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Simulation of pomegranate (*Punica granatum* L.) growth and yield under different climatic conditions, water and soils using crop simulation models in Egypt.

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ABSTRACT

Crop simulation models (CSM) are now widely used to predict the future crop yields, to find the suitable measures for increase the crops productivity and to simulate the potential effects of genetic characteristics, irrigation water, soil and climatic conditions, together with the management practices on yield. The objective of this work is to evaluate the ability of AquaCrop model to simulate growth and yield of pomegranate under different climatic conditions, soil and irrigation water. Experiments were conducted during 2016 and 2017 seasons in tow governorates of Egypt (ElBehera and North of Sinai). The data required to run the AquaCrop model relate to climate were obtained from the America's space agency (NASA) and the physical and chemical characteristics of soil and irrigation water for different study locations were obtained from field sample analysis of soil and irrigation water . The validation and calibration of model was performed using field observations relative to yield data in 2016 and 2017. The results show the observed values of pomegranate yield in the field were greater than the simulated values in two seasons of study 28.543, 30.433 for first location of study (ElBehera) respectively and 10.638, 10.978 ton/ha for second location of study (North of Sinai) respectively, but the differences between them were very low. The averages of annual climatic data have the most significant impact on pomegranate yield. The agreement between observed and simulated yield data was good with root mean square error (RMSE), index of agreement (D) and coefficient of determination ($R^٢$). Statistical indicators, RMSE, D and $R^٢$ confirmed that the model is very reliable for simulating pomegranate yield for experiments (ElBehera and North of Sinai) in 2016 and 2017 seasons (low RMSE, D and $R^٢$ near 1), The relationship between observed and simulated yield produced RMSE ranged from 0.53 to 9.11%, D ranged from 0.985 to 0.994 and ($R^٢$) = 0.99. It was concluded that calibrated AquaCrop model was able to simulate growth and yield of pomegranate in tow experiments.

1. INTRODUCTION

The pomegranate (*Punica granatum* L.), is a crop that grows in all soil types and diverse climates (from semi-arid temperate zones to subtropical climates); they are widely cultivated in Asia, and the Mediterranean countries such as Egypt, Tunisia, Morocco, Turkey and Spain Levin, (2006), Jalikop, (2007), El-Falleh *et al.*, (2009) and Ahmet *et al.*, (2009). In Egypt the production of pomegranate is concentrated in four governorates Assiut, Sohag, ElBehera and North Sinai Salman *et* *al.*, (2016); recent statistics data provided by the Ministry of Agriculture in 2018 indicate that a total of 79040 fadan are planted with pomegranate trees, with a total production of 382587 tons (annual report of ministry of agriculture and land reclamation 2018).

P. granatum crop yields simulation is certainly a complicated task, it is affected by a multitude of variables (soil, meteorology, nutrients, pests, management, etc.), many of them, in turn, difficult to model.

AquaCrop is a simulation model designed by FAO for the analysis of the productivity of different crops in diverse agro-ecosystems Steduto *et al.*, (2009) fig 1 is application being possible for a wide range of ecological conditions and production systems. This model integrates the effect of genetic characteristics, fertilization, soil and climatic variables, together with the management variables, to simulate crop production in response to water in the soil-plant system Geerts *et al.*, (2010).

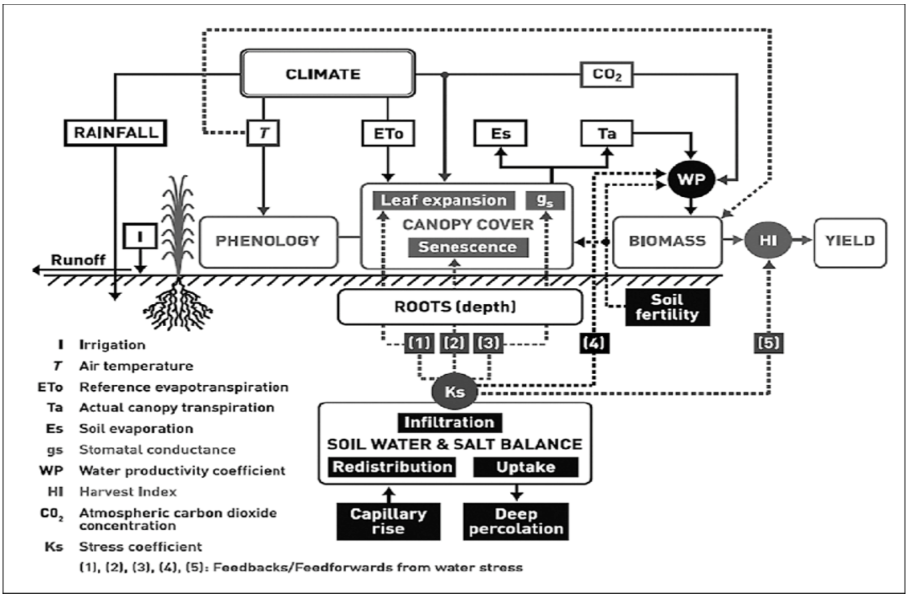

Fig1. Diagram of AquaCrop modeling Source: Steduto *et al.*, (2012).

The data required by the AquaCrop program includes climate (maximum temperature (Tmax), minimum temperature (Tmin), Relative humidity(RH), Wind speed (WS), Solar radiation (SR), precipitation (P), reference evapotranspiration (ETo) and an average annual concentration of CO_2, according to observatory measurements in Mauna Loa, Hawaii.), crop, soil, and management data. With this information, the program predicts the daily production of biomass and the final yield of crop, in our case of the pomegranate.

The objective of this work is evaluated the AquaCrop model to simulate growth and yield of pomegranate under different climatic conditions, soil and irrigation water in Egypt during 2016 and 2017.

2. MATERIALS AND METHODS

2.1. The Field Experimental Site:

Experiments were conducted during 2016 and 2017 seasons in tow governorates located in the north of Egypt, private farm located at the 64 km on the Cairo-Alexandria desert road, ElBehera (latitude 30.47 ˚N, longitude 30.09˚E, 94.5 m above sea level) and experimental farm of El Maghara Station of Desert Research Center, North of Sinai (latitude 30.35˚N, longitude 33.20˚E, 414.15 m above sea level). Respect to the experiments characteristics were obtained from previous studies Bakeer, (2009), Seidhom and Abd-El-Rahman, (2011), Shaheen *et al.,* (2016), Salama *et al.,* (2016) and Farag *et al.,* (2017) table 1.

Table 1. Characteristics of experiments.

Character	ElBehera	North of Sinai
Planting distances (m)	3 × 3	3.6× 3.6
Varieties	Wonderful	Manfalouty
Tree age (Year)	5	15
Irrigation system	Drip	Drip
Irrigation water levels	100% (11404 m^3/ha).	100% (5576 m3/ha)

*according to the extensions of the Ministry of Agriculture, Egypt (2015).

With respect to fertilization on ElBehera, organic manure in December at75 kg/tree were added and mineral fertilization of (NPK) were added at 2kg/tree ammonium sulfate (20.6%) in two doses in March and May after the fruit eased, 1kg/tree superphosphate (15%) in December and from 500g/tree potassium sulfate (48%) in March). On North of Sinai, plants were fertilized by Organic manure in December at 100 kg/tree and mineral fertilization of (NPK) were used as 3.5kg/tree ammonium sulfate (20.6%) in two doses in March and May after the fruit eased, 2kg/tree superphosphate (15%) in December and from 1kg/tree potassium sulfate (48%) in March).

2.2. Weather data:

The weather data were obtained from the website of the America's space agency (NASA https://power.larc.nasa.gov/data-access-viewer/). Data in Table 2 and 3 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 (ElBehera and North of Sinai) during the period 201٥ to 2017. Respect to the evapotranspiration (ETo) data was calculated using the FAO Penman-Monteith equation as described by Allen *et al.,* (1998).

Table 2. Average of annual weather data of the experiment site at ElBehera during the period 2015 – 2017 growing seasons.

Weather Data	2015	2016	2017
Max. air temperature (Tmin˚C)	28.61	29.11	28.06
Min. air temperature (Tmin˚C)	14.95	14.98	14.22
Relative humidity (%)	52.13	52.24	55.40
Wind speed (km/day)	2.93	2.94	2.76
Solar radiation (MJ/m^2.day)	20.62	20.86	20.88
Precipitation (mm day^{-1})	0.21	0.59	0.47
Evapotranspiration (ETo) mm/day	3.03	3.16	3.12

Table 3. Average of annual weather data of the experiment site at North of Sinai during the period 2015 – 2017 growing seasons.

Weather Data	2015	2016	2017
Max. air temperature (Tmin˚C)	26.31	26.92	26.19
Min. air temperature (Tmin˚C)	13.5	13.61	13.15
Relative humidity (%)	54.17	53.54	55.29
Wind speed (km/day)	2.94	2.97	2.78
Solar radiation (MJ/m^2.day)	21.3٠	21.32	21.27
Precipitation (mm day^{-1})	0.21	0.43	0.18
Evapotranspiration (ETo) mm/day	3.08	3.09	3.07

2.3. Soil Data:

The physical and chemical characteristics of soil for different study locations (ElBehera and North of Sinai) were collected from previous studies Bakeer, (2009), Seidhom and Abd-El-Rahman, (2011), Shaheen *et al.*, (2016), Salama *et al.*, (2016) and Farag *et al.*, (2017) table 4.

2.4. Irrigation water Data:

Data of chemical composition of irrigation water for different study locations (ElBehera and North of Sinai) were obtained from previous studies Bakeer, (2009), Seidhom and Abd-El-Rahman, (2011), Shaheen *et al.*, (2016), Salama *et al.*, (2016) and Farag *et al.*, (2017) table 5.

2.5. AquaCrop Input Data:

The AquaCrop model (version 6.1) was used and evaluated in the current study to simulate growth and yield of pomegranate in two Egyptian governorates (ElBehera and North of Sinai) during 2016 and 2017.

The input data and parameters for AquaCrop are shown in Fig 2. The weather 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.

2.6. Model Calibration and Testing:

During calibration, certain model parameters were adjusted to make the simulation results match the observed values. Some of the parameters were used in the calibration during the experiment, such as observations of phenological stages of the crop (days to maximum canopy cover CC, duration of flowering and days to

Table 4. Mean physical and chemical characteristics of the 0-60 cm depth ElBehera and North of Sinai soil layer.

Parameter	ElBehera	North of Sinai
Particle size distribution %		
Sand	85.20	98.25
Salt	8.63	0.90
Clay	6.17	0.85
Texture class	Loamy sand	Sand
Bulk Density (g/cm^{-3})	1.68	1.50
Organic matter %	0.06	0.23
Field Capacity (%)	12.6٠	10.1٠
Wilting Point (%)	4.38	4.48
CaCO3	17.5	4.85
pH	7.71	7.7٠
E.C. (dSm^{-1})	3.03	0.65
Soluble cations (meq/L^{-1})		
Ca2^{+}	8.88	2.75
K^{+}	0.98	0.06
Na^{+}	12.8	1.42
Mg2^{+}	7.65	1.75
Soluble anions (meq/L^{-1})		
Cl^{-}	14.9	1.70
SO4^{2-}	3.60	2.48
HCO^{3-}	11.80	1.80
CO3^{2-}	Not detected	

Table 5. Chemical composition of the ElBehera and North of Sinai water used for irrigation.

Parameter	ElBehera	North of Sinai
pH	6.50	8.36
E.C. dSm^{-1}	6.44	4.99
Soluble cations (meq/L^{-1})		
Ca2^{+}	20.40	13.33
Mg2^{+}	8.95	5.78
Na^{+}	33.00	25.33
K^{+}	2.01	1.15
Soluble anions (meq/L^{-1})		
CO32^{-}	0.00	0.00
HCO^{3-}	20.5	7.44
Cl^{-}	39.30	4.49
SO4^{2-}	4.59	33.66

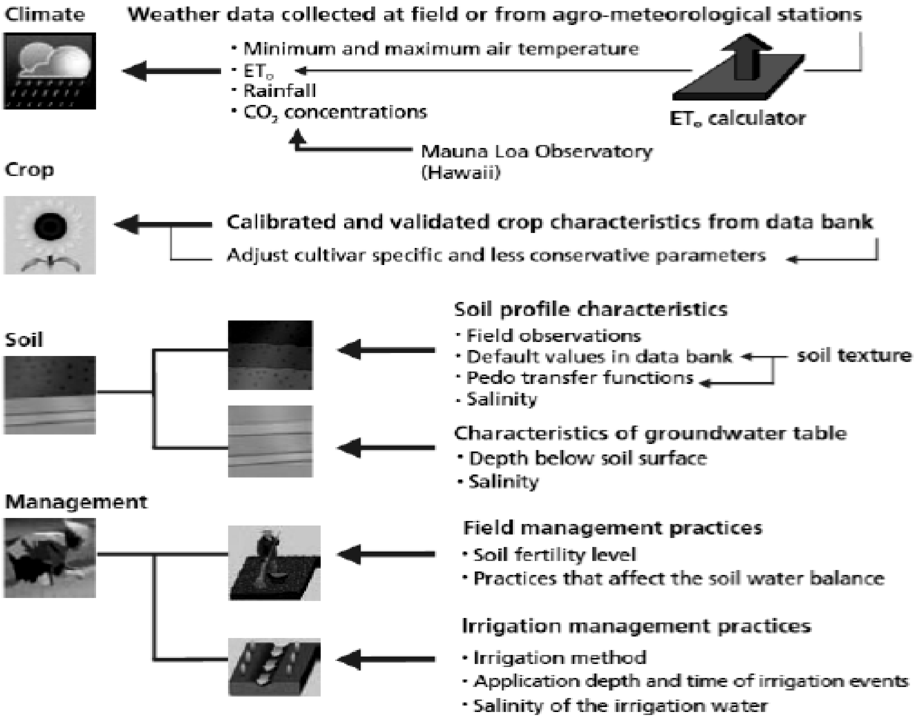

Fig 2. Input data and parameters for AquaCrop model Source: Steduto *et al.*, (2012).

Table 6.Calibration of the variables of the AquaCrop modules

Parameters	ElBehera	North of Sinai
Days to harvest	225 days	202 days
Days to maximum canopy cover CC	39 days	37 days
Duration of flowering	63 days	60 days
Maximum canopy cover	3.7m^3/tree	10m^3/tree
Plant density	1111 tree/ha	772 tree/ha
Hydraulic conductivity	1.9x10^{-3} cm/sec^{-1}	0. 72x10^{-4} cm sec^{-1}
Water holding capacity WHC	28.1%	22.3%
Reference harvest index HI	61.23%	60.6 %
Crop coefficient KC	0.65	0.63

harvest), hydraulic conductivity, water holding capacity, reference harvest index HI and crop coefficient KC Table 6.

Performance of AquaCrop in simulating yield was evaluated by comparing simulated results against observed data. The statistical indices used in the validation were correlation coefficient (r), root mean square error (RMSE) and willmott index of agreement (d) Willmott (1981) Samiha Ouda *et al.*, (2015).

The correlation coefficient (r) is an indicator of degree of closeness between simulated and observed data.

It ranges from 0 to 1, with values close to 1 indicating a good agreement, and typically values greater than 0.50 are considered acceptable in simulations Moriasi *et al.*, (2007).

The correlation coefficient was calculated using the following equation:

$$r = \frac{\sum_{i=1}^{n}(O_i - MO)\times(S_i - MS)}{\sqrt{\sum_{i=1}^{n}(O_i - MO)^2 \times \sum_{i=1}^{n}(S_i - MS)^2}}$$

Where:
O_i observed value, S_i simulated value, MO mean of observed values and MS mean of simulated values.

The root mean square error (RMSE) is a measure to calculate the total or mean deviation between the observed and simulated values. The adjustment of the model improves when the value is close to zero. The root mean square error (RMSE) was estimated by the following equation Loague and Green (1991):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{N}}$$

Where:
S_i simulated value, O_i observed value and N number of observations.

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 observed data Krause *et al.*, (2005). The index of agreement (d) was calculated using the Willmott *et al.*, (1985) equation:

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}\left(|S_i - MO| + |O_i - MO|\right)^2}$$

Where:
O_i observed value, S_i simulated value and MO mean of observed values.

3. Results and Discussions.

The pomegranate yield data obtained from the field and AquaCrop module are shown in table 8. In experiments 2016 and 2017, the observed values in the field were greater than the simulated values 28.543, 30.433, 10.638 and 10.944 ton/ha respectively, but the difference between them was very low.

Table 8. Observed and simulated pomegranate yield data obtained in tow experiments (ElBehera and North of Sinai) during 2016 and 2017.

Season	ElBehera			North of Sinai		
	Observed Ton/ha	Simulated Ton/ha	D* Ton/ha	Observed Ton/ha	Simulated Ton/ha	D* Ton/ha
2015-2016	28.543	28.324	219	10.638	10.588	50
2016-2017	30.433	30.421	12	10.978	10.944	34

* Difference between the observed and simulated values.

In general, statistical indicators express a good fit between the observed and simulated values. As shown in fig 3, the model simulated crop yields in an acceptable form for a wide range of agroecological conditions with a correlation coefficient (r) = ٠.99 for tow experiments (ElBehera and North of Sinai).

According to the values of root mean squared error (RMSE) for tow experiments (ElBehera and North of Sinai), indicated in table 9 , the differences between observed and simulated values varied between 0.043 and 0.155 Ton/.ha, which represents, in average percentage terms for tow experiments, 4.82 %.

Finally, the data of the index of agreement (Willmott 1981 and Willmott 1982) for tow experiments indicating a perfect agreement between the simulated and observed data table 9. Similar results were obtained by Ismail *et al.*, (2015) on peach trees.

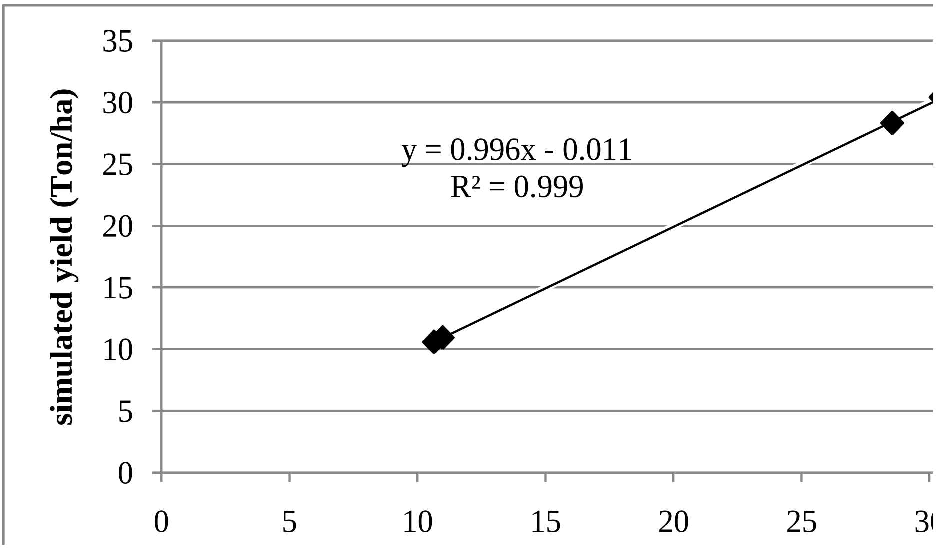

Fig 3. Relation between observed and simulated values of the pomegranate yield obtained in tow experiments (ElBehera and North of Sinai) during 2016 and 2017.

Table 9. Statistical indices derived for evaluating the performance of AquaCrop model in simulating pomegranate yield in tow experiments (ElBehera and North of Sinai) during 2016 and 2017.

Season	ElBehera			North of Sinai		
	RMSE*		d*	RMSE*		d*
	Ton/ha	%		Ton/ha	%	
2015-2016 2016-2017	0.155	0.53	0.994	0.043	9.11	0.985

* (RMSE) Root Mean Square Error and (d) Index of Agreement (Willmott 1981 and Willmott 1982).

4. Conclusions

The AquaCrop model was able to simulate growth and yield of pomegranate in tow experiments.

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الملخص العربى

التنبؤ بنمو وانتاج الرمان تحت ظروف مختلفه من المناخ ، الماء و التربه بواسطة استخدام نظم المحاكاه للمحاصيل فى مصر.

ابراهيم الدسوقى عرفات و صفية عبد المنعم ابوطالب و محمد ابو الوفا احمد

معهد بحوث البساتين بمركز البحوث الزراعية مصر

تستخدم الآن نماذج محاكاة المحاصيل على نطاق واسع للتنبؤ بإنتاجية المحاصيل في المستقبل، إيجاد التدابير المناسبة لزيادة إنتاجية المحاصيل ومحاكاة الآثار المحتملة للخصائص الوراثية، مياه الري، التربة والظروف المناخية ، جنبًا إلى جنب مع العمليات الزراعية على الإنتاج. الهدف من هذا العمل هو تقيم قدرة النموذج Aquacrop لمحاكاة نمو وإنتاج الرمان في ظل ظروف مناخية مختلفة ، التربة ومياه الري. أجريت تجارب خلال الموسميين ٢٠١٦ و ٢٠١٧ في محافظتين بمصر (البحيرة وشمال سيناء). تم الحصول على البيانات اللازمة لتشغيل نموذج AquaCrop المتعلق بالمناخ من وكالة الفضاء الأمريكية (NASA) وتم الحصول على الخصائص الفيزيائية والكيميائية للتربة ومياه الري لمواقع الدراسة المختلفة من خلال تحليل عينات حقلية للتربه ومياه الرى. تم إجراء التحقق من صحة ومعايرة النموذج باستخدام الملاحظات الحقلية المتعلقة ببيانات الإنتاج في ٢٠١٦-٢٠١٧. أظهرت النتائج أن القيم المرصودة لإنتاجية الرمان في الحقل كانت أكبر من القيم المحاكاة في موسمين الدراسه ٢٨.٥٤٣ ، ٣٠.٤٣٣ طن / الهكتار لموقع الدراسة الأول (محافظة البحيره) على التوالي و ١٠.٦٣٨ ، ١٠.٩٤٤ طن / هكتار لموقع الدراسة الثانى (محافظة شمال سيناء) على التوالي ، لكن الفروق بينهما كان منخفضًا جدًا. متوسطات البيانات المناخية السنوية كان لها تأثير معنوى أكبر على إنتاجية محصول الرمان. أظهرت النتائج أن الاتفاق بين بيانات الإنتاج الفعلية والمحاكاة كانت جيدة مع جذر متوسط مربع الخطأ (RMSE) ، دليل التوافق (D) ومعامل الإرتباط (R^2) . تشير المعايير الإحصائية ،RMSE ، D و R^2 إلى أن النموذج فعال للغاية لمحاكاة محصول الرمان لتجربة البحيرة وشمال سيناء في المواسم ٢٠١٦ و ٢٠١٧ (RMSE منخفض ، D و R^2 قريب من ١). العلاقة بين بيانات الإنتاج المشاهده والمحاكاة انتجت RMSE تراوح بين ٠.٥٣ إلى ٩.١١٪ ، D تراوح بين ٠.٩٨٥ إلى ٠.٩٩٤ و R^2 = 0.99. استنتج أن النموذج AquaCrop المعايير كان قادرًا على محاكاة نمو و إنتاجية الرمان فى التجريتين.