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ASSESSMENT OF AQUACROP MODEL IN SIMULATING MANGO (MANGIFERA INDICA L.) YIELD UNDER DIFFERENT CONDITIONS OF CLIMATE, IRRIGATION WATER AND SOIL IN EGYPT

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ABSTRACT

Simulation models have been used successfully to forecast productivity of fruit crops under various climate and management scenarios. This research focuses on the assessment of the ability of AquaCrop model to simulate yield of mango under different conditions of climate, irrigation water and soil in Egypt. Experiments were conducted during two seasons (2020-2021) in three governorates of Egypt (Behira, Ismailia and Al-Sharkia).The calibration and validation of model was performed using field observations relative to phenological stages and total yield in 2020 and 2021.The results indicated that the average district simulated yield was estimated at 12.87 t/ha in 2020 and 13.26 t/ha in 2021 which is also consistent with the measured district average. Simulated values underestimated measured mango yield in Bihera, North of Sinai and Al-Sharkia by 1.02%, 5.38%, and 7.92% respectively. Statistical comparisons of measured and simulated yield data showed that R^2 ranged from 0.97 to 0.99, RMSE values were lower and ranged from 0.18 ton/ha to 0.99 ton/ha and index of agreement (D) for yield closer to 1 in the tow seasons (2020-2021). It was concluded that the calibrated Aquacrop model had well simulated mango yield under different conditions of climate, irrigation water and soil in Egypt.

Keywords: Simulation, Aquacrop, model, mango, yield.

1. INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most important horticultural crops in Egypt due to its high economic value especially through exportation. The total area occupied by mango in 2019 was 126716 hectare produced 1091535 tons of fruits (Agricultural economics bulletin, 2019).

AquaCrop model provide the means to simulate the effects of climate, soil, water and management on growth and productivity of crops (Steduto et al. 2009 and 2012; Geerts et al. 2010; Raes et al. 2012). AquaCrop model simulates the soil water content by calculating the soil water balance from input data (climatic data, crop characteristics, and soil and management characteristics). Based on the soil water content, climatic data and crop parameters, canopy development and crop transpiration are simulated. Biomass production is directly derived from crop transpiration, by use of the normalized water productivity. Then, yield is calculated by multiplying the biomass production with the harvest index (Raes et al. 2009a).

To date, no study on simulation of the effects of climate, soil, irrigation water and management on growth and productivity of mango with AquaCrop has been reported in literature. Therefore, some previous studies that have applied AquaCrop for other fruit crops are presented as follows. Ismail et al. (2015) investigated the AquaCrop model to simulate the yield of the peach (*Prunus persica* (L.) Batsch) under full and deficit irrigation regimes in Egypt. While Arafat et al. (2019) evaluated the AquaCrop model (version 6.1) to simulate the yield of pomegranate (*Punica granatum* L.) under different climate regions, irrigation water and soil in Egypt. They showed that the AquaCrop model has been tested well and showed a good fitness on simulating yield of peach and pomegranate. In addition the researchers found that the model can reduce the need for expensive and time-consuming field trials and could be used to analyze yield gaps in various fruit crops.The objective of this research was to validate and apply AquaCrop model to simulate yield of mango under different conditions of climate, irrigation water and soil in Egypt.

2. MATERIALS AND METHODS

Study site:

Experiments were was carried out during 2020 and 2021 seasons in three governorates located in the north of Egypt (Figure 1), private orchards located at El-Nobaria region Behira governorate (latitude 30.65˚N, longitude 30.70˚E, 130 m above sea level), Dir Almalak valley Al-Sharkia governorate (latitude 30.73˚N, longitude 31.71 ˚E, 20 m above sea level) and El Tall El Kbeer region Ismailia governorate (latitude 30.60˚N, longitude 32.25˚E, 82.91m above sea level) (America's space agency (NASA), 2021 https://power.larc.nasa.gov/data-access-viewer/). Respect to the experiments characteristics are presented in table 1.

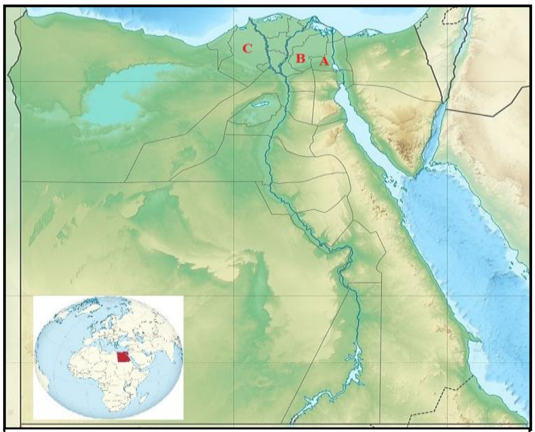

Figure 1. Geographical location of the study site (A) Ismalia, (B) Shrkia and (C) Bihera governorates.

Table 1. Characteristics of experiments.

Character	Behira	Ismalia	Al-Sharkia
Planting distances (m)	5 × 5		7 × 7
Varieties	Fajri Kalan		Zebda
Tree age (Year)	15	14	17
Irrigation system	Drip		
Irrigation water levels (l/h^{-1})	1680		850
Fertilization	250g/tree Ammonium nitrate (NH_4NO_3, 33.5 % N), 50g/tree phosphoric acid (H_3PO_4, 80 % P2O4) and 150g/tree potassium sulfate (K_2SO_4 - high soluble 50 % K_2O). The chemical fertilizers were added into two equal doses at the first week of February and two weeks later of fruit set through drip irrigation system during 2020 and 2021 experimental seasons.		

Climate data:

The climate data were obtained from the website of the America's space agency (NASA https://power.larc.nasa.gov/data-access-viewer/). Data in tables 2, 3 and 4 shows the average of annual weather data (maximum air temperature, minimum air temperature, wind speed, relative humidity, solar radiation and evapotranspiration (ETo) for study locations (Behira, Ismalia and Al-Sharkia) during the period 2020 – 2021 respectively. Respect to the evapotranspiration (ETo) data was calculated using the FAO Penman-Monteith equation as described by Allen *et al.,* (1998).

Table 2. Average annual climate data of the experiment site at Behira during the period 2020-2021 growing seasons.

Climate Data	2019	2020	2021
Maximum air temperature (^{0}C)	28.11	29.27	28.99
Minimum air temperature (^{0}C)	14.27	15.43	14.79
Relative humidity (%)	55.36	52.82	50.7
Wind speed (m/s)	3.34	3.44	3.59
Solar radiation (MJ/m^2.day)	20.91	20.66	20.77
Precipitation (mm day^{-1})	171.47	0.24	0.17
Evapotranspiration (mm/day)	0.17	0.45	0.34

Table 3. Average annual climate data of the experiment site at Ismalia during the period 2020-2021 growing seasons.

Climate Data	2019	2020	2021
Maximum air temperature (^{0}C)	28.37	29.3	28.79
Minimum air temperature (^{0}C)	16.11	17.12	16.32
Relative humidity (%)	55.85	54.45	53.33
Wind speed (m/s)	3.35	3.42	3.61
Solar radiation (MJ/m^2.day)	21.27	21.15	21.14
Precipitation (mm day^{-1})	114.31	0.27	0.18
Evapotranspiration (mm/day)	0.19	0.47	0.38

Table 4. Average annual climate data of the experiment site at Al-Sharkia during the period 2020-2021 growing seasons.

Climate Data	2019	2020	2021
Maximum air temperature (^{0}C)	29.71	30.71	30.2
Minimum air temperature (^{0}C)	15.67	16.8	15.98
Relative humidity (%)	53.16	51.23	50.09
Wind speed (m/s)	3.39	3.47	3.67
Solar radiation (MJ/m^2.day)	20.41	20.19	20.3
Precipitation (mm day^{-1})	135.41	0.21	0.18
Evapotranspiration (mm/day)	0.21	0.51	0.42

Soil Data:

The physical and chemical characteristics of soil for different study locations (Behira, Ismalia and Al-Sharkia) are presented in table 5.

Table 5. Some physical and chemical characteristics in initial state of the three studied locations.

Parameter	Behira	Ismalia	Al-Sharkia

Particle size distribution %			
Sand	90.00	97.7	96.35
Salt	5.00	1.10	2.27
Clay	5.00	1.20	1.38
Texture class	Sandy	Sandy	Sandy
Bulk Density (g/cm^{-3})	1.68	1.7	1.27
Organic matter %	0.06	0. 20	1.67
Field Capacity (%)	12.6	9.60	12
Wilting Point (%)	4.38	1.34	2.4
CaCO3	17.50	3.89	1.60
pH	8.20	7.70	8.23
E.C. (dSm^{-1})	1.50	0.79	0.42
Soluble cations (meq/L^{-1})			
N	0.10	0.08	0.20
P	0.44	0.20	0.22
Ca^{2+}	8.88	3.07	4.17
K^{+}	0.98	0.20	0.36
Na^{+}	12.80	3.31	4.69
Mg^{2+}	7.65	1.32	1.36
Soluble anions (meq/L-1)			
Cl^{-}	14.90	3.76	3.96
SO$_4^{2-}$	3.60	3.32	6.14
HCO^{3-}	11.80	0.82	1.02
CO$_3^{2-}$	Not detected		

Irrigation water Data:

Data of chemical composition of irrigation water for different study locations (Behira, Ismalia and Al-Sharkia) are presented in table 6.

Table 6. Chemical characteristics of the used irrigation water in three studied soil locations.

Parameter	Behira	Ismailia	Sharkia
pH	6.50	7.71	7.20
E.C. dSm^{-1}	6.44	0.32	3.28
Soluble cations (meq/L^{-1})			
Ca^{2+}	20.40	1.63	3.11
Mg^{2+}	8.95	0.25	6.16
Na^{+}	33.00	0.27	20.30
K^{+}	2.01	1.09	0.40
Soluble anions (meq/L^{-1})			
CO3^{2-}	0	0	0
HCO^{3-}	20.50	1.65	3.20
Cl^{-}	39.30	0.43	22.50
SO4^{2-}	4.59	1.16	4.27

AquaCrop model

The AquaCrop model (version 6.1) was used and evaluated in the current study to simulate yield of mango in three governorates (Behira, Ismalia and Al-Sharkia) of Egypt during 2020 and 2021.

The input data and parameters for AquaCrop are shown in Fig 1. The climate data include maximum air temperature, minimum air temperature, wind speed, relative humidity, solar radiation, evapotranspiration and CO_2 concentration. The management, soil, irrigation water characteristics and cultivar parameters.

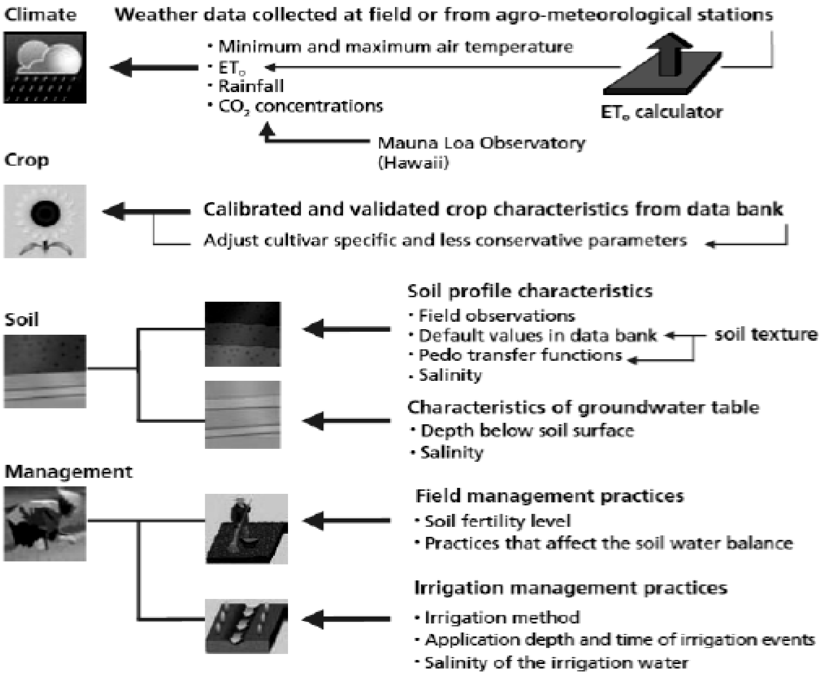

Fig 2. Input data and parameters for AquaCrop model Source: Steduto *et al.,* (2012).

AquaCrop model calibration and validation procedures:

The AquaCrop model was calibrated using measured growth and phenological data collected during the two seasons (2020-2021) for three locations (Behira, Ismalia and Al-Sharkia). In the calibration process certain model parameters were adjusted to make the simulation results match the measured values. For some of the parameters were used in the calibration during the experiments, such as observations of phenological stages of the crop (days to maximum canopy cover (CC), duration of flowering and days to harvest), hydraulic conductivity, water holding capacity, reference harvest index (HI), crop coefficient (KC) and yield (t/ha) table 7.

Calibration of the parameters of the AquaCrop module are shown in Table 7.

Parameters	**Behira**	**Ismalia**	**Al-Sharkia**
Days to harvest (days)	185	215	204
Days to maximum canopy cover CC (days)	45	44	39
Duration of flowering (days)	52	48	41
Maximum canopy cover (m^3/tree)	9.20	10.40	14.35
Plant density (tree/ha)	403	403	205
Hydraulic conductivity (cm/sec^{-1})	$1.9x10^{-3}$	$0.74x10^{-4}$	$1.7x10^{-4}$
Water holding capacity (%)	28.10	20.10	22.30
Reference harvest index HI (%)	60.23	61.40	69.60

Crop coefficient KC		0.92	0.96	0.95
Yield (Ton/ha)	**2020**	16.08	14.26	8.66
	2021	17.58	16.68	7.22

Performance evaluation of AquaCrop model:

Validation of Aquacrop model for yield was done by comparing simulated outputs against the measured data collected from the field using different statistical indicators.

The statistical indices used in the validation were coefficient of determination (R^2), the root mean square error (RMSE) and the index of agreement (d) (Ouda et al. 2015 and Paredes et al. 2014).

The coefficient of determination is an indicator of degree of closeness between simulated and measured data. It is unit less and may assume values ranging from -∞ to +1, with values close to 1 indicating a better model simulation efficiency, and typically values greater than 0.50 are considered acceptable in simulations Moriasi *et al.,* (2007).

The coefficient of determination (R^2) was calculated using the following equation:

$$R^2 = \left[\frac{\sum_{i=1}^{n} (M_i - \bar{M})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n} (M_i - \bar{M})^2 \sum_{i=1}^{n} (S_i - \bar{S})^2}} \right]^2$$

Where:
S, M, and n are the simulated, measured, and the number of measurements, respectively.
The root mean square error (RMSE) is a measure to calculate the total or mean deviation between the measured and simulated values. The closer the value is to zero, the better the model simulation performance. The root mean square error (RMSE) was estimated by the following equation (Loague and Green 1991):

$$\text{RMSE} = \left[\sum_{i=1}^{n} \frac{(S_i - M_i)^2}{n} \right]^{0.5}$$

Where:
S, M, and n are the simulated, measured, and the number of measurements, respectively.
The index of agreement (d) is a measure of the relative error in the model estimates. It is a dimensionless number that ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between the simulated and measured data Krause *et al.,* (2005).
The index of agreement (d) was calculated using the Willmott *et al.,* (1985) equation:

$$D = 1 - \left[\frac{\sum_{i=1}^{n} (S_i - M_i)^2}{\sum_{i=1}^{n} \left(|S_i - \bar{M}| + |M_i - \bar{M}| \right)^2} \right],$$

Where:
S, M, and n are the simulated, measured, and the number of measurements, respectively.
All the statistical tests were conducted using microsoft excel version 2007 and XLSTAT version 2021(Addinsoft 2021).

3. RESULTS AND DISCUSSIONS

The measured and simulated yield of mango using AquaCrop model (version 6.1) model for the three locations (Behira, Ismalia and Al-Sharkia) of Egypt in 2020 and 2021 is shown in Table 7. Results of simulated yield show that Behira produces the highest yield of mango averaging at 15.76 t/ha in 2020 and 17.57 t/ha in 2021 while Al-Sharkia the lowest yield with only 8.65 t/ha in 2020 and 7.22 t/ha in 2021 which is in line with measured yields reported in the three regions of Egypt (Bihera, Ismalia and Al-Sharkia) in the district which represent different peculiarities in the water irrigation, soil types and microclimates in those regions. The average district simulated yield was estimated at 12.87 t/ha in 2020 and 13.26 t/ha in 2021 which is also consistent with the measured district average (table 7).

Comparison between measured and simulated mango yields revealed that simulated values underestimated measured mango yield in Bihera, North of Sinai and Al-Sharkia by 1.02%, 5.38%, and 7.92% respectively. Similarly, the district simulated mango yield is also underestimated by 2.2%. These results agreed with Ismail et al. (2015) noted that simulation models can underestimate the simulated yield of peach by up to 17.82 %, without necessarily undermining reasonability of estimates obtained.

All the simulated yields therefore are within what can be termed as reasonable estimates of the measured yield and therefore they can be used for planning and decision making. The results have also shown that despite heterogeneity in the three regions evaluated, AquaCrop model has showed a consistent pattern of estimates which are all in line with measured mango yield.

Table 7. Yield of mango under field and AquaCrop simulation model by location during 2020 and 2021.

Season	Location	Measured (t/ha)	Simulated (t/ha)	Deviation (%)
2019-2020	**Behira**	16.08	15.76	1.99
	Ismalia	14.26	14.20	0.42
	Al-Sharkia	8.66	8.65	0.12
2020-2021	**Behira**	17.58	17.57	0.05
	Ismalia	16.73	15.00	10.34
	Al-Sharkia	7.22	7.20	0.28
	District Average	13.42	13.06	2.20

The results illustrated a good match between measured and simulated yield data. The R^2 ranged from 0.97 to 0.99, RMSE values were lower and ranged from 0.18 t/ha to 0.99 t/ha and index of agreement (D) for yield closer to 1 in the tow seasons (2020-2021) (Table 8). These results confirmed that calibrated AquaCrop model was efficient and consistent forecasters of productivity of mango under different conditions of climate, irrigation water and soil in Egypt.

Similar results were obtained by Arafat et al. (2019) in pomegranate crop, Neelam and Rajput (2010) and Datta et al. (2018) in potato crop.

Also, Ismail et al. (2015) reported that AquaCrop model had a good performance in simulating yield of peach under different stress condition, with R^2 values in the range of 0.82 - 0.83, the D-values of 0.86 - 0.90, and RMSE values of 0.47- 1.41 t/ha.

Table 8. Statistical indicators relative to total yield for mango under different locations (Behira, Ismalia and Al-Sharkia) and two growing seasons (2020 -2021).

Location	2019-2020		
	RMSE (t/ha)	**D**	**R^2**
Behira **Ismalia** **Al-Sharkia**	0.18	0.99	0.99
	2020-2021		
Location	**RMSE (t/ha)**	**D**	**R^2**
Behira **Ismalia** **Al-Sharkia**	0.99	0.98	0.97

* (RMSE) Root Mean Square Error and (D) Index of Agreement (Willmott 1982).

4. CONCLUSIONS

Based on results of this investigation, it can be concluded that the calibrated Aquacrop model had well simulated mango yield under different conditions of climate, irrigation water and soil in Egypt. This study showed that Aquacrop model may be used to simulate the yield of mango in different regions of the world. But, is a need to calibrate the model with local data in order to ensure excellent performance.

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