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Original Research Article

Assessment of AquaCrop Model in the Simulation of Potato Yield and Water Use Efficiency under Different Water Regimes

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ABSTRACT

Conducting field experiments to determine the optimum amount of consumption water and achieve the optimal yield of plants is costly and time-consuming. Therefore, the aquacrop computer model was used to determine crops yield. The present study evaluates the performance of AquaCrop, a crop simulation model developed by FAO, in simulating potato (S*olanum tuberosum* L.) yield and water use efficiency under different water regimes in Jiroft region, Iran. Three irrigation levels, 100%, 75% and 50 % of water requirement, were arranged as a stripe-plot arrangement based on randomized block. The AquaCrop model revealed that potato yield was increased with increasing water consumption. The simulated potato yield was lower than measured potato yield in 100% and 70% of potato requirement scenarios but not in 50% conditions. The highest water use efficiency in the field conditions occurred under 75% of water requirement but the highest water use efficiency predicted by AquaCrop was found to be under 100% water requirement. Overall, results showed that the AquaCrop model could predict relatively good tuber yield, water use efficiency and water requirement values of potato under Jiroft conditions.

Key words: Deficit irrigation, Potato yield, Water use efficiency, Aquacrop model, Water requirement

INTRODUCTION

Development the optimum strategies in using and management of available water resources in the agricultural sector is a critical issue (Smith, 2000). Crop growth models have been developing along with the progress of computer technology since the 1960s, which can provide the simulation of plant physiological processes and crop growth and development (Boote *et al.*, 2003).

Considering that water shortage is a main factor for high yield over the world, FAO recently introduced a crop growth model – AquaCrop. This model is relatively easy to use and the 33 types of required input data related to climate, soil, agricultural techniques and crop characteristics can be readily derived from experimental research (Stricevic *et al.*, 2011). The AquaCrop model focuses on water input as the main factor limiting crop growth, especially in arid and semiarid regions (Bradford and Hsiao, 1982).

Several studies have shown that deficit irrigation considers as a one of the promising irrigation strategies (Ali and Talukder, 2008; Behera and Panda, 2009; Blum, 2009; Geerts and Raes, 2009), by which less water than required is used during the growing period. Stricevic *et al.* (2011) studied the FAO AquaCrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower, and concluded that the model can be used to well reliably estimate yield and IWUE in areas with water limited resources.

In a study set out to simulate maize growth and grain yield, Zand-Parsa *et al.* (2006) developed a Maize Simulation Model (MSM). This model was validated for the Fars area in Iran, using two years data of research of maize growth for regimes different of fertilization and irrigation. Their research showed that the model to be very reliable for the estimation of maize yield.

Alizadeh *et al.* (2011) used AquaCrop model to assess wheat performance under different regimes of irrigation (100, 80, 60, 40, 20 % of water requirement and single-irrigation). Their research revealed that the model simulated satisfactorily in simulation of grain yield, water use efficiency in all of the irrigation treatments with irrigation intervals of 7 days, but it was less satisfactory in simulating treatments with irrigation intervals of 14 days and it was a valuable model for estimating crop productivity under different irrigation water levels

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conditions. In the present study, the performance of AquaCrop model is estimated in simulating potato (*solanum tuberosum* L.) yield and water use efficiency under different water regimes in Jiroft region.

MATERIALS AND METHODS

Site and Climate of the Experimental Field

This research was carried out in 2010 at Jiroft-Bandarabas road (VakilAbad Farm of Jiroft Agro-industrial), Jiroft, Iran (Kerman province, southern east Iran; 57° 03′ N, 27° 52′ E, 690 masl). The soil of the experimental field was sandy loam. The climate of the Jiroft is hot and humid, nearly tropical, with average annual rainfall of about 140mm, distributed mostly during winter and spring. The maximum and minimum temperature and relative humidity were 48^0 C, 1^0C and 55-65%, respectively.

Potato cultivar of kuzima, a late mature cultivar, was cultivated in 3 October 2010 under different water regimes. Potato was sown at a density of 4.5 plants m^{-2}. A stripe-plot arrangement based on randomized block was adopted as the experimental design, with three replicates for each treatment. The Plots were 6 m long by 3 m wide constituting 4 rows of 75 cm apart. Treatments were 100%, 75% and 50 % of water requirement. Crop water requirement was computed based on pan evaporation and FAO method (7). In the present study the output evaporation data was collected from pan evaporation located in the experimental farm to estimate the amount of irrigation water.

$$ET_C=K_P*K_C*E_P \qquad (1)$$

In which, ET_C is evapotranspiration of crop (mm per day), K_P is evaporation pan factor, K_C is crop factor and E_P refers to evaporation from pan surface (mm per day). Pan coefficient depends on its settlement and its surroundings ranging from 0.5 to 0.85 and it is considered to be 0.66 for practical work (Alizadeh, 2011). KC values were determined according to the book documented the water requirements of field and horticultural crops (Farshi *et al.*, 1999). The drip irrigation system was used to irrigate in the strips type with a discharge of 4 L hr^{-1} for 3 days. The amount of water used to 100 % water requirement during growing season of potato with irrigation interval of 3 days is presented in Table 4. Depth of irrigation water was estimated for 75% and 50% water treatments and the relevant data were entered in Aquacrop model. Water use efficiency (WUE), indicating the amount of yield produced per unit of water used and determine the optimal use of water, was calculated using the equation

$$WUE=Y/Etc \qquad (2)$$

Where Y is yield (kg ha^{-1}), Etc is water used during plant growth period (m^3 ha^{-1}) (2).

Soil data required included; saturated hydraulic conductivity (k_{sat}), soil volumetric water content at saturation (Θ_{vsat}), soil volumetric water content at field capacity (Θ_{VFC}), volumetric soil moisture content at wilting point (Θ_{VPWP}). Soil saturated hydraulic conductivity was 700 mm day. Soil water balance, the input and output flows from the boundaries of root zone and water stored in the soil was simulated in daily intervals.

Sensitive analysis of Aquacrop model

The sensitivity of model outputs to the input data was determined using Liu et al (2007) equation. To do this the measured input data were found to be as the base outcome. With each run, one of the input data was changed as much as 25 ± and the others were kept constant. Then, parameters sensitivity coefficients were calculated according to Liu et al (2007) equation

$$S_c = \frac{\frac{\Delta W}{\overline{W}}}{\frac{\Delta P}{\overline{P}}} \qquad (3)$$

In which, S_c is sensitive factor, ΔW is the difference of output parameter amount before and after changing of input parameter, $\overline{W}$ is the average of output parameter before and after changing of input parameter, ΔP is the difference of input amounts of base and changed input, and $\overline{P}$ is the average of input amounts of a parameter into a model.

The range of suggested sensitive changes presented by Liu et al (2007) is given in Table 1 (Singh *et al.*, 2005; Stricevic *et al.*, 2011).

Table 1. The sensitivity classification of input parameters with sensitivity factors.

The ratio of changes	S_c=0	0<S_c<0.3	0.3<S_c<1.5	S_c>1.5
The intensity of sensitivity	Without sensitivity	Low sensitivity	Moderate Sensitivity	High sensitivity

Data analysis

The following statistical methods were used to analyze the efficiency of model. The first method is the root mean square error (RMSE) which indicates the total values or average deviation of simulated values from measured values. In fact, it is a measure of comparison with baseline values. The root mean square error (RMSE) method was calculated based on equation 4;

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2} \times 100 / \overline{M} \qquad (4)$$

where Si and mi are the simulated and measured values, respectively, and n is number of observations. The unit of RMSE is the same for both variables, and M is the mean of the n measured values. The model's simulation improves when RMSE tends toward zero.

Coefficient of efficiency (E) was calculated using 5. E values range from 0 to 1. The simulation of model for the studied parameter is better improves when the value approaches 1.

$$E = 1 - \frac{\sum_{i=1}^{n}(M_i - S_i)^2}{\sum_{i=1}^{n}(M_i - \overline{M})^2} \qquad (5)$$

The index of agreement (d) was determined according to the Willmott (1982) equation:

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i - M_i)^2}{\sum_{i=1}^{n}(\left|S_i - \overline{M}\right| + \left|M_i - \overline{M}\right|)^2} \qquad (6)$$

In which $\dot{M}$ is the mean value of measured data. The index of agreement is a descriptor and its rates range from 0 to 1. The simulation of model for the studied parameter improves when the value closer to 1.

Maximum Error (ME) was calculated using equation7; the more the values of ME, the worst the simulation of model.

$$ME = Max\left|S_i - M_i\right| \times 100 / \bar{M} \qquad (7)$$

Coefficient of Residual Moss (CRM) which indicates the model tendency for overestimation or underestimation of values compared to the measured values was calculated using equation 8;

$$CRM = \frac{\sum_{i=1}^{n} M_i - \sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} M_i} \qquad (8)$$

RESULTS AND DISCUSSION

Aquacrop model was run by cultivation calendar, after entering the required information. The model has ability to simulate root development, the growth of crop chlorophyll and transpiration in the period of growth season. It also has ability to estimate the crop yield, amount of required water for plant, and water use efficiency based on plant, soil and water data.

Sensitivity analysis

The values of sensitivity coefficients estimated for some of the input parameters of Aqua Crop model are presented in Table 2. The model was found to have a little sensitivity to the time to seed germination, duration of tuberization, number of days from planning to the maximum growth of root, the plant density, and the duration from planning to the beginning of tuberization. So the errors arise from the measurement of these parameters in the farm was negligible. The results also showed that the model sensitivity was found to be high to changes in canopy growth, water productivity normalized (WP), harvest index, time to aging and initial moisture under deficit irrigation treatments (75% and 50 % of water requirement). Thus, these data must be measured by more accuracy. Otherwise, a significant error was created in yield prediction of model. The model sensitivity was different to the depth of irrigation water in different regimes of irrigation. The model sensitivity was increased to changes in water depth with decreasing water depth. This is due to reduction in water use efficiency with increasing water depth.

Calibration of the model

The AquaCrop model was calibrated for the sensitive parameters. According to the results, the highest model sensitivity was found for evaporation factor (K_{cb}), water productivity normalized (WP), and harvest index. Transpiration coefficient was considered to be 1.1 for potato, and it was changed to 1.12 by model for Jiroft region. Normal water use efficiency was found to be 13 - 18 and 28-32 for C_3 and c4plants, respectively. The normal water use efficiency was determined to be 18-20 by model for potato. Considering the especial condition of this region, water efficiency was normalized at 23 in order to better simulation between the predicted and observed yield. The normalization of water climate provides an opportunity for model to have good efficiency in the different climate scenarios. The values of harvest index were found to be 70-85% which it was considered 87% for jiroft (Heng *et al.*, 2009a; Heng *et al.*, 2009b; Hsiao and Kxu, 2000; Hsiao, 1993).

Table 2. The sensitivity coefficients of input parameters of model.

	Input parameters	The amount of Sc in +%25	The amount of Sc in - %25	The degree of sensitivity
Agronomical Parameters	K_{cb}	0.84	1.03	moderate
	Density of cultivation	0.08	0.10	low
	Cover Growth Crest(CGC)	0.27	0.51	moderate
	water productivity Normalized(WP)	1	1	moderate
	Harvest Index(HI_0)	1	0.99	moderate
	Time to seed germination	0.17	0.00	No-low
	Time to aging	0.3	1.46	Moderate-high
	Duration of tuberization	0.00	0.05	No-low
	number of days from planning to the maximum growth of root	0.00	0.00	No
	the duration from planning to the beginning of tuberization	0.01	0.00	No-low
Initial soil humidity	a3	0.00	0.00	no
	a2	0.00	0.04	No-low
	a1	0.00	0.17	No-low
Initial soil conditions	soil hydraulic conduction	0.00	0.00	no
Irrigation	a3	0.00	0.28	No-low
	a2	0.28	0.63	Low-moderate
	a1	0.63	1.11	moderate

Comparison of the estimated and measured values of water used in the farm

The Model simulated root and chlorophyll development of crop during the growing season after entering the output data. The Model was able to estimate the required values of water based on the water-soil and crop data. In the present study, Etc was found to be equal to the water requirements of crop, because no significant rainfall occurred regardless of water losses during the growing season. The estimated values of water required for potato by the model AquaCrop during the growing season in field experiments are presented in Table 3. The simulated values by the model were close to the measured values.

Table 3. The simulated the measured values of water used by the model for potato in Jiroft.

Treatments	The measured water amount (m^3 ha^{-1})	The simulated water amount (m^3 ha^{-1})
100% of water requirement	3542.13	2795
75% water requirement	2655.09	2471
50% water requirement	1770.23	1984

Table 4 shows the amount of water used in the potato farm under 100% of water requirement during the growing season. The values 75 and 50% of the crop water requirements were calculated according to 100% of water requirements.

Table 4. The amount of water used in the potato farm under 100% of water requirement with irrigation interval of 3 days.

The day after cultivation	Depth of water irrigation (mm)	The day after cultivation	Depth of water irrigation (mm)	The day after cultivation	Depth of water irrigation (mm)	The day after cultivation	Depth of water irrigation (mm)	The day after cultivation	Depth of water irrigation (mm)	The day after cultivation	Depth of water irrigation (mm)
1	15	22	8	43	6	64	6	85	7	106	12
4	14	25	8	46	7	67	4	88	8	109	12
7	15	28	10	49	7	70	5	91	8	112	12
10	15	31	9	52	6	73	7	94	7	115	13
13	12	34	8	55	10	76	5	97	8	118	14
16	11	37	7	58	8	79	7	100	8	121	11
19	8	40	6	61	9	82	8	103	12	124	12

Grain yield

The simulated potato yield showed a relatively good agreement with measured potato yield. The maximum (25.312 t ha-1) and minimum (18.142 t ha-1) simulated potato yield was found to be under 100% and 50% of water requirement scenarios (Table 5). The AquaCrop model revealed that potato yield was increased with increasing water consumption. As found in Table 5, the simulated potato yield was lower than measured potato yield in 100% and 70% of potato requirement scenarios but not in 50% conditions. The simulated and measured potato yields were decreased with decreasing water consumption. The calculated model evaluation criteria between simulated and measured yield were normalized RMSE = 9 %, E= 0.65 D-index = 0.87, ME-17.8, CRM=0.08 and r2 = 0.91 (Table 6). Overall, the AquaCrop model could predict relatively good tuber yield of potato under Jiroft conditions.

Table 5. Simulated and measured potato yields under Jiroft conditions.

Treatments	Measured (t ha^{-1})	Simulated (t ha^{-1})
100% of water requirement	29.65	25.312
75% water requirement	26.52	23.357
50% water requirement	16.95	18.142

Table 6. AquaCrop model parameters in the estimation of potato yield in Jiroft conditions.

Treatments	RMSE%	E	d	ME%	CRM	r^2
yield	9.213	0.654	0.871	17.8	0.086	0.91

Water use efficiency

Water use efficiency is one of the most important indicators in the designating of optimized irrigation level under deficit irrigation. The highest water use efficiency in the field conditions occurred under 75% of water requirement but the highest water use efficiency predicted by AquaCrop was found to be under 100% of water requirement (Table 7). This is may be due to that in the AquaCrop model evaporation part is separate from transpiration one and the model does not consider the evaporation part in the water use efficiency calculation. Hence, the model was calculated the real water use efficiency of crop. The AquaCrop model overpredicted water use efficiency values as compared with measured data. Apparently, the model was considered only the potato transpiration, whereas under filed conditions both evaporation and transpiration were involved in the estimation of water consumption.

Table 7. The simulated the measured water use efficiency by the model for potato in Jiroft.

Treatments	The measured water efficiency (kg m^{-3})	The simulated water efficiency (kg m^{-3})
100% of water requirement	8.37	10.18
75% water requirement	9.98	10.08
50% water requirement	9.57	9.71

The AquaCrop model could predict the values of water use efficiency with acceptable accuracy and modest deviation. The calculated model evaluation criteria between simulated and measured water use efficiency is given in Table 8. A negative value of CRM indicates that the AquaCrop model overpredicted water use efficiency values as compared with measured data. Aacording to Stricevic *et al.* (2011), the AquaCrop model showed a good performance in the simulated and observed yields and water use efficiency of maize, sugerbeet and sunflower.

Table 8. AquaCrop model parameters in the estimation of potato water use efficiency in Jiroft conditions.

Treatments	RMSE%	E	d	ME%	CRM	r^2
Water Use Efficiency	7.98	-1.36	0.6	19.46	-0.0734	0.88

CONCLUSIONS

The AquaCrop model was developed by FAO to provide a tool to help designers, farmers and managers in order to select the optimal management of irrigation under agriculture various systems across the world. Thus, evaluation and validation of the AquaCrop model is essential for strategic crops. The present study indicate that the potato yield depends on factors such as crest cover growth, crop transpiration factor, water normal use, beginning of old time, index of harvesting. Moreover, the amount of water irrigation was more sensitive than other factors. The assessment of aquacrop model showed that model has good ability in predicting and estimating of evaporation and transpiration of crops (ET_c), yield, and water use efficiency of potato.

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