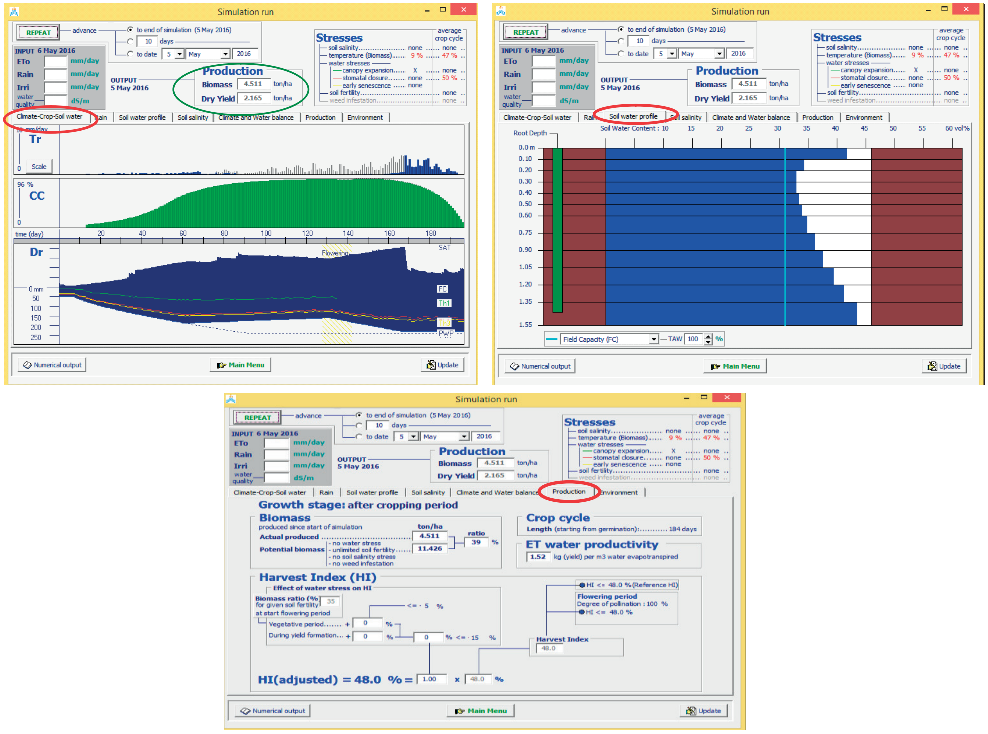


Figure 13. Comparisons of the values of potential evapotranspiration and of the reference evapotranspiration period April 21-September 05, 2017 (NMA Agromteoteo)

AquaCrop run program simulates the soil water content (SWC), crop water use, crop growth, total biomass production (B) and yield (Y) based on the climatological and environmental conditions given in the files mentioned above (Figure 14).



● to end of simulation (5 May 2016)
○ 10 days
○ to date 5 May 2016

INPUT 6 May 2016
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 5 May 2016

Production
Biomass 4.511 ton/ha
Dry Yield 2.165 ton/ha

Stresses		average crop cycle
soil salinity	none	none
temperature (Biomass)	9 %	47 %
water stresses		
canopy expansion	X	none
stomatal closure	none	50 %
early senescence	none	
soil fertility		none
weed infestation		none

Soil Water Content : 10 15 20 25 30 35 40 45 50 55 60 vol%

TAW 100 %

Growth stage: after cropping period

Biomass
produced since start of simulation (ton/ha)
Actual produced 4.511
Potential biomass (- no water stress - unlimited soil fertility - no soil salinity stress - no weed infestation) 11.426
ratio 39 %

Crop cycle
Length (starting from germination): 184 days

ET water productivity
1.52 kg (yield) per m3 water evapotranspired

Harvest Index (HI)
Effect of water stress on HI
Biomass ratio (%) for given soil fertility at start flowering period 35
<= 5 %
Vegetative period + 0 %
During yield formation + 0 %
0 % <= 15 %
HI <= 48.0 % (Reference HI)
Flowering period
Degree of pollination : 100 %
HI <= 48.0 %
Harvest Index 48.0

HI(adjusted) = 48.0 % = 1.00 x 48.0 %

Figure 14. AquaCrop simulation products

The most productive year for the maize crop in the study area was 2014, the cumulated precipitation quantity was the highest and the number of days with the maximum air temperature which exceeds 32°C was the lowest (Figure 15).

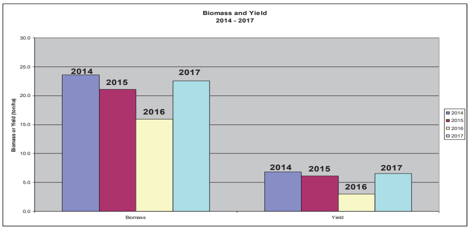


Figure 15. Biomass and Yield AquaCrop simulation

Agricultural production simulated with AquaCrop software (using calculated evapotranspiration (ETP) and simulated evapotranspiration (ETo) for maize crop in the period 2014-2017 were compared with INSSE (National Institute of Statistics data), thus, Figure 12 shows the differences between the simulated productions within the AquaCrop model by the two methods and the available statistical data, the differences being between 0 and 4 t/ha (Figure 16).

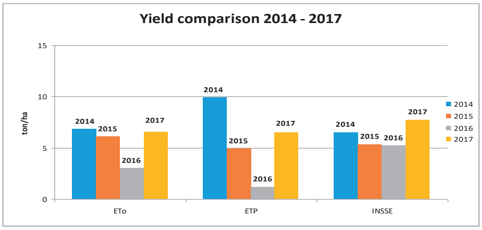


Figure 16. ETo-Calculator and FAO Penman-Monteith method comparing with the registered data of maize yield (2014-2017)

CONCLUSIONS

AquaCrop can be used as a planning or supplement / aid tool in decision making in both irrigated and non-irrigated agriculture. The model is particularly useful in: development of irrigation strategies under pedological drought conditions, studying the effect of geographical location, soil type, sowing date on agricultural production; analyzing the effect on agricultural production of different techniques of land management; comparing the possible production with the actual production of an agricultural land, a farm or a region, better forecast of the impact of climate change on agricultural production.

AquaCrop is a water-driven simulation model that requires a relatively low number of parameters and input data to simulate the yield response to water of most major field and vegetable crops cultivated worldwide. When compared to other crop simulation models, its parameters are explicit and mostly intuitive and the model was built to achieve a balance between accuracy, simplicity, and robustness. The goal was to make the model as transparent as possible to users that generally do not belong to the research community and are not very familiar with the discipline of crop physiology.

Although the model is relatively simple, it gives particular attention to the fundamental processes involved in crop productivity and in its responses to water deficits, both from physiological and agronomic background perspectives. The fact that the simulated results agreed generally well with the measured data in the examples presented suggests that AquaCrop may be successful in achieving a good balance in simplicity, robustness, accuracy, and ease of use. These findings are particularly promising as they have been obtained with only limited calibration of the model.

The ETo values simulated using the ETo Calculator application are generally similar to the ETP data calculated from the weather data using the Penman-Monteith equation. It turns out that the differences between the two methods of determining the potential evapotranspiration analyzed over the entire growing season of maize crop are very small. The maximum differences are between -1.4 mm and 1.7 mm. These maximum deviations of the two compared parameters are generally recorded in July and August, these months corresponding to the flowering phases of the panicle and maturity (milk, wax and full) for the corn crop.

One important application of AquaCrop it is to compare the attainable with actual yields in a field, farm, or a region, to identify the constraints limiting crop production and the water productivity levels. It can also be used by economists, water agencies, and managers for scenario analysis and for planning purposes. It is suited for prospective studies such as those of future climate change scenarios. Overall, it is particularly suited to develop agricultural water management strategies for a variety of objectives and applications.

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