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FAO AquaCrop Model Performance: in Green Canopy Cover, Soil Moisture and Production of Maize at Middle and Lower Reaches Plain of Yangtze River of China[1]

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Abstract—Crop water productivity models are valuable tools for investigate the crop responses to the water-management strategies and ameliorate the efficiency of water use in agriculture. The objective of this study was to evaluate the performance of AquaCrop model for maize crop (*Zea mays* L.) under full, excessive and deficit applications of drip irrigation in semi-humid region of China. The evaluation results emphasized the model accuracy in simulations CC, SWC, B*, Y and WUE with satisfactory performance in full irrigation, and moderate water stressed treatment T_2 of 75% of full irrigation. This accuracy declines in circumstances of excessive irrigation T_1 of 125% of full irrigation, and high water stressed T_3 of 50% of full irrigation. The RMSEs and NRMSEs in simulated CC, and SWC for full irrigation, T_1, T_2 and T_3 treatments were 7.3–8.6, 6.3–7.2, 5.4–6.3 and 4.9–5.6% CC, respectively, and 9.4–4.8, 16.1–8.1, 16.4–9.3 and 20.9–13.4% SWC, respectively. Whereas, the D-index and R^2 of CC varied between 0.72 to 0.89 and 0.99 to 1.0, while in the SWC varied between 0.54 to 0.83 and 0.48 to 0.96 for the four irrigation treatments. The differences (S.D) in final biomass and grain yield were within the range of 0.23 to 4.45% and 0.30 to 1.46% between the measurement and simulation. Simulated WUEs of biomass and yield under different irrigation treatments ranged between 6.07 to 6.52 kg/m^3 and 3.07 to 3.16 kg/m^3, AquaCrop's performance trends to underestimate the WUEs of biomass and yield, and emphasizes that the yield WUE increased linearly with water stress condition increased.

Keywords: AquaCrop, crop yield, irrigation management, model evaluation, soil moisture, water productivity

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INTRODUCTION

The crop and water simulation models have been widely used in recent decades due to the laborious and expensive to investigate the crop-water relationships in the field experiments or controlled conditions as empirical parameters. Crop-water models are tools designed to operations with the climatic data that had a relation with the crop water requirements and crop production such as maximum and minimum air temperatures, rainfall, humidity, wind speed and sun radiation. Since that, the weather information in most of the countries is costly and not easily available to all users, particularly as the historical long-term data, the most of the crop-water models had direct or indirect linked with different meteorological stations or the data has been indexed in the model's user files and covered most of the regions but not all. So, for the real and accurate decisions, the locality of the information is an essential factor and an indispensable.

AquaCrop is one of the crop-water productivity models developed by Food and Agriculture Organization (FAO) [1–3] to predict crop productivity, water requirement, and water-use efficiency under water limiting conditions [4]. The model evolved from the concepts of crop yield responses to water, which developed by [5]. It's beside to simulate crop yield; AquaCrop also simulates soil water content using basic soil and weather data [6]. The model seeks the balance among simplicity, accuracy and robustness. To facilitate wide application, this multi-crop and water model requires only a relatively small number of explicit parameter values and mostly intuitive input variables, which are obtainable by straightforward methods [3, 4, 7].

Recently, many studies have used the AquaCrop model to simulate various crop's growth responses to irrigation water and environments for the different crops and regions; Maize [1, 8–12], cotton [13] and

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sunflower [14]. The above researchers have emphasized the model performance is satisfactory in simulates the crops production and water productivity (WP), but they suggested more tests for calibration's key parameters in diverse climates, soils, crops, irrigation and field managements. Moreover, the model performance findings under water stress conditions (deficient or excessive irrigation) still stand doubtful and lacked, required intensive investigations to be adapted with different local conditions. Here are some existing problems, we are trying to figure out with current study: AquaCrop model had never tested under water stress conditions or local parameters of the study area. Such model simulations accompanied with experimentations will provide a useful and powerful information for this region and other similar conditions.

The objectives of this research were: to evaluate the performance of FAO-AquaCrop model for maize crop (*Zea mays* L.) under full, excessive and deficit irrigation in the semi-humid region of China (Middle and Lower Reaches Plain of Yangtze River). Assess the model capability and effectiveness in simulation the green canopy cover, soil water content, final biomass, dry grain yield and water use efficiencies for maize drip irrigation using greenhouse experimental records for model calibration and validation.

MATERIALS AND METHODS

Site Description and Data

The Site has an average altitude of 3.5 m, subtropical monsoon climate with humid and changeable wind, average temperature of 15°C, annual precipitation of 1030 mm, mean sunshine duration of 2177 h, and frost-free period of 222 days. The raining season is from mid-June to July. The climatic data provided to AquaCrop was obtain from the observatory located at the study area in Middle and Lower Reaches Plain of Yangtze River, China. While, the maize crop parameters, irrigation, soil and field managements acquired from the greenhouse experiment carried out at the study area during the period of 2012–2013 growing season.

Crop Management and Irrigation Practices

Maize plant seeds sown on August 5, 2012 at 5 cm depth from soil surface with 0.30 m distance between the plants in one row, spaced at 0.50 m between two planting rows in each replicate and oriented east-west direction. The experimental design under drip irrigation method was a completely randomized has four different irrigation treatments with four replicates. The total crop density of 66000 plant ha^{-1} was gained after thinning and full canopy cover stabled, the density was taken from local practices of the region. Harvesting started on October 27, 2012.

The water applied via drip irrigation system in the four different irrigation treatments as (T_1, T_2, T_3 and Control or full irrigation). The full irrigation treatment provided with actual percentage water depth of crop evapotranspiration (ET_c) that was determined based on Penman-Monteith method as described in [15] and T_1, T_2 and T_3 received 1.25, 0.75, and 0.50 of full irrigation, respectively. The total irrigation amounts of full irrigation treatment was 471.35 mm of water depth.

Estimation of Reference Evapotranspiration (ET_o)

ET_o calculator version 3.2 September, 2012 for Land and Water Division in FAO organization was used for calculating ET_o based on Penman-Monteith method [15] from the 35 years of historical weather data (1980–2014), the weather data included maximum and minimum air temperature, relative humidity, sunshine and wind speed. Afterward, the ET_o and temperature files exported to the AquaCrop model platform to use in accompany with rainfall data in model as the climatic file (Fig. 1), which required during the model calibration, validation and parameterization processes.

AquaCrop Model Description

The AquaCrop model designed to recognize the data as the daily, ten days or monthly for the terms of maximum temperature (T_{max}), minimum temperature (T_{min}), rainfall/precipitation (P_p) and reference evapotranspiration (ET_o); that besides the consideration of annual average concentration of CO_2 in the atmosphere. The model is a multi-crop water productivity able to simulate biomass production based on the amount of water transpired from green canopy cover (CC) instead of leaf area index (LAI). The simulations of biomass and grain production refer to crop parameters such as stomatal conductance, senescence of the vegetal canopy, water productivity and harvest index (HI). AquaCrop uses the cumulative actual crop transpiration during the growing season (Tr) and normalized water productivity (WP^*) for simulating total biomass (B^*) as Eq. (1) [3].

$$B^* = WP^* \times \sum \mathrm{Tr}. \tag{1}$$

The estimated crop yield (Y) is a function of B^* and harvest index (HI) as Eq. (2).

$$Y = B^* \times \mathrm{HI}. \tag{2}$$

For AquaCrop parameterization, the maize input parameters as conservative and non-conservative crop parameters were described by [1] and validated by [8]. Conservative crop parameters are constant for all maize cultivars while non-conservative parameters may need fine tuning to be applicable to specific local cultivar characteristics.

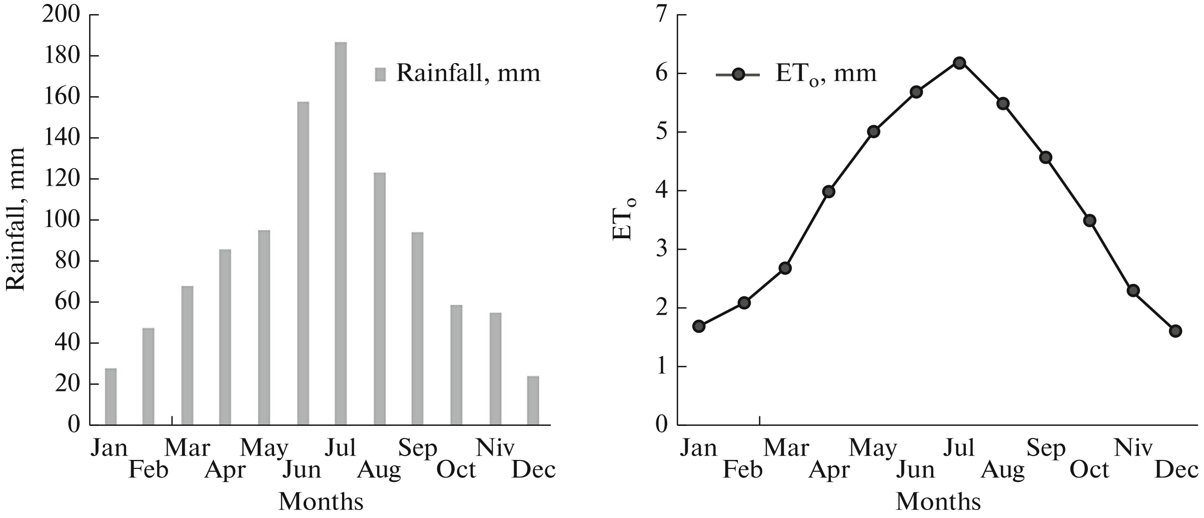

Fig. 1. ET_o calculated and rainfall data provided to the AquaCrop model.

Model Calibration and Validation

During the model calibration and validation, the climate and crop management practice files were retained constants all time of the simulation, that because of the files contents do not change with time. In order to calibrate the model, the data of treatment (fully irrigated) in maize was chosen to avoid the water stress in simulations and getting fair results. The most important canopy cover parameters for modeling calibration are canopy growth coefficient (CGC), canopy decline coefficient (CDC), and the stress indices for water stress affecting leaf expansion and early senescence [16]. These parameters could be obtained by inputting some phonological data to the model, thereafter, they were calibrated by trial and error approach. By entering some of the phonological dates as dates to maximum canopy cover, senescence, maturity, and emergence of the studied crop cultivar, the canopy expansion rate was automatically estimated by the model. The initial canopy cover (CCo) was estimated from the seeding rate density [8] and the changes in (CC) over the growing season was calculated from the measured LAI. After the calibration process for crop parameters, the validated model used with the other experiment treatments T_1, T_2 and T_3, and all the other calibration parameters were considered as constants during this stage.

Model Evaluation

In order to evaluate the model performance in simulation the daily or seasonal values of canopy cover (CC), total biomass (B^*), water productivity (WP), crop yield (Y), soil water content, actual evapotranspiration (ET), and water use efficiency in each water treatment of maize crop the root mean square error (RMSE) provides a measure (%) of the relative difference between the simulated and observed results, the coefficient of determination (R^2), and the index of agreement (D-index) proposed by [17] with a linear regression analysis were applied as the common test methods for goodness of fit of the model outputs [18].

RESULTS AND DISCUSSION

The AquaCrop model was calibrated using the maize measured data of full irrigation treatment during 2012–2013 growing season. The simulations were performed focused on the green canopy cover (CC), soil water content (SWC), final biomass and dry grain yields. Figure 2 and Table 1 showed the model key parameters that were fine-tuned around their default values in AquaCrop v5.0 as reported by [1, 2]. The maximum value for canopy cover (CC_x) was 90% is set after 36 DAS (days after sowing) and the crop cycle duration to maturity about 110 days, synchronizing of 16 days earlier the crop canopy started to senescence. Maximum effective rooting depth (Z_x) was 0.65 m shorter than that in default values whereas, the values of the reference harvest index (HI_o) and normalized water productivity (WP*) were same as reported by [1, 2]. The reason of small rooting depth during the crop cycle that might be due to the differences in maize varieties.

Canopy Cover (CC)

The statistical values in (Table 2) along with the graphical presentations in (Figs. 3A and 3B), shown the CC simulations of four irrigation treatments in different days after sowing (DAS) for calibration and validation data. It is appearing that the model is capable to simulate the CC development. The common trends of model simulations in maize CC (Fig. 3) were

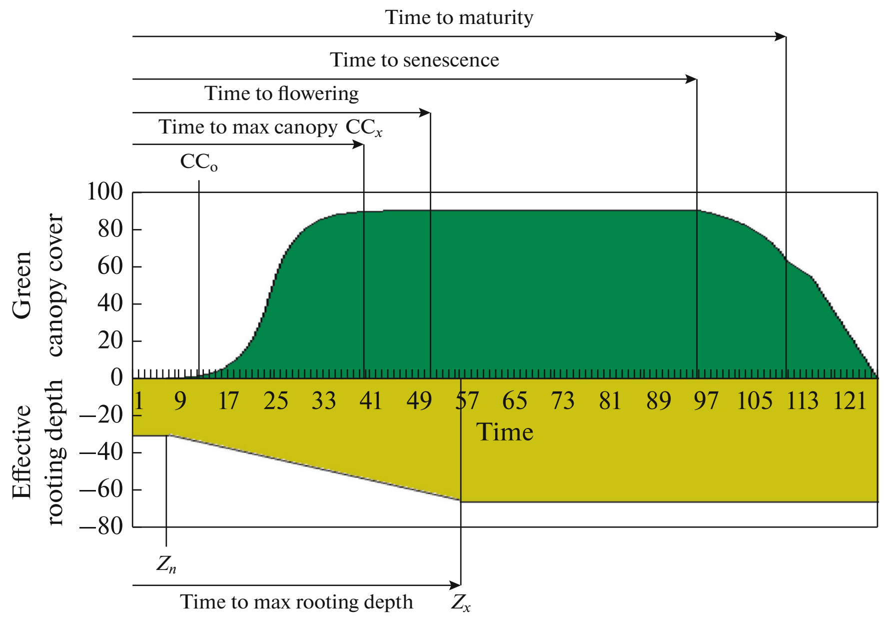

Fig. 2. Maize green canopy cover development and effective rooting depth extension described with initial canopy cover (CC_o), maximum canopy cover (CC_x), minimum effective rooting depth (Z_n) and maximum effective rooting depth (Z_x).

achieved perfect matching between simulated and measured in control and T_2 treatments, and slightly underestimated the CC in T_1 and T_3 treatments. AquaCrop underestimated CC reported by [12] in maize.

The low RMSEs and NRMSEs in (Table 2) indicate satisfactory simulations for calibration and validation data. The RMSEs are ranged from 4.9–7.3% and the NRMSEs from 5.6–8.6%, which proving excellent simulations for CC development in different irrigation treatments. Higher values in R^2 shown strong 1 : 1 correlation between simulated CC against measured CC for individual treatments. The D values obtained in calibration and validation data indicate perfect agreement between the simulated and measured data in all treatments. In general, the model trends systematically overestimated the CC in early vegetative growth of all irrigation treatments (Figs. 3A and 3B), conversely result observed by [8, 12] as slightly underestimation and [19] as overestimation.

Soil Water Content (SWC)

Table 3 and Figs. 4A and 4B, illustrate the SWC simulations of full irrigation and other three treatments in different DAS for calibration and validation dataset. In general, the model performed very well for simulating the SWC dynamics in roots zone of all irrigation treatments. AquaCrop simulation results of SWC in (Figs. 4A and 4B) showed that, the model trended slightly overestimation in control (full irrigation) and T_1 treatments and tended as slightly underestimation in T_2 and T_3 of water stress treatments. Overestimated SWC findings agreed with [1, 13, 20, 21] whereas, the underestimated results in line with [22–24]. The statistical values of RMSEs, NRMSEs, R^2 and D were varied between 9.4–20.9, 4.8–13.4, 0.48–0.96 and 0.54–0.83% in the four irrigation treatments of maize. The above variation in statistical values indicated the simulation quality is excellent in the term of NRMSE and good in the term of RMSE.

Final Biomass and Dry Grain Yield

The measured and simulation results of final biomass and dry grain yield were evaluated in comparison to control treatment (Table 4). In general, the model was overestimated the final biomass in control and T_2 treatments and underestimation it in T_1 and T_3 treatments. In respect of three validation treatments, the higher measured and simulated biomass were 29.61 and 27.40 t/ha recorded on T_3 and T_1 treatments, respectively. The measured grain yield of T_1 and T_3 treatments were 13.31 and 14.21 t/ha, these values increased on average of 6.14 and 13.32% over full irrigation treatment (Table 5). While, the T_2 treatment of 11.79 t/ha yield was decreased by 5.98%. Furthermore, the simulated yield values of T_1 and T_3 were 12.89 and 12.15 t/ha, which decreased on average by 0.16 and 5.89% from control. Whereas, the T_2 treatment of 13.12 t/ha yield increased by 1.63% over full irrigation (Table 5). The reductions in measured and simulated grain yield less than that were reported by [12, 25]. The differences (S.D) in final biomass and yield were within range of 0.23 to 4.45% and 0.27 to 1.46% respectively, these S.Ds were less than [25] who

Table 1. The default and calibrated values for maize crop and the other parameters not included in the table were left as the default values contained in the (AquaCrop v5.0) files

Parameter description	Maize	
	default	calibrated
Base temperature, °C	8.0	8.0
Cut-off temperature, °C	30.0	30.0
Plants per hectare (n.)	75000	66000
Canopy cover per sowing/transplanting at 90% emergence (CC_o), cm^2	6.5	6.5
Maximum canopy cover (CC_x), %	96	90
Canopy growth coefficient (CGC), %/day	16.3	26.5
Canopy decline coefficient (CDC) at senescence, %/day	11.7	11.7
Days from sowing/transplanting to maximum rooting depth, days	108	55
Days from sowing/transplanting to start of senescence, days	107	95
Days from sowing/transplanting to maturity, days	132	110
Days from sowing/transplanting to flowering, days	66	51
Length of flowering stage, days	13	12
Building up of Harvest Index, days	61	54
Water productivity (WP*) normalized for ET_o and CO_2, g/m^2	33.7	33.7
Reference Harvest Index (HI_o), %	48	48
Allowable maximum increase of specified HI (%)	15	15
Effect of canopy cover in reducing soil evaporation in late season stage, %	50	50
Maximum effective rooting depth, Z_x, m	2.3	0.65
Minimum effective rooting depth , Z_n, m	0.3	0.3
Soil water depletion threshold above which canopy expansion starts declining, P_{upper}	0.14	0.2
Soil water depletion threshold above which canopy expansion ceases, P_{lower}	0.72	0.80
Shape factor for water stress coefficient for canopy expansion	2.9	2.9
Soil water depletion threshold above which stomata start closing, P_{upper}	0.69	0.50
Shape factor for water stress coefficient for stomatal control	6.0	6.0
Soil water depletion threshold above which canopy starts senescence, P_{upper}	0.69	0.82
Shape factor for water stress coefficient for canopy senescence	2.7	2.7

Table 2. Statistical indices of AquaCrop simulated results for the calibration and validation data of maize crop

Crop	Irrigation treatments	Statistics of calibration and validation data in canopy cover, *CC*			
		RMSE, %	NRMSE, %	R^2	*D*
Maize	Control (full irrigation)	7.3	8.6	0.99	0.72
	T_1	6.3	7.2	0.99	0.77
	T_2	5.4	6.3	1	0.81
	T_3	4.9	5.6	0.99	0.89

reported that the less difference was observed ±10% and ±4% for biomass and yield, respectively. Also, lower than 2.4 to 20.7% biomass and 2.9 to 15.3% grain yield, which announced by [23] and within the range of <10% for biomass and <5% grain yield mentioned by [12]. The lower S.Ds indicated high accuracy in model simulations for final biomass and dry grain yield as in control, T_1 and T_2 treatments, while the model accuracy declines in circumstance of high water stressed in T_3 treatment.

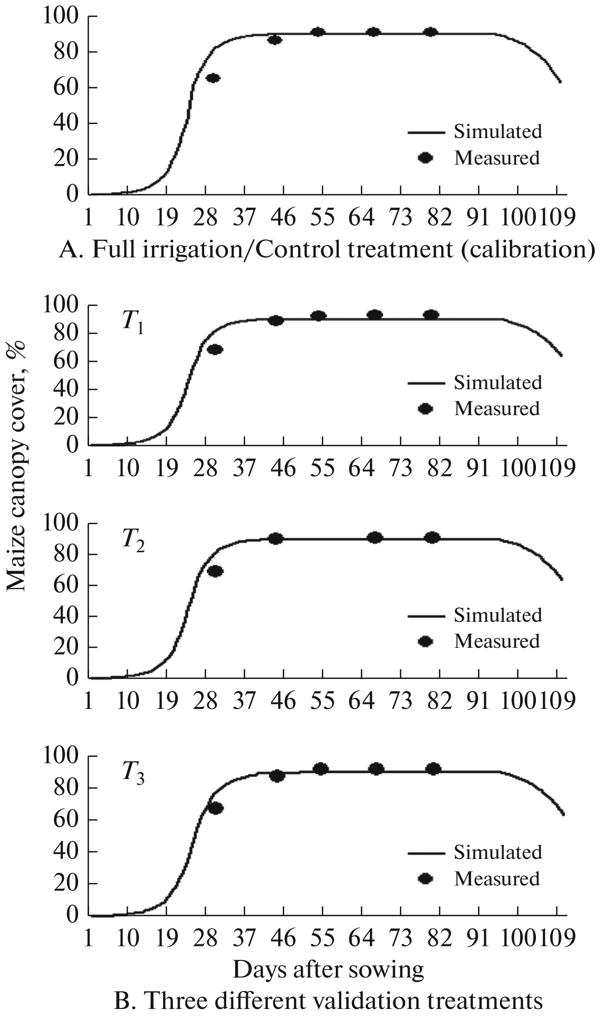

Fig. 3. AquaCrop model calibration and validation results for canopy cover in irrigation treatments of maize crop.

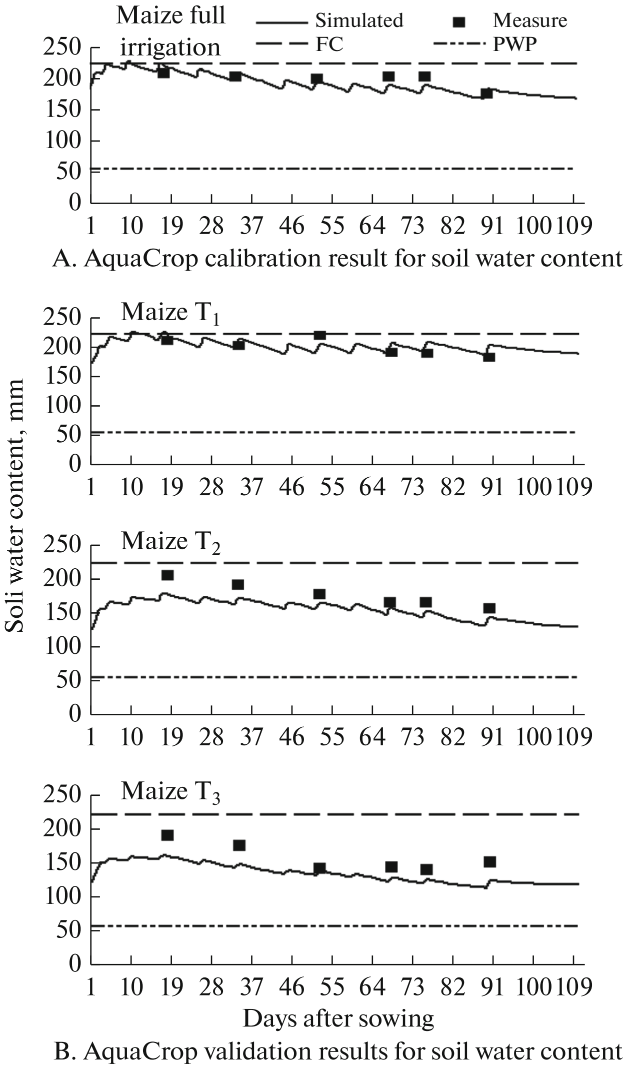

Fig. 4. Variation in soil water content between measured and simulated values for different irrigation treatments.

Water Use Efficiency (WUE) and Water Saving Potential (WSP)

The water use efficiency (WUE) of biomass and grain yield in (Table 5) calculated as the ratio of produced biomass/grain yield to cumulative evapotranspiration (ET_c). AquaCrop in this study was underestimation the simulated ET_c values of control and T_1 treatments and overestimated it in T_2 and T_3 treatments.

Table 5 reveals the simulated WUEs in term of biomass varied from 4.65 to 9.91 kg/m^3. While, in the term of grain yield the WUEs varied from 2.19 to 5.16 kg/m^3. Obviously, the WUEs of biomass and grain yield

Table 3. Statistical indices of AquaCrop simulated results for the calibration and validation data of maize crop

Crop	Irrigation treatments	Statistics of calibration and validation data in soil water content, *SWC*			
		RMSE, %	NRMSE, %	R^2	*D*
Maize	Control (full irrigation)	9.4	4.8	0.69	0.83
	T_1	16.1	8.1	0.48	0.54
	T_2	16.4	9.3	0.96	0.74
	T_3	20.9	13.4	0.9	0.69

Table 4. Final biomass and dry grain yield measured values compared with AquaCrop simulated values in different irrigation treatments with their standard deviations (S.D)

Crop	Irrigation treatments	Biomass			Yield		
		measured, t/ha	simulated, t/ha	S.D., %	measured, t/ha	simulated, t/ha	S.D., %
Maize	Control (full irrigation)	26.13	27.40	0.90	12.54	12.91	0.27
	T_1	27.73	27.40	–0.23	13.31	12.89	–0.30
	T_2	24.56	27.21	1.87	11.79	13.12	0.94
	T_3	29.61	23.32	–4.45	14.21	12.15	–1.46

S.D., standard deviation.

Table 5. Data measured and simulated by AquaCrop for crop water applied, water use efficiency (WUE), and variations of water applied and yield

Crop	Irrigation treatments	Water applied, mm	Sim. biomass WUE, kg/m^3	Sim. yield WUE, kg/m^3	Var. in water applied, %	Var. in Meas. yield, %	Var. in Sim. yield, %
Maize	Control (full irrigation)	471.4	5.81	2.74	–	–	–
	T_1	589.2	4.65	2.19	–24.99	–6.14	0.16
	T_2	352.9	7.71	3.72	25.14	5.98	–1.63
	T_3	235.4	9.91	5.16	50.06	–13.32	5.89

Cal., Meas., Sim. and Var. are indicated the calibration, measured, simulated data and variation.

increased as the water applied in irrigation treatments decreases.

The water saving potential (WSP) in maize with consider to control treatment shown that, T_2 treatment is able to save 25.14% of water applied in case accepted 5.98% reduction in measured grain yield. Similarly, afford 5.89% reduction from simulated yield of T_3 leads to save 50.06% of water. Consequently, the final biomass and grain yield decreased when the WUEs and water saved increased.

CONCLUSIONS

Irrigation must be contributing in improve the water use efficiency, crop productivity per any drop of water applied and water saving potential. Four different irrigation treatments of maize were taken as percentage of water depth from crop evapotranspiration (ET_c) and tested with AquaCrop model. The graphical and statistical results of tested crop and water parameters proved the satisfactory simulations of model used with no symptoms of water stresses in canopy expansion or stomatal closure. The maximum simulated of final biomass and dry grain yield achieved by T_1 and T_2 irrigation treatments as 27.40 and 13.12 t/ha. The results showed that the WUEs of biomass and grain yield increased as the water applied in irrigation treatments decreases. The high reductions in measured and simulated yield observed on T_2 and T_3 as compared to full irrigation treatment. In general, the final biomass and grain yield decreased when the WUEs and water saved increased. The findings of crop and water parameters that were obtained in this research are valid to be use in this region and other similar conditions, and its able to provide useful and powerful information for incoming version of AquaCrop model.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

REFERENCES

1. Hsiao, T.C., Heng, L., Steduto, P., Rojas-Lara, B., Raes, D., and Fereres, E., AquaCrop—the FAO crop model to simulate yield response to water, III. Parameterization and testing for maize, *Agron. J.,* 2009, vol. 101, no. 3, pp. 448–459.

2. Raes, D., Steduto, P., Hsiao, T., and Fereres, E., AquaCrop—The FAO Crop Model to Simulate Yield Response to Water: Reference Manual Annexes, 2009. https://www.fao.org/nr/water/aquacrop.html.
3. Steduto, P., Hsiao, T.C., Raes, D., and Fereres, E., Aquacrop—The FAO crop model to simulate yield response to water: I. Concepts and underlying principles, *Agron. J.,* 2009, vol. 101, no. 3, pp. 426–437.
4. Raes, D., Steduto, P., Hsiao, T.C., and Fereres, E., AquaCrop—The FAO crop model to simulate yield response to water: II. Main algorithms and software description, *Agron. J.,* 2009, vol. 101, no. 3, pp. 438–447.
5. Doorenbos, J. and Kassam, A., Yield response to water, *Irrig. Drain. Pap.,* 1979, vol. 33, p. 257.
6. Mkhabela, M.S. and Bullock, P.R., Performance of the FAO AquaCrop model for wheat grain yield and soil moisture simulation in Western Canada, *Agric. Water Manage.,* 2012, vol. 110, pp. 16–24.
7. Vanuytrecht, E., Raes, D., Steduto, P., Hsiao, T.C., Fereres, E., Heng, L.K., Vila, M.G., and Moreno, P.M., AquaCrop: FAO's crop water productivity and yield response model, *Environ. Modell. Software,* 2014, vol. 62, pp. 351–360.
8. Heng, L.K., Evett, S.R., Howell, T.A., and Hsiao, T.C., Calibration and testing of FAO aquacrop model for rainfed and irrigated maize, *Agron. J.,* 2009, vol. 101, pp. 488–498.
9. Salemi, H., Soom, M.A.M., Mousavi, S.F., Ganji, A., Lee, T.S., Yusoff, M.K., and Verdinejad, V.R., Irrigated silage maize yield and water productivity response to deficit irrigation in an arid region, *Pol. J. Environ. Stud.,* 2011, vol. 20, no. 5, pp. 1295–1303.
10. Flores-Gallardo, H., Ojeda-Bustamante, W., Flores-Magdaleno, H., Sifuentes-Ibarra, E., and Mejia-Saenz, E., Simulation of corn (*Zea mays* L.) yield in Northern Sinaloa using the Aquacrop model, *Agro Cienc. Mex.,* 2013, vol. 47, pp. 347–359.
11. Mhizha, T., Geerts, S., Vanuytrecht, E., Makarau, A., and Raes, D., Use of the FAO AquaCrop model in developing sowing guidelines for rainfed maize in Zimbabwe, *Water SA,* 2014, vol. 40, no. 2, pp. 233–244.
12. Greaves, G.E. and Wang, Y.M., Assessment of FAO AquaCrop model for simulating maize growth and productivity under deficit irrigation in a tropical environment, *Water-SUI,* 2016, vol. 8, no. 12, p. 557.
13. Farahani, H.J., Izzi, G., and Oweis, T.Y., Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton, *Agron. J.,* 2009, vol. 101, no. 3, pp. 469–476.
14. Stricevic, R., Cosic, M., Djurovic, N., Pejic, B., and Maksimovic, L., Assessment of the FAO AquaCrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower, *Agric. Water Manage.,* 2011, vol. 98, no. 10, pp. 1615–1621.
15. Allen, R.G., Pereira, L.S., Raes, D., and Smith, M., Crop evapotranspiration—guidelines for computing crop water requirements, *Irrig. Drain. Pap.,* 1998, vol. 56.
16. Araya, A., Habtu, S., Hadgu, K.M., Kebede, A., and Dejene, T., Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (*Hordeum vulgare*), *Agric. Water Manage.,* 2010, vol. 97, no. 11, pp. 1838–1846.
17. Loague, K. and Green, R.E., Statistical and graphical methods for evaluating solute transport models: Overview and application, *J. Contam. Hydrol.,* 1991, vol. 7, nos. 1–2, pp. 51–73.
18. Bouman, B. and Van Laar, H., Description and evaluation of the rice growth model ORYZA2000 under nitrogen-limited conditions, *Agric. Syst.*, 2006, vol. 87, no. 3, pp. 249–273.
19. Rinaldi, M., Garofalo, P., Rubino, P., and Steduto, P., Processing tomatoes under different irrigation regimes in Southern Italy: Agronomic and economic assessments in a simulation case study, *J. Agrometeorol.,* 2011, vol. 3, pp. 39–56.
20. Zeleke, K.T., Luckett, D., and Cowley, R., Calibration and testing of the FAO AquaCrop model for canola, *Agron. J.,* 2011, vol. 103, no. 6, pp. 1610–1618.
21. Ahmadi, S.H., Mosallaeepour, E., Kamgar-Haghighi, A.A., and Sepaskhah, A.R., Modeling maize yield and soil water content with AquaCrop under full and deficit irrigation managements, *Water Resour. Manage.,* 2015, vol. 29, no. 8, pp. 2837–2853.
22. Biazin, B. and Stroosnijder, L., To tie or not to tie ridges for water conservation in Rift Valley drylands of Ethiopia, *Soil Tillage Res.,* 2012, vol. 124, pp. 83–94.
23. Mebane, V.J., Day, R.L., Hamlett, J.M., Watson, J.E., and Roth, G.W., Validating the FAO AquaCrop model for rainfed Maize in Pennsylvania, *Agron. J.,* 2013, vol. 105, no. 2, pp. 419–427.
24. Iqbal, M.A., Shen, Y., Stricevic, R., Pei, H., Sun, H., Amiri, E., Penas, A., and del Rio, S., Evaluation of the FAO AquaCrop model for winter wheat on the North China Plain under deficit irrigation from field experiment to regional yield simulation, *Agric. Water Manage.,* 2014, vol. 135, pp. 61–72.
25. Katerji, N., Campi, P., and Mastrorilli, M., Productivity, evapotranspiration, and water use efficiency of corn and tomato crops simulated by AquaCrop under contrasting water stress conditions in the Mediterranean region, *Agric. Water Manage.,* 2013, vol. 130, pp. 14–26.