Effects of micronutrient mixture foliar spraying on sunflower yield under water deficit and its evaluation by AquaCrop model

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Abstract: AquaCrop model is a leading and powerful scientific tool for simulating the response of different field crops to irrigation. An experiment was carried out on the farm of the National Research Centre of Research and Production at El-Nubaria district, El-Buhaira Governorate (Egypt) with sunflower on 2018 and 2019 summer seasons. The treatments were 80%, 60% and 40% of water holding capacity (WHC), and micronutrients (vitamins B, E and microminerals iron, cobalt, chromium, copper, iodine, manganese, selenium, zinc, and molybdenum) at 4 mixture levels (0, 1%, 2% and 3%). Results found that the simulated and observed values of seed yield were in agreement for the water stress treatments. This means that differences in vegetative growth, yield and water productivity of sunflower crop had no significant effect on the model calibration results. There was an inverse relationship between the water productivity and water treatments, while a direct correlation was found between water productivity and micronutrient mixture coefficients. NPK content, and the protein ratio in sunflower leaves was generally increased by increasing the mixture of micronutrients. There was a direct relationship between both study factors, the characteristics of the vegetative growth and yield of the sunflower plants, that is, the more water is added, the more measured values will be simulated by the AquaCrop model. It could be concluded that using maximum of water treatment (80% WHC) and the 3% and 2% mixture of micronutrients was better due to the increases in values of vegetative growth, seed yield and water productivity of sunflower.

Keywords: simulation model, drip irrigation, sunflower, foliar application, micronutrient.

Citation: Hellal F., S. El-Sayed, H. Mansour and M. Abdel-Hady. 2021. Effects of micronutrient mixture foliar spraying on sunflower yield under water deficit and its evaluation by AquaCrop model. Agricultural Engineering International: CIGR Journal, 23(2): 43-54.

1 Introduction

Sunflower (*Helianthus annuus* L) is the most important source of edible vegetable oil after soybean, rapeseed and peanut, with a worldwide seed production of 33.3 million tons destined almost exclusively to oil extraction, providing 8.5% of the total world volume (FAO, 2018; Hellal et al., 2019a; Mansour et al., 2020a, 2020b). Sunflower is an important oilseed crop because it has a wide adaptability to different climatic conditions. Sunflower has a short growing season and thus lower irrigation needs have helped plant breeders more interest in this crop in different regions.

The development of crop growth models began in the 1960s and have advanced and become more refined since then (El-Sharkawy, 2011). Crop models can be useful for the agronomic research since they are tools that predict the growth, development and crop yield (Steduto et al., 2009). There are many existing crop models that are used around

Received date: 2020-03-24 **Accepted date:** 2020-08-14

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the world, having all of them different structures, methods, inputs and algorithms for Model simulations typically go through a calibration phase, where the modeller is tuning a model by making comparisons with the measured data. Biological systems such as crop cultivation are very complex systems, making them a challenge to the model. However, because of annual crops go through their complete life cycle in one year or a growing season, they belong to a repetitive biological system (Mansour and Aljughaiman, 2020).

AquaCrop model is a powerful tool for the simulation of crop response to the different quantitative and qualitative management of irrigation that was deveoloped by FAO (Steduto et al., 2009). AquaCrop model was developed for using fewer parameters in the balance of the simplicity, accuracy, and robustness. Water is used as the main driver in AquaCrop for simulating yield production since it is one of the major limiting factors in crop growth (De Wit and Van Keulen, 1987). Crops use the water to carry the minerals, the sucrose and the hormones through the plant. Water is also very critical factor in the chemical reaction of photosynthesis (Geerts et al., 2009). Water-limiting conditions will result in the lower yields at the end of the season, so it is an important factor for crop modelling. Vanuytrecht et al. (2014) performed a global sensitivity analysis of AquaCrop in an attempt to create guidelines for model simplification and efficient calibration. The parameters that were determined to be a priority for AquaCrop describe the crop phenology, crop response to extreme temperatures, water productivity, root development, and soil water characteristics.

The objective of this research work was to evaluate the effect of micronutrient mixture on sunflower yield by AquaCrop under different treatments of water deficits.

2 Materials and methods

2.1 Experiment description

Sunflower (*Helianthus annuus* L) Giza 125 and Giza 134 varieties were cultivated in the farm of the National Research Centre of Research and Production at El-Nubaria district, Elbuhaira Governorate (Egypt) on 2018 and 2019 summer seasons. Soil physical and chemical characteristics are shown in Tables 1 and 2.

Table 1 Soil physical analysis

Particle size distribution, %				Texture class	θ_S % on weight basis			HC ($cm\ h^{-1}$)	BD ($g\ cm^{-3}$)
Coarse sand	Fine sand	Silt	Clay		F.C.	P.W.P	A.W		
8.8	78.7	7.6	5.9	Sand	12	4.1	7.9	6.17	1.62

Note: θ_S %: Soil water content (%), F.C.: Field capacity, P.W.P: Permanent Wilting point, A.W : Available Water , HC: Hydraulic Conductivity and BD: Bulk density

Table 2 Soil chemical analysis

Soluble cations (me l-1)				Soluble anions (me l-1)			
Na+	K+	Ca++	Mg++	CO3=	HCO3-	Cl-	SO4=
1.12	0.48	1.32	1.04	0.00	1.82	0.58	1.57

Available macronutrients ($mg\ 100\ g^{-1}$ soil)			Available micronutrients (ppm)			
N	P	K	Fe	Mn	Zn	Cu
3.87	0.87	16.7	6.34	3.11	2.45	0.32

Treatments were 40%, 60% and 80% of water holding capacity (WHC), and 4 micronutrient mixture levels (0, 1%, 2% and 3%) sprayed twice 40 and 60 days after sowing. The meteorological data required by AquaCrop model were taken from the nearest station (Wadi Elnatron, located about 5 km far away) and were daily values of minimum and maximum air temperature, reference evapotranspiration (ETo), rainfall and mean annual carbon dioxide concentration (CO_2).

Crop data (vegetative growth, grain and stover yield) were obtained from the current experimental field. The experiment was laid on Randomized Complete Block Design (RCBD) and three replications were carried out. Plots were 2.5 m × 6 rows with 0.20 m row spacing and sowing density was adjusted to 300 g m^2. The crop component was divided into 4 subcomponents including initial canopy, canopy development, flowering and yield formation and rooting depth. Both of yield formation and rooting depth were measured visually while the canopy was measured in field at regular intervals.

At heading stage, chlorophyll content was estimated in fresh leaves using a SPAD-502Plus A1RT-206 chlorophyll meter (Konica Minolta, Japan). At harvest, the following characters were recorded: capitulum values (external diameter, fresh and dry weight), grain values (fresh and dry weight, seed number and seed yield) and 1000 grain weight. Representative grain samples were dried at 70^0C, ground and digested by a mixture of sulfuric and perchloric acids, and then micronutrients determined according to Motsara and Roy (2008). Nitrogen in plant was analyzed using Microkjeldahl technique. Phosphorus was determined by molybdtae color reagent and analyzed calorimetrically. Potassium was determined using a PFP7 flame photometer (Lenway, UK). Figure 1 shows the canopy cover, flowering, effective root depth and yield formation of sunflower as defined by AquaCrop model. Figure 2 reflects the relationship between sunflower water productivity and CO_2.

Canopy cover was estimated based on the method developed by Mansour and Aljughaiman (2020) and Farahani et al. (2009):

$$CC = 1 \exp^{(-0.65LAI)} \quad (1)$$

Where CC is canopy cover as shown in Figure 1 and LAI is the leaf area index. LAI was calculated as LAP×NPM^2, LAP is the leaf area per plant (m^2), and NPM^2 the number of plants per m^2 (Royo et al., 2004). The biomass and grain yield were obtained from all plots after maturity from an area of 6 m^2 in all cropping seasons.

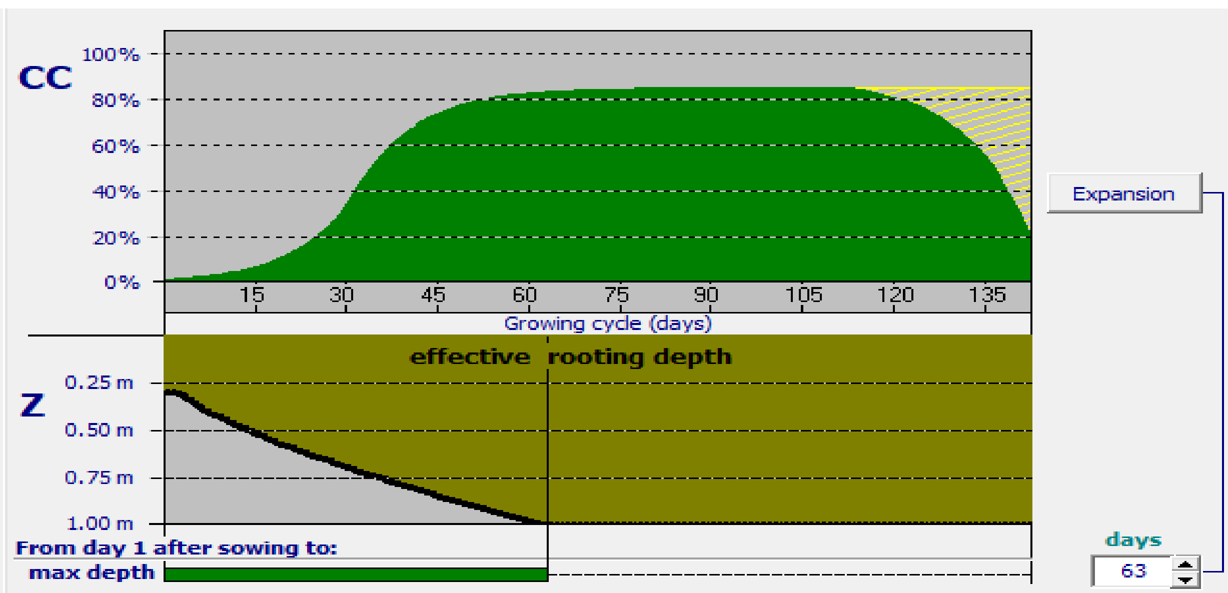

Figure 1 Canopy cover, flowering, effective root depth and yield formation of sunflower by AquaCrop model

2.2 Description of the irrigation system

The control head was located at the water inlet and consisted of a centrifugal electric pump (0.75 kW, n ≈ 2900 rpm and discharge 3 m^3 h^{-1}), 1.5” screen filter (155 µm filtration level, maximum flow 7.2 m^3 h^{-1} and maximum pressure 150 kPa), 1” Venturi injector (rang of suction capacity 0.034- 0.279 m^3 h^{-1}), 2” spring brass non return valve 2", pressure gauges, control valves and flow meter.

The main line connected the control head to a submain unit and consisted of a poly venile chloride (PVC) pipe of 63 mm external diameter and 600 kPa maximum pressure, A submain with a 32 mm external diameter PVC pipe delivered water to the group of the laterals which represent treatments.

Laterals were 16 mm external diameter PE pipes, with built in drippers of 4 l h^{-1} discharge at 100 kPa operating pressure and spaced 30 cm. Distance between laterals was 0.9 m. Irrigation system has been designed according to Mansour (2015) and Mansour and Aljughaiman (2020).

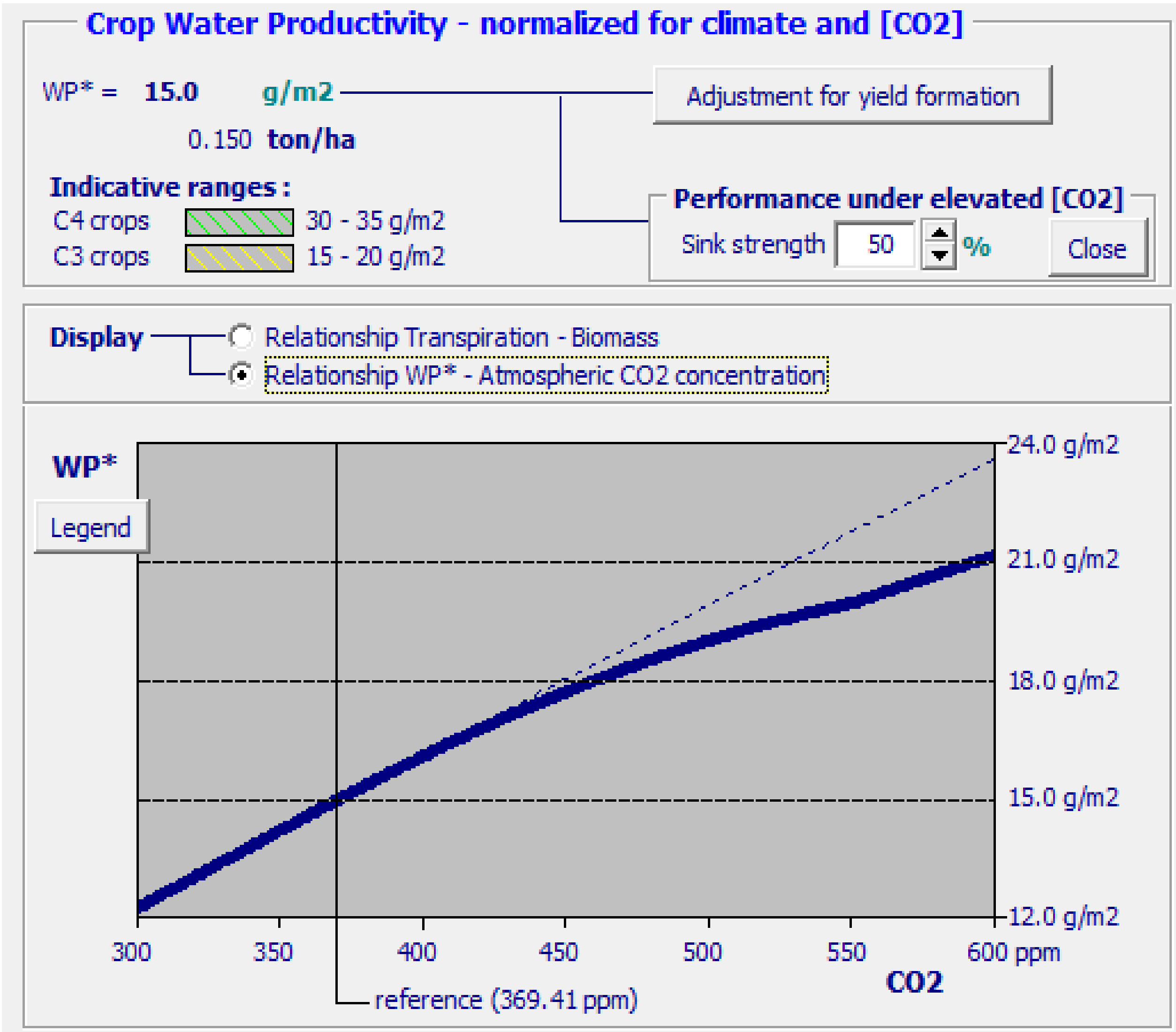

Figure 2 The relationship between sunflower water productivity and CO_2

2.3 AquaCrop model

AquaCrop has four sub-model components: (i) soil (water balance); (ii) crop (development, growth and yield); (iii) atmosphere (temperature, rainfall, evapotranspiration (ET) and carbon dioxide (CO_2) concentration); and (iv) management (major agronomy practices such as planting dates, fertilizer application and irrigation if any).

AquaCrop calculates a daily water balance that includes all the incoming and outgoing water fluxes (infiltration, runoff, deep percolation, evaporation and transpiration) and changes in soil water content. There are five weather input variables required to run AquaCrop including daily maximum and minimum air temperatures (T), daily rainfall, daily reference evapotranspiration (ETo) and the mean annual CO_2 concentration in the bulk atmosphere. The advantage with AquaCrop is that it requires only a minimum of input data, which are readily available or can easily be collected. AquaCrop has default values for several crop parameters that it uses for simulating different crops, including sunflower. However, some of these parameters are not universal and thus have to be adjusted for local conditions, cultivars and management practices. Deviation has been calculated by the following equation (Equation 2):

$$\text{Deviation }\% = 100- ((Oi.100)/Si) \quad (2)$$

Where Oi: Measured values and Si: Simulated values.

The AquaCrop model uses the yield response to water equation (Equation 3) as a starting point for the model.

$$(Yx-Ya)Yx= (ETx-ETa)\text{Ky} \quad (3)$$

Where Yx and Ya are maximum and actual yield (t ha^{-1}), ETx and ETa are maximum and actual evapotranspiration (m^3 ha^{-1}) and Ky is the proportionality factor between relative yield loss and relative reduction in evapotranspiration.

Doorenbos and Kassam (1979) developed Equation 3, which was widely used to estimate the yield response to water by planners, economists and engineers (Howell et al., 1990). AquaCrop evolved from this approach by separating the evapotranspiration into crop transpiration and soil evaporation to develop a final yield as a function of the final biomass of the crop (Equation 4). This separation allows distinguishing the effects on the non-productive consumptive use of water, soil evaporation, to better simulate crop growth. The water productivity (WP, the biomass produced per unit of cumulative transpiration) is a conservative parameter, which is considered to be constant for giving climatic conditions (Steduto et al., 2009) .

$$B=WP* \Sigma Tr \quad (4)$$

Where B is the final biomass (kg ha^{-1}), WP is the water productivity (kg m^{-3}) (biomass per unit of cumulative transpiration), and Tr is the crop transpiration(m^3 ha^{-1}).

The WP parameter is based on the atmospheric evaporative demand and the atmospheric CO_2 concentration for the purpose of being applicable to diverse locations and simulating future climate scenarios. Equation 5 shows the procedure for calculating the normalized WP based on adjustments to annual CO_2 concentrations. This approach has a tendency to over-simulate future crop yields caused by CO_2 fertilized when compared to free air CO_2 enrichment (FACE) experiments (Vanuytrecht et al., 2011). This lead to the introduction of a crop sink strength parameter to address the response of WP, resulting in higher yields (Vanuytrecht et al., 2011), but there are still many uncertainties and more research is needed for a better understanding of crop behavior with increased CO_2 concentrations.

$$WP=(B\Sigma(TrETo))CO_2 \quad (5)$$

Where CO_2 is the mean annual CO_2 concentration (ppm) and ETo is the atmospheric evaporative demand (m^3 ha^{-1}). The CO_2 outside the bracket is the normalization concentration for a given year. Once the final biomass is calculated at harvest, the final yield output is the function of the final biomass (B) and the Harvest Index (HI). HI is the ratio between the harvested product and the total above ground biomass (Mansour et al., 2015a, 2015b, 2015c; Hu et al., 2019a, 2019b; Mansour and Aljughaiman, 2020). AquaCrop simulates the build-up of HI starting from the flowering stage to reach the reference HI, a crop parameter set by the user. The build-up of HI increases linearly with time, but adjustments of HI are made depending on crop stresses during simulations, resulting in lower yields or even zero yields under conditions of pollination failure caused by severe stress (Steduto et al., 2009).

AquaCrop is effective for modelling yields under a limited number of site locations. In the current version of AquaCrop (6.0), this issue has been overcomed by the creation of two external utility programs called AquaData and AquaGIS (Lorite et al., 2013). The flow chart (Figure 3) describes the process of using AquaCrop with the two utility programs AquaData and AquaGIS. This allows a spatial visualization of crop yields over a greater area, enabling the capability to perform a spatial analysis (Lorite et al., 2013). Aqua Data acts as a database that contains all data necessary for creating input files used in AquaCrop. FAO has developed an AquaCrop plug-in program that will run AquaCrop without a user interface, which allows an application like AquaData to automatically run multiple crop simulations much more efficiently (Raes et al., 2013). The AquaCrop plug-in program can be used for iterative runs for calibration purposes or for inputting into a Geographical Information System (GIS) for subsequent spatial analysis. Table 3 shows the AquaCrop default values and calibrated values for main parameters used in sunflower simulation.

Table 3 AquaCrop default values and calibrated values for main parameters used in sunflower simulation

Parameter	Default	Calibrated
Growth and production	-	-
Normalized crop water productivity (g m^{-2})	33.7	33.7
Reference harvest index (%)	48	52
Phenology		
Base temperature (^oC)	8	8
Cutoff temperature (^OC)	30	30
Time from sowing to anthesis (GDD)	800	882.2
Time from sowing to maturity (GDD)	1700	1469
Morphology		
Initial canopy cover (%)	0.49	0.42
Canopy cover (CC) per seedling (cm^2 $plant^{-1}$)	6.5	6.0
Maximum canopy cover (%)	96	94
Maximum rooting depth (M)	2.3	1.0
Canopy growth coefficient (% day^{-1})	16.3	13.6
Canopy decline coefficient (% day^{-1})	11.7	16.2
Crop coefficient for transpiration	1.05	1.02
Decline of crop coefficient (% day^{-1})	0.30	0.30
Effect of CC on Reding evaporation (%)	50	50
Upper threshold for leaf expansion growth	0.14	0.14
Lower threshold for leaf expansion growth	0.72	0.72
Leaf growth, stress coefficient curve shape	2.9	2.9
Upper threshold for canopy senescence	0.69	0.69
Senescence stress coefficient curve shape	2.7	2.7
Upper threshold for stomatal closure	0.69	0.69
Stomata stress coefficient curve shape	6	6.0
Aeration stress coefficient (% vol. saturation)	5	5

Source: Hsiao et al. (2009) and Heng et al. (2009)

The main concepts of connecting the soil-crop-atmosphere continuum in AquaCrop are illustrated in Figure 3. The soil component of the continuum is focused on the water balance within the soil, the plant represents the growth, development and yield processes, and the atmosphere is represented by air temperature, rainfall, evaporative demand, carbon dioxide concentrations and irrigation (Steduto et al., 2009). Figure 3 shows the interaction of different variables that AquaCrop combines for simulating yield output. The model uses separating input components of climate data, crop parameters, management (irrigation and field), soil (soil characteristics and ground water) and the simulation period for simulating crop yield.

2.4 Statistical treatment

MSTATC program (Michigan State University) was used to carry out the statistical analysis. Treatment means were compared using the technique of analysis of variance (ANOVA) and the least significant difference (LSD) test between systems at 1% had been done according to Snedecor and Cochran(1980), RMSE and normalized mean square error were calculated according to James et al. (2013).

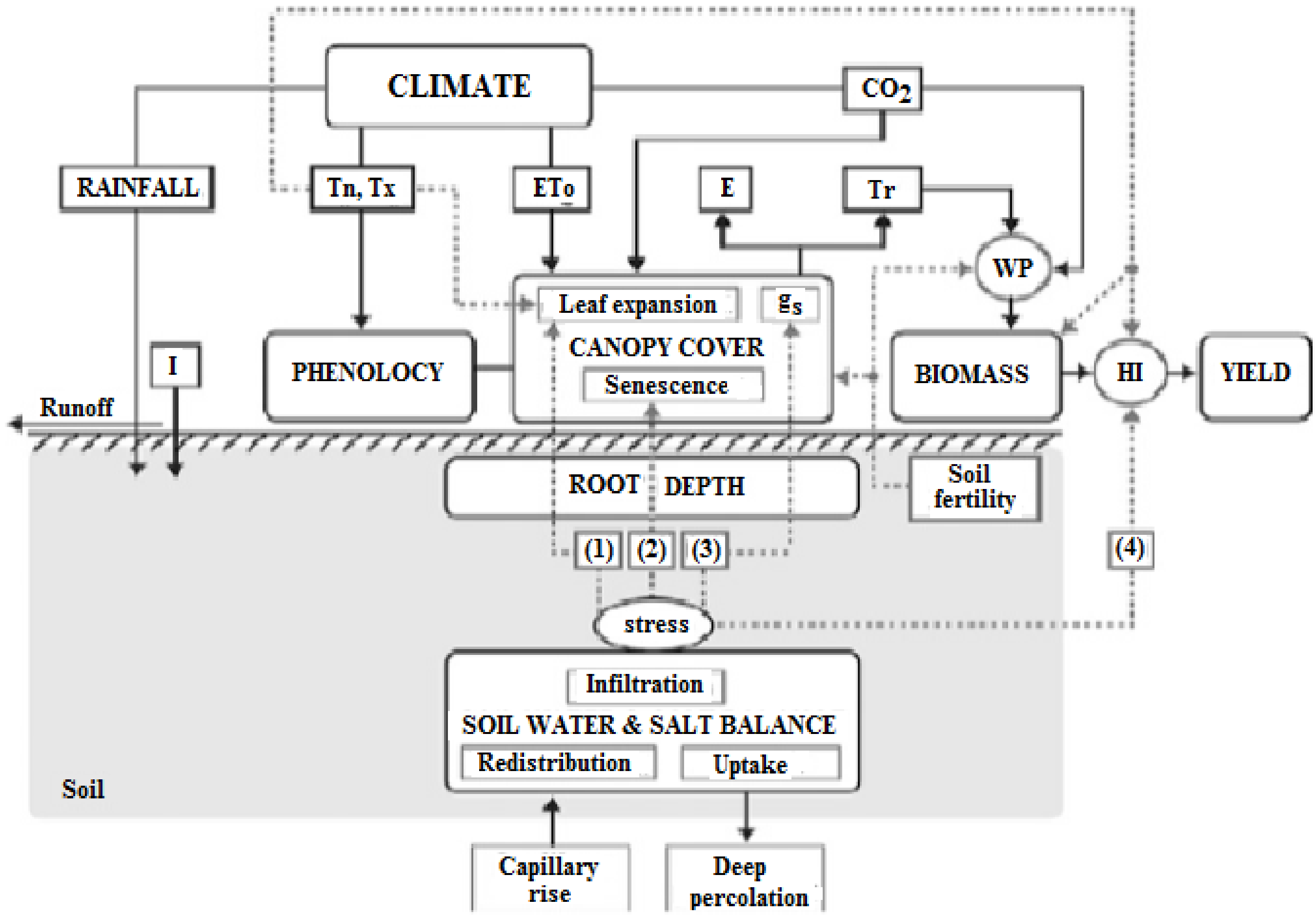

Figure 3 Chart of AquaCrop indicating the main components of the soil–plant–atmosphere continuum and the parameters driving phenology, canopy cover, transpiration, biomass production, and final yield (I) irrigation; (Tn) lowest air temperature; (Tx) highest air temperature; (ETo) reference evapotranspiration; (E) soil evaporation; (Tr) canopy transpiration; gas, stomatal conductance; (WP) water productivity; HI, harvest index (Steduto et al., 2009).

3 Results

The calibrated data by the model of AquaCrop (FAO), was validated using data of the 2016 version of this model. The validation ran with calibrated data in AquaCrop showed good results for seed yield as indicated by observed and simulated values. The simulated and observed values of seed yield were rather well in agreement for both Giza 125 and Giza 134 varieties.

Tables 4, 5 and 6 and Figures 4 and 5 illustrate the effect of the addition of water stress factors (80%, 60%, 40% of WHC) and rates of micronutrient mixture of simulation values by the AquaCrop model, which were field-estimated for each of the vegetative growth characteristics, namely vegetation, plant length, wet and dry weight, and stem external diameter of sunflower crop plants. It can be observed that the simulation values in the AquaCrop model and the field and laboratory measured values for the vegetative growth characteristics, were more accurate under the treatment of 80% WHC followed by treatment of 60% WHC and finally treatment of 40% WHC. The higher the amount of added water, the more the values of the vegetative growth measurements of sunflower crop plants increased with a clear direct proportional fit.

Table 4 Effect of foliar application of micronutrient mixture on growth parameter of sunflower under water stress

Treatments		Plant Height (cm)	Capitulum values		
WHC*	Micronutrients (%)		External diameter (cm)	Fresh weight (g plant^{-1})	Dry.weight (g plant^{-1})
80% of WHC	0%	112.67	10.90	109.50	19.91
	1%	123.33	12.03	112.78	21.99
	2%	130.00	14.50	129.85	24.35
	3%	136.67	19.77	135.77	26.62
60% of WHC	0%	106.67	10.57	86.83	17.65
	1%	118.33	12.00	99.41	19.24
	2%	125.00	13.07	104.57	21.56
	3%	135.00	16.85	115.51	22.62
40% of WHC	0%	74.20	7.12	53.29	9.22
	1%	81.67	8.17	60.59	11.56
	2%	86.33	8.63	64.86	13.90
	3%	91.00	10.83	69.13	14.02
Mean of WHC	80%	125.67	14.30	121.97	23.22
	60%	121.25	13.12	101.58	20.27
	40%	83.30	8.69	61.96	12.17
Mean of Micronutrients	0%	97.85	9.53	83.21	15.6
	1%	107.78	10.73	90.93	17.6
	2%	113.78	12.07	99.76	19.9
	3%	120.89	15.82	106.80	21.1
LSD 0.05	WHC	2.37	0.95	2.54	0.72
	Micro	3.55	1.09	2.94	0.83
	WHC* Micro	5.15	1.81	5.10	1.13

Note: WHC: water holding capacity; LSD: least significant difference.

Table 5 Effect of foliar application of micronutrient mixture on yield parameter of sunflower grain and leaves under water stress

Treatments		1000 grain weight (g)	Capitulum values			
WHC*	Micronutrients (%)		Fresh weight (g plant^{-1})	Dry weight (g plant^{-1})	Seed number	Seed yield (ton ha^{-1})
80% of WHC	0%	23.79	34.53	10.59	823	3.95
	1%	33.33	36.38	13.63	964	4.14
	2%	38.1	39.63	15.82	1004	4.52
	3%	45.46	51.86	25.92	1105	5.93
60% of WHC	0%	21.52	32.65	7.53	746	3.72
	1%	27.24	34.83	12.15	815	3.95
	2%	36.01	37.4	15.53	971	4.26
	3%	40.17	46.84	21.58	1012	5.36
40% of WHC	0%	11.58	19.96	4.84	427	2.28
	1%	17.4	21.93	7.7	548.8	2.51
	2%	24.97	24.33	9.78	648.2	2.77
	3%	27.79	27.9	11.77	690.2	3.19
Mean of WHC	80%	35.17	40.6	16.49	974	4.64
	60%	31.23	37.93	14.2	886	4.33
	40%	20.43	23.53	8.52	578.6	2.70
Mean of Micronutrie nts	0%	18.96	29.05	7.65	665.3	3.31
	1%	25.99	31.05	11.16	775.9	3.53
	2%	33.03	33.79	13.71	874.4	3.84
	3%	37.81	42.2	19.76	935.7	4.83
LSD 0.05	WHC	0.95	1.55	0.73	11.02	0.19
	Micro	1.09	1.79	0.7	13.24	0.19
	WHC* Micro	1.81	2.81	1.39	22.56	0.30

Note: WHC: water holding capacity; LSD: least significant difference.

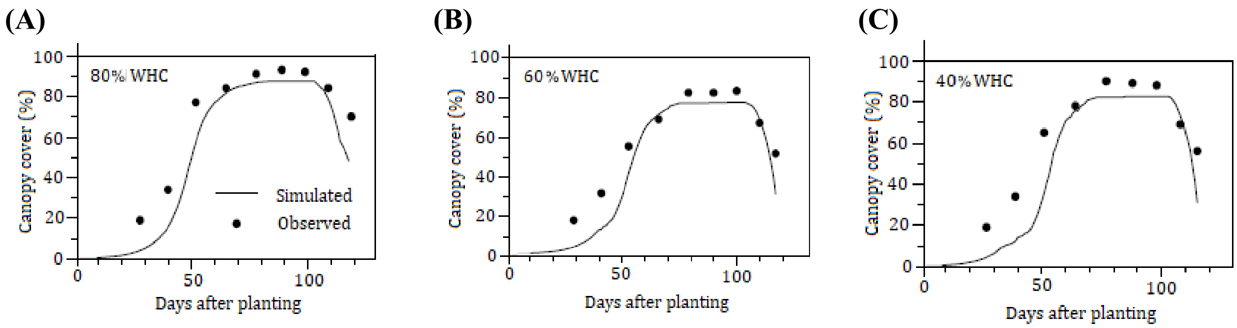

Figure 4 Simulated with AquaCrop and measured sunflower canopy covers for the different irrigation water stress treatments.

Table 7 and Figure 6 illustrate simulated values of the AquaCrop model and field-measured values for water productivity. They took a completely opposite direction to the characteristics of vegetative growth and yield under water stress water transactions WHC. It was found that there was an inverse relationship between water stress and water productivity of sunflower. A direct correlation was found between water productivity and micronutrient mixture Amino acid (Aa%) coefficients. The higher of the ratio of the micronutrient mixture added Aa%, the higher the unit values for the water unit of sunflower crop plants.

Table 6 Statistical indicators for dry biomass under deficit irrigation

Statistical indicator	Dry biomass WHC 80	Dry biomass WHC 60	Dry biomass WHC 40
Pearson Correlation Coefficient (r)	0.96***	0.98***	0.97***
Root mean square error (RMSE) (ton ha^{-1})	1.29*	0.93*	1.34*
Root mean square error (RMSE) (%)	21.79*	21.79*	28.09*

Note: ***: High significant ($p<0.001$); *: Low significant ($p<0.05$)

Table 7 Water productivity of the sunflower crop observed and simulated by AquaCrop model

Treatment		Yield	Applied water	Water productivity (WP) (kg m^{-3})		RMSE
WHC*	Micro (%)	(kg ha^{-1})	(m^3 ha^{-1})	Observed	Simulated	(kg m^{-3})
80% of WHC	0%	3952	4560	3.31	4.71	5.54
	1%	4142	4560	3.46	4.94	5.95
	2%	4522	4560	3.76	5.40	6.49
	3%	5928	4560	4.94	7.07	6.72
60% of WHC	0%	3724	3420	4.14	5.93	7.20
	1%	3952	3420	4.41	6.27	7.82
	2%	4256	3420	4.71	6.76	7.83
	3%	5358	3420	5.97	8.51	7.81
40% of WHC	0%	3268	2280	5.43	7.79	8.11
	1%	3572	2280	5.97	8.51	8.08
	2%	3952	2280	6.57	9.42	8.03
	3%	4560	2280	7.60	10.87	7.86
Mean of WHC	80%	4636	4560	3.88	5.51	7.92
	60 %	4324	3420	4.79	6.88	7.85
	40 %	3838	2280	6.38	9.12	7.63
Mean of Micronutrients	0 %	3648	3420	4.07	5.78	7.05
	1 %	3887	3420	4.33	6.16	7.28
	2 %	4245	3420	4.71	6.73	7.35
	3 %	5282	3420	5.85	8.40	6.84
LSD 0.05	WHC	54		0.08	0.11	0.14
	Micro	44		0.15	0.19	0.08
	WHC* Aa	48		0.11	0.15	0.12

Note: WHC: water holding capacity; LSD: least significant difference.

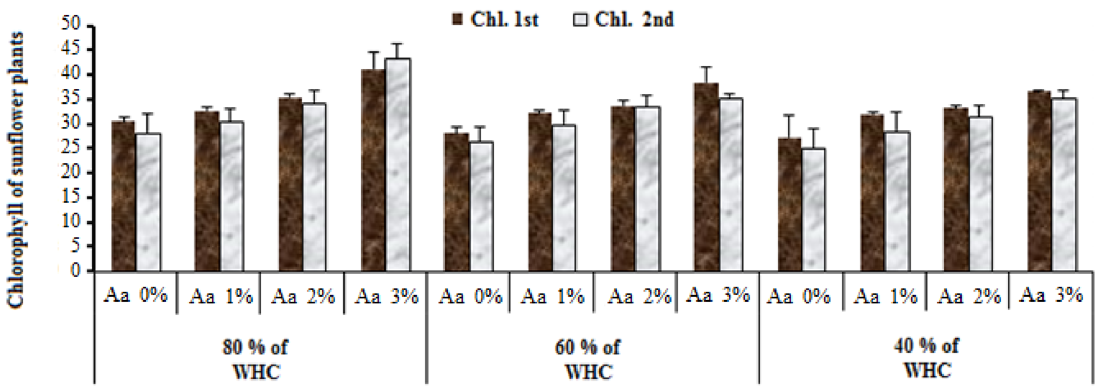

Figure 5 Effect of foliar application (average and error bars) of micronutrient mixture on mhlorophyll of sunflower under water stress.

On the other hand, it can be observed that the simulation values of the AquaCrop model and the field and laboratory measured values for the vegetative growth characteristics (vegetation, plant length, wet and dry weight, and external diameter of the stem) were more closely related under micronutrient treatment 3%, followed by treatment 2%, treatment 1%, and finally treatment 0%. Increasing the percentage of micronutrient in mixture increased Aa% added and also the values of the vegetative growth measurements of sunflower crop plants. A direct proportion was observed where the data took the same direction as the effects of the amount of water added under water stress.

Table 7 shows water stress water treatments water holding capacity (WHC) and micronutrient mixture Aa% on NPK content, protein content in sunflower grains and leaves. It can be observed that both NPK content and the protein ratio in sunflower leaves were generally increased by increasing the mixture of micronutrients Aa%. It was found that there was a direct proportion between the micronutrient mixture Aa% water and the NPK content, and the protein ratio, while it found an inverse proportion between the NPK content and the protein ratio and the water stress water plants in sunflower crops.

4 Discussion

AquaCrop model was able to simulate canopy cover development accurately. The simulated and observed data for canopy cover, yield and water productivity under different treatments, the relationship between canopy cover, yield and water productivity with water stress treatments and micronutrient mixture treatments gave interesting results. The predicted maximum canopy cover data were observed under all treatments for sunflower plants. However, important seed yield reduction can be caused by reducing canopy growth due to water stress. Severe water stress after crop establishment and at the end of the vegetative stages has induced fast senescence as well as the decline of the canopy cover when compared with the non stressed treatments. The canopy cover for the stressed treatment 40% showed a rapid decline when compared with the irrigated by 80% and 60% water stress treatments, which is in accordance with Hellal et al. (2019a, 2019b, 2020), Hsiao et al. (2009), Heng et al. (2009), Vanuytrecht et al. (2014), Steduto et al. (2009), and Lorite et al. (2013).

The results revealed that, the simulation values had clearly approached estimated values in sunflower plants for water stress water treatments in the following order: 80% greater than 60%, and 60% greater than 40% of WHC, and also in the following order for micronutrient mixture coefficients 3% greater than 2%, 2% greater than 1%, and 1% greater than 0%. These results are due to the nature of the sandy soil in the lands for reclamation as presented in Tables 1 and 2, as it does not maintain water and the percentage of deep leaching is large, and therefore we found that the amount of water 80% of the WHC in the case of water stress in sandy soil was the best in replacing the soil with the amount closest to the optimum condition and was followed by less quantities 60%, 40%, respectively.

These results match with those from Hellal et al. (2019a, 2019b), and Mansour et al. (2014, 2015a, 2015b, 2015c).

The response of 80% WHC showed the minumum RMSE values (Table 7), while the highest were observed under 40% WHC. On the other hand, considering the mean of micronutrients, the lowest RMSE values were obtained under 3% mixture, followed by 2%, 1% and 0%, which show the highest RMSE.

5 Conclusion

The relationship between canopy cover, yield and water productivity with water stress treatments and micronutrient mixture treatments gave interesting results. The predicted maximum canopy cover by AquaCrop model, the data were observed under all treatments under study for sunflower plants. There was an inverse relationship between the water productivity and water treatments, while a direct relationship was found between water productivity and micronutrient mixture coefficients. NPK content, and the protein ratio in sunflower leaves and cereals was generally increased by increasing the mixture of micronutrients. It is suggested using maximum of water treatment (80% of water holding capacity) and the mixtures 3% and 2% of micronutrients, due to that there is a direct relationship between the study factors, the characteristics of the vegetative growth and yield of the cereal crops for sunflower plants.

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