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Research Article

Evaluation of AquaCrop model in soybean cultivation under different planting dates and deficit irrigation treatments

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ABSTRACT - Water stress has been identified as the major effective factor on soybean production growth in semi-arid regions. Planting date and irrigation management are the most important agronomic practices, which affect soybean growth and economic yield production. Today, to assess the impacts of destructive environmental stresses, calibrated models can be used to simulate and evaluate the growth of the crops under different scenarios. In this research, the AquaCrop model was evaluated for simulation of soybean yields and water productivity on varying irrigation levels and planting dates in northeast of Iran. For this purpose, root mean square error (RMSE), model efficiency (E), coefficient of determination (R^2), and prediction error (P_e) were applied to test the model performance. The calibrated AquaCrop model predicted soybean grain yield and biomass for all treatments with the prediction error statistics 0.27<RMSE<0.41 t ha^{-1}, 5.1<P_e<5.6%, 0.91<R^2<0.92 and 0.92<E<0.94. In addition, the water productivity (WP) was simulated with RMSE of 0.86 kg mm^{-1} ha^{-1}, R^2 of 0.88, and P_e of 7.6%. Subsequently, validation results were 0.93<E<0.96; 0.92<R^2<0.95 and RMSEs were 0.22 and 0.40 t ha^{-1} for grain and biomass yield, respectively. The soybean yields and growth response to different irrigation water management and planting dates was adequately predicted by the AquaCrop model. Overall, the AquaCrop model is a suitable support tool for decision makers to simulate WP, grain yield (GY), and biomass (Bi) in soybean cultivation under various field management in semi-arid environment.

INTRODUCTION

Soybean is one of the most prevalently grown and used oilseeds in the world. Its uses range from human foods to animal foods, to industrial products, to ingredients, and to precursor materials. In recent decades, the expansion of oil crop production has been very rapid, accounting for a large share of the expansion of the world's agricultural lands. According to the FAO annual report, Iran imports approximately 85% of its vegetable oil, which includes 800 000 tons of soybean oil worth 960 million USD (FAO 2013). Therefore, there is a pressing need to increase the yield and production of oilseeds including soybean. The average area under soybean cultivation in Golestan province is 55 to 60 thousand hectares per year and approximately 120 to 140 thousand tons of soybean oil is produced, which is equivalent to 75% of the cultivation and production area of this product in the country (Nehbandani et al., 2017).

Apart from this, the main challenge and constraint of the agricultural sector in Iran is the lack of water resources, especially in summer cultivations. Therefore, it is important to determine the best planting date for maximum use of rainwater in the arid and semiarid areas. The date of sowing specifies the relative growth of different crop growth stages and crop exposure to water and heat tensions. For example, if soybean is cultivated late, the grain formation stage can be exposed to heat and water tensions, and there will not economic yields. In addition, the planting date depends on the type of soybean variety. Long-period varieties need to be planted early to avoid cold weather in the flowering period while short period varieties should be planted late. In this regard, Yuba et al., (2016) indicated that farmers persuaded to sow soybean early (late April or early May) at the same time to achieve maximum yield in the Midwestern United States and Canada. Licht et al., (2013) indicated that a denser soybean canopy was occurred by early-sown due to receiving more sunlight and increasing photosynthesis. Kawasaki et al., (2018) studied the effects of late planting on soybean yields and yield components in southwestern Japan. They revealed that, under full-irrigated conditions, late planting could achieve stable soybean production if combined with dense planting in the study regions.

Deficit irrigation (DI) is a flexible management and its successful implementation is dependent on a sound irrigation schedule, in terms of both timing and application amount in the arid and semi-arid areas. Hence, by applying less than the exact plant water requirements, specifically during drought-tolerant growth stages (minimum crop coefficient (KC) value), crop yields could be stabilized and maximum water productivity (WP) attained. Judicious planning is therefore required as supplying crops with less than their water requirements. It can significantly affect crop growth and development, and inevitably affecting yield, especially if water stress occurs during the susceptible growth stage. Therefore, there will be existed numerous possibilities when investigating and imposing a DI management plan. Some of strategies that can be used included growth-stage-specific DI, intermittent DI (irrigation is applied on specific days or different amounts), and root zone soil moisture depletion. In each case, different water amounts can be applied. In this regard, Comlekcioglu and Simsek (2011) revealed that differences of yield between soybean cultivars in response to irrigation levels made it necessary to select less sensitive cultivars to water stress, especially in semi-arid and arid areas.

Also, a field research was done to determine the effects of different levels of water deficit (I_{100}: full irrigation, I_{65}: 35% deficit, I40: 60% deficit and I0: no irrigation) on yield and chemical composition of soybean in Serbia. It was observed that full-irrigation treatment (I_{100}) provided no potential benefit in terms of soybean yield. For higher economic yield, water-saving treatment I_{65} could be suitable in soybean management in Srem region of Serbia as in other regions with similar soil and climate conditions (Kresović et al., 2017).

The effects of deficit irrigation and planting date on crop growth (i.e. crop canopy, WP, grain and biomass yield, etc.) could be studied using field data and crop simulation models.

Different crop models viz. CERES-Maize (Jones and Kiniry, 1986), WOFOST model, CropSyst (Stockle et al., 2003), and the APSIM (Keating et al., 2003), have been used for simulation of yield of soybean crop. Most of these models, however, are quite sophisticated; require advanced modeling skills for their calibration and subsequent operation, and require large number of model input parameters. In this context, the FAO AquaCrop model (Raes et al., 2009; Steduto et al., 2009) is a water-driven FAO model, which keep an optimal balance between precision, validity, and clarity and requires a low number of data in comparing to other crop models. In this regard, Raja et al., (2018) reported that AquaCrop model could be used to decide the planting date of maize (principal crop of Jammu and Kashmir) as per the availability of water resources under a temperate environment. Therefore, an important attribute of the modelling approach is that it permits extension of the sector findings to conditions not tested within the field.

Thus, itis helpful in providing sensible suggestions that may facilitate in up irrigation management choices.

To our knowledge, the AquaCrop has not been tested and evaluated to simulate the soybean growth under different irrigation and planting date in the Gorgan region.

Therefore, the objectives of this study were designed:

- to calibrate and validate the AquaCrop model for soybean under different planting dates and irrigation water levels.
- To simulate soybean aboveground biomass, grain yield and water productivity (WP).

MATERIALS AND METHODS

Field Experimental Site and Soil Characteristics

In this research, the experiment was performed at Gorgan city in the Golestan province of northeastern of Iran during the spring and summer seasons of 2014 and 2015. The experimental field was located at 36° 51' N Latitude and 54° 29' E Longitude, at an elevation of 86 m above mean sea level (Fig. 1). The soil of the experimental site was silty clay loam, which its physical characteristics is presented in Table 1.

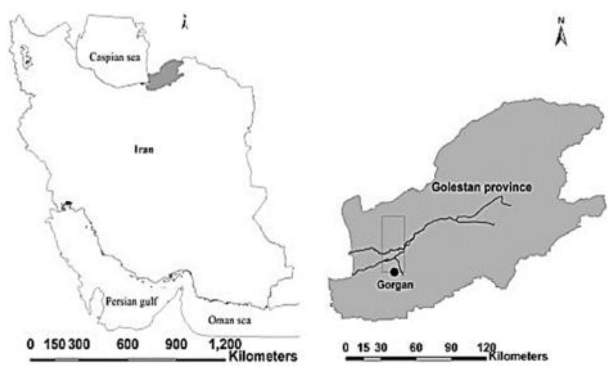

Fig. 1 Location of the experimental field

Table 1. Soil physical properties of the experimental field

		Water content (g g^{-1})			
Soil Depth (Cm)	Soil Texture	FC (%)	PWP (%)	B_d (g cm^{-3})	Ks (m day^{-1})
0-20	S.C.L	35.2	17.3	1.26	
20-40	S.C.L	34.6	17.1	1.27	1.9
40-60	C.L	34.2	17.2	1.29	
60-80	C.L	34.1	17.1	1.3	1.86
80-100	C.L	34.5	17.3	1.28	

FC, field capacity; PWP, permanent wilting point; B_d, bulk density; Ks, Saturated hydraulic conductivity

Weather Data

The mean historical annual rainfall and potential evapotranspiration (PET) of the study area are 568.4 mm and 1332 mm, respectively. In general, crops water requirement increases at the end of spring and in the summer season in the study area. The Weather data during the experiment period for use in the model was acquired from the Gorgan synoptic climatology station. The total amount of rainfall during the research period was 206 and 165 mm for 2014 and 2015, respectively.

Experimental Treatments and Irrigation Managements

The factorial experiment was conducted as a randomized complete block design with three-irrigation regimes comprised (I_1): full irrigation (FI), (I_2): irrigation at 80% of FI and (I_3): irrigation at 60% of FI as main treatments and three planting dates *viz.*15 April: (PD_1), 30 April: (PD_2) and 15 May: (PD_3) with three replications.

For the full irrigation treatment (I_1), irrigation was applied after 50% of total available water depleted. Then, irrigation was initiated to bring the soil water contents before irrigation (Θ_i) to field capacity (FC). Subsequently, for other irrigation treatments (I_2 and I_3), irrigation applied at the same time but irrigation depth was decreased to 60% and 80% of the full irrigation (FI). In this research, irrigation depth was calculated as Eq. (1):

$$I_d = (FC - \Theta_i) \times B_d \times D_r \quad (1)$$

where I_d is irrigation depth in meter; B_d is the soil bulk density (g cm^{-3}), and D_r is crop root depth (m).

Depths of applied irrigation water for all treatments are presented in Table 2.

Also, Crop water productivity (WP) was calculated using Eq. (2)

$$WP = \frac{Y}{ETC} \quad (2)$$

where Y is grain yield (kg ha^{-1}), ETC is crop evapotranspiration (mm), Soil moisture were measured regularly at varying soil depths of 20 cm to 90 cm and also before and after irrigation treatments to measure the parameters required for estimation of actual crop evapotranspiration (ETC, mm day^{-1}) using Eq. 3 (Jensen 1973).

$$ETC = \frac{(I + P - D) + \sum_{i=1}^{n} (\theta_1 - \theta_2) \Delta S}{\Delta t} \quad (3)$$

where I, P and D, are irrigation, precipitation and deep percolation from the bottom of root zone (mm), respectively. n is the number of layers, ΔS is the thickness of each soil layer (mm), θ_1 and θ_2 are the volumetric soil water content (cm^3 cm^{-3}) 24 hr after and before next irrigation respectively, and Δt is the time interval between two consecutive measurement (day).

Since, the furrows in the experimental plots were closed by bunds, also, the water table depth was below 4m from the ground surface, therefore, the surface runoff and the vertical upward seepage or the capillary flow to the root zone was assumed negligible.

Besides, the drainage below root zone, after a number of soil-water content measurements, was considered to be negligible. Therefore, the Eq. 3 was summarized to Eq. 4 as follows:

$$ET = I + P \pm \Delta S \quad (4)$$

The field water budgeting as mentioned above is commonly used to measure total actual water use or crop evapotranspiration (ETC) when lysimeter facilities are not available (Farahani 2009).

Field Preparation and Agronomy Practices

Before planting, the experimental field was disked (depth of 20 cm), then levelled and 27 plots, each with size of 8 m×3 m with ridges and furrows were prepared. The experimental field was divided into twenty-seven plots with 8 m length and 3 m width. Then, all plots were enclosed by appropriated bunds to prevent the surface runoff and infiltrate the water into the soil. Seven planting ridges (rows) were generated in each plot which were 40 cm apart. Seeds were planted on the top of the ridges.at a distance of 20 cm on each ridge. The soybean cultivar selected for the study was DPX, the maximum yielding and most cultivated variety in the Golestan province. Soybean seeds were planted at the depth of 3-5 cm with a density of 280 crops per plot on three planting dates *viz.*15 April: (PD_1), 30 April: (PD_2) and 15 May: (PD_3) in years of 2014 and 2015, respectively. Single- phosphate fertilizer was applied at planting at a rate of 60 kg P ha^{-1}. In 2014, harvested dates for PD_1, PD_2 and PD_3 treatments were 16 September, 23 and 16 September respectively, and for the second year (2015), the harvested dates were 15^{th} September 21 and 13 September, respectively (Table 2). Leaf area index (LAI) which is the rate of total leaf area by the mean ground area per plant was measured at two times (flowering and grain formation stages). In this study, the canopy cover (CC) was obtained based on LAI (Eq.5) as discussed by Hsiao et al., (2009).

$$CC = 1.005\,[1 - \exp(-0.6\,LAI)]^{1.2} \quad (5)$$

The crop was harvested by cutting the plants from the 5 central rows and 4 m length of each row in the plots. The harvested plants were dried in a drying oven for 48 hours at 70 °C to measure the weight of the aboveground biomass. Grains were separated by threshing out the cobs to measure the grain yield.

AquaCrop Model Description

AquaCrop is a crop water driven model that considering the soil-plant-atmosphere continuum to simulate the grain, biomass, harvest index and crop water productivity. Basically, AquaCrop is an expression of Eq. 6 (Doorenbos and Kassam, 1979) but with refinements.

$$\left(1 - \frac{Y}{Y_x}\right) = K_y \left(1 - \frac{ET}{ET_x}\right) \quad (6)$$

where Yx and Y are the maximum and actual yield, ETx and ET the maximum and actual evapotranspiration, respectively. Ky is the proportionality factor between relative yield decline and relative reduction in evapotranspiration. The crop evapotranspiration (ET) is separated into soil evaporation (E) and crop transpiration (Tr) to avoid the confounding effect of the non-productive consumptive use of water (E). This is particularly important when canopy cover of the ground is incomplete and soil E may be the major component of

ET. The harvestable yield (Y) is expressed as a function of biomass (B) and harvest index (HI) to distinguish between environmental stresses effects on B from those on harvest index. The separation of these two kinds of effects, which differ fundamentally, makes it possible to introduce functional links based on underlying physiological processes. The changes described led to the following equations at the core of the AquaCrop growth engine:

$$B = WP.\ ET_r \qquad (7)$$

$$Y=B.\ HI \qquad (8)$$

where WP is the water productivity parameter in units of $kg.m^{-2}.mm^{-1}$. Stepping from Eq. (7) to Eq. (8) makes the model more robust and more applicable, due to the conservative behavior of WP when normalized for climatic conditions (Steduto et al., 2007), although both equations are expressions of a water-driven growth-engine in terms of crop model design (Steduto 2003).

Table 2. Timeline of soybean growth stages in days after planting (DAP) and total water applied planting dates and water treatments.

Agronomic characteristics	1ST experimental year (2014)			2ND experimental year (2015)		
	PD_1	PD_2	PD_3	PD_1	PD_2	PD_3
Planting date	15 April	30 April	14 May	16 April	31April	15 May
Planting density (plant m^{-2})	15	15	15	15	15	15
Emergence (DAP)	8	10	12	8	9	11
Flowering (DAP)	63	58	55	62	59	57
Maturity (DAP)	154	144	138	152	142	135
	Depth of water applied (mm)					
Full irrigation (FI)	240	225	225	265	215	215
80% FI	190	180	180	210	175	175
60% FI	145	130	130	160	130	130

This crop model has four main sections including climate, crop, soil, and field management. The field management components include irrigation, fertilizer, planting time and mulching. These components may be changed by the user to improve yield and water productivity

Model Evaluation

Performance of the model in predicting biomass, WP and grain yield was assessed by comparing predicted results against measured data. The statistical indices applied in the calibration and validation of the model were prediction error (P_e), root mean square error (RMSE), model efficiency (E) and coefficient of determination (R^2).

Model performance was evaluated using the following statistical indices:

$$P_e = \frac{(S_i - O_i)}{O_i} \times 100 \qquad (8)$$

$$E = 1- \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \qquad (9)$$

where S_i and O_i are simulated (predicted) and observed (measured) data, $\bar{O}$ is mean value of O_i and n is the number of measurements.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - S_i)^2} \qquad (10)$$

where O_i and S_i are the observed and simulated values, N is the number of measurements and $\bar{O}$ is the average of measured data.

RESULTS AND DISCUSSION

Grain Yield, Biomass and Water Productivity

In 2014 for the first planting date (PD_1: 01 April) under non-stressed condition (I_1: full irrigation or 100% (FI), the measured grain yield and biomass were 4.55 and 8.98 t ha^{-1}, respectively. Also, for the second planting date (PD_2: 15 April), these amounts were 4.15 t ha^{-1} and 8.55 t ha^{-1}, respectively. Subsequently, these data for the third planting date (PD_3: 01 May) were achieved at the rate of 3.85 t ha^{-1} and 8.15 t ha^{-1}, respectively (Table 3). The results showed that the measured yield decreased from PD_1 to PD_2 and from PD_1 to PD_3 12% and 15.3 %, respectively, apparently due to delayed planting. Under similar conditions in 2015, the measured grain yield for the PD_1, PD_2 and PD_3 in full irrigation (I_1) treatment were 4.35, 3.90 and 3.80 t ha^{-1} while the biomass yield were 8.6, 8.4 and 8.0 t ha^{-1}, respectively (Table 6). Therefore, the reduction of grain yield for the second experimental year due to delayed planting were at the rate of 10.7 % and 14.3% from PD_1 to PD_2 and from PD_1 to PD_3, respectively. The percentage of yield reduction due to delayed in planting under different irrigation water treatments have been shown in Fig. 3. According to Fig. 3 data, yields reduction was increased due to delay in planting date from 15 April to 01 May in all irrigation treatments. The highest reduction in grain yield was observed in I3PD3 treatment which was 27.7% of grain yield in I1PD1 treatment (treatment with minimum reduction) (Fig. 2). In addition, grain yields reduction was increased due to the reduction in water applied in all planting date treatments, which the maximum grain yield reduction was observed in I_3PD_3 treatment which was 38.9% of grain yield of early planting date (PD_1) in interaction with full irrigation treatment (I_1PD_1) (Fig. 3).

The results of this study are in agreement with the results obtained by Mazaheri et al., (2005) for the same region. In that study, maximum soybean grain yield of 437.2 g m^{-2} was attained by early-planted soybean. The rate of decreasing in grain yield was noted about 22.5 g m^{-2} reduction with one-week delay in sowing. Yuba et al., (2016) observed up to 29.8% grain yield increasing when soybean cultivars were planted in early May compared with mid-June in Illinois, Indiana, Iowa, and Ontario, USA.

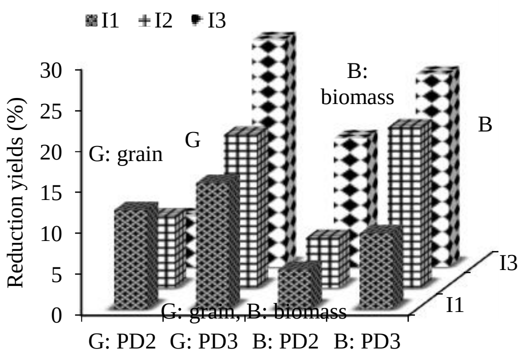

Fig. 2. Percentage of grain and biomass yield reduction of delayed planting dates (PD_2 and PD_3) when compared to corresponding yields in early planting date (PD_1) in interaction with different irrigation treatments.

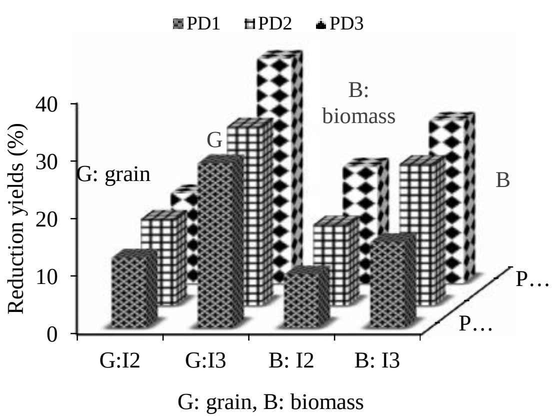

Fig. 3. Percentage of yields reduction of deficit irrigation treatments (I_2 and I_3) when compared to corresponding yields in full irrigation (I_1) treatment in interaction with different planting dates

Calibration for Aboveground Biomass, Grain Yield, WP and ET

The soybean grain yield, above ground biomass, water productivity (WP) and ET under full irrigation (FI), 80% FI and 60% FI treatments in interaction with different planting dates in 2014 are presented in Table 3. The results showed, soybean water productivity (WP) ranged from a maximum of 10.2 kg $ha^{-1}mm^{-1}$ to a minimum of 7 kg $ha^{-1}mm^{-1}$ in 2014. In addition, water productivity for early planting date (PD_1) under full irrigation (I_1) treatment was highest; whereas that for late planting date (PD_3) treatment under irrigation, at 60% FI (I_3) was lowest (Table 3).

For model calibration process, at the first step, data from the treatment with non-limiting soil water regime (full irrigation) and planted in the recommended planting date was used to calibrate AquaCrop for the conservative parameters which released by Steduto et al., (2009). Then, this process was used to compare the measured and simulated data for grain yield, water productivity and aboveground biomass for the deficit irrigated treatments. Generally, measured soybean growth parameters and conservative parameters were used in the calibrating phase (Table 4).

Also, it was observed from Table 3 that under all planting dates, the grain yield calibration results for I_1 and I_2 irrigation treatments were better (2.2< P_e<9.2%) than those in the highest deficit irrigation treatment, I_3 (P_e = 10.6%). In addition, the highest and lowest error in grain yield estimation was in I_3PD_3 and I_1PD_1 treatments amounting to 10.6% and 2.2%, respectively (Table 3). Subsequently, for the biomass yield, the model agreed well for the full irrigation treatment in early planting date (P_e= 0.3%). The AquaCrop model calibration results for the WP under full irrigation treatment (I_1) was better than the deficit irrigation treatments (I_2 and I_3) in all planting dates which, the best-calibrated result for WP was achieved with P_e ranging from the minimum of 4.3% in I_1PD_1 treatment to the maximum of 11.4% in I_3PD_3 treatment, respectively (Table 3). In addition, the ability of the model to simulate the cumulative crop evapotranspiration (ET) was evaluated. The results showed that the model was able to simulate the value of ET with an error of less than 7.3 %. The results of this study are in good agreement with the results of Heng et al., (2009) and Steduto et al., (2009) studies, which they reported, the error resulting from the simulation was less than 5%.

Overall, the best-calibrated model was achieved with prediction error (P_e) ranging from a minimum of 0.3% for the full irrigation treatment (I_1) to a maximum of 10.2% in I_3 (60% FI) for all planting dates. The observed and calibrated data of grain yield for all treatment combinations were plotted in Fig. 5. The agreement was measured using different statistical fitting parameters (RMSE, P_e, R^2, and E). The fitting parameters for all the treatments and variables are presented in Table 5. The measured and simulated values of GY, BY, ET, WP and values of statistical fitting parameters have been shown in Fig. 4). The measured evapotranspiration (ET) were calculated using water balance method. Thus, the simulation waspreformed cumulatively throughout the whole season. As it is shown in Table 3, the model performed reasonably well for non-stressed water (I1) treatment compared to other treatments. The model was calibrated for cumulative ET with E of 0.96, Pe of 1.3% and R^2 of 0.95 (Table 5).

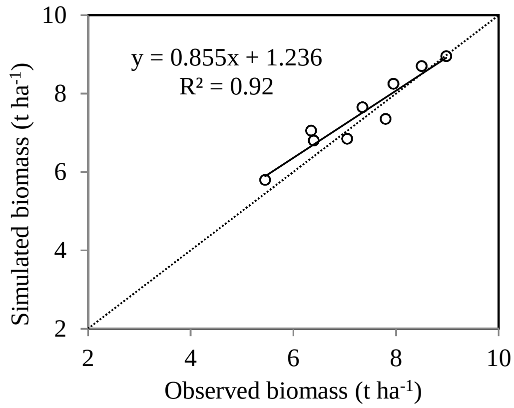

Fig. 4 Calibration results for biomass under all planting dates and irrigation water treatments

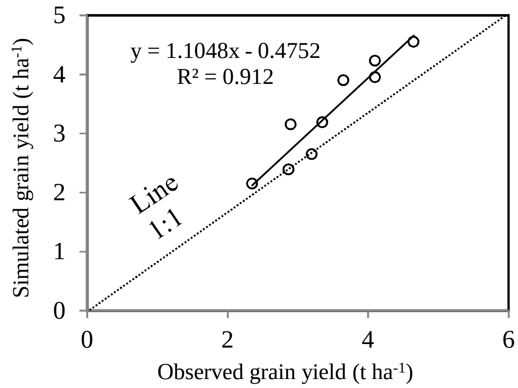

Fig. 5. Calibration results for grain yield under all planting dates and irrigation water treatments

The simulated cumulative evapotranspiration were lower compared to measured values. In addition, the calibrated values were achieved for biomass yield with E and R^2 of 0.94 and 0.92, respectively. Table 5 shows the prediction error statistics of the calibrated AquaCrop model. The model was calibrated for simulation of grain yield and biomass for all planting dates and irrigation treatments with the prediction error statistics of $0.92 < E < 0.94$, $0.27 < RMSE < 0.41$ t ha^{-1} and $0.91 < R^2 < 0.92$. In addition, the WP during the calibration process was with E of 0.90 and R^2 of 0.88 (Table 5). Similar results of AquaCrop model for soybean under different water stress levels were reported by Paredes et al., (2015) and Battisti et al., (2017).

Also, Adeboye et al., (2019) reported that, the AquaCrop model simulated soybean dry above ground biomass with RMSE ≤ 0.25 t ha^{-1} and R^2 of 0.90. Grain yield was simulated with $R^2 = 0.96$ and RMSE of 0.03 t ha^{-1} and the maximum deviation between the simulated and predicted grain yields was 3%. Their results were similar to the results of this study. The model estimations for all variables including Bi, GY and WP were in line with the measured values corroborated with R^2 data approaching one (Fig. 4). These results indicated that the model had better performance in simulating for the condition without water deficit throughout the soybean cultivation dates and was the most accurate model for irrigation treatments that did not undergo water deficit. For calibration, the model underestimated grain yield for all treatments (Table 3), probably due to water deficit in the reproductive stage (flowering and grain formation), in which there is greater water demand by the plant.

Table 3. Calibration results of grain yield, biomass, water productivity (WP) and evapotranspiration (ET) under different planting dates and water treatments (2014)

Water Treatment	Grain yield (t ha^{-1})		P_e (%)	Biomass (t ha^{-1})		P_e (%)	WP (kg mm^{-1} ha^{-1})		P_e (%)	ET (mm)		P_e (%)
	M	S		M	S		M	S		M	S	
Planting date: 15 April (PD_1)												
100 % FI (I_1)	4.55	4.45	2.2	8.98	8.95	0.3	10.2	9.78	4.3	450	440	2.2
80 % FI (I_2)	4.00	3.80	5.0	8.15	7.75	4.9	10.1	9.40	6.9	396	485	3.2
60% FI (I_3)	3.25	3.00	4.6	7.65	7.15	6.5	9.26	8.55	7.7	350	335	4.4
Planting date: 30 April (PD_2)												
100 % FI (I_1)	4.15	4.00	3.6	8.55	8.10	5.2	9.63	9.18	4.7	430	415	3.6
80 % FI (I_2)	3.65	3.40	6.8	7.35	6.90	6.1	9.46	8.71	7.9	386	370	4.3
60% FI (I_3)	3.05	2.80	8.2	6.45	6.05	6.2	9.08	8.30	8.6	236	225	5.0
Planting date: 15 May (PD_3)												
100 % FI (I_1)	3.85	3.55	7.8	8.15	7.85	4.9	8.93	8.20	8.2	430	410	4.8
80 % FI (I_2)	3.25	2.95	9.2	6.55	6.20	9.9	8.42	7.51	10.8	386	360	7.2
60% FI (I_3)	2.35	2.15	10.6	5.85	5.35	8.5	7.0	6.20	11.4	236	220	7.2

M, measured; S, simulated; P_e, prediction error

Table 4. Input data of soybean crop parameters used in AquaCrop model for calibration

Description	**Value**	**Unit**
Base temperature	5.0	°C
Cut-off temperature	35.0	°C
Maximum air temperature above which pollination starts to fail (heat stress)	40.0	°C
Canopy growth coefficient (CGC)	0.005	% day^{-1}, Conservative parameter
Canopy decline coefficient (CDC) at senescence	0.015	% day^{-1}, conservative parameter
Maximum canopy cover	85	(%)
Soil water depletion threshold for canopy expansion - Upper threshold	0.18	
Soil water depletion threshold for canopy expansion - Lower threshold	0.65	
Shape factor for Water stress coefficient for canopy expansion	3.0	
Soil surface covered by an individual seedling at 90% emergence (CC_o)	5.0	(cm^2/plant)
Leaf growth threshold (P_{lower})	0.7	% of TAW
Expansion stress coefficient (P_{upper})	0	% of TAW
Expansion stress coefficient (P_{Lower})	0.3	% of TAW
Expansion stress coefficient curve shape	1.4	% of TAW
Stomatal conductance threshold (P_{upper})	0.6	Unit less
Stomatal stress coefficient curve shape	1.01	Unit less (High convex curve)
Reference harvest index (HI_o)	40	(%)
Coefficient describing negative impact of stomatal closure during yield formation on HI	Strong	Strong
Maximum basal crop coefficient (K_{cb})	1.28	Unit less
Normalized Water Productivity (WP*)	15	g/m^2
Minimum effective rooting depth (Z_n)	0.25	(m)
Shape factor describing root zone expansion	1.5	
Maximum effective rooting depth (Z_x)	1.0	(m)

Table 5. Prediction error statistics of the calibrated AquaCrop model for all treatments

Model output	Mean		RMSE	E	P_e (%)	R^2
Parameter	Obs.	Sim.				
Grain yield, (t ha^{-1})	3.55	3.34	0.27	0.92	5.9	0.91
Biomass, (t ha^{-1})	7.52	7.14	0.41	0.94	5.1	0.92
WP, (kg ha^{-1} mm^{-1})	9.12	8.43	0.86	0.90	7.6	0.88
ET (mm)	367	362	0.16	0.96	1.3	0.95

Obs., observed; Sim., simulated

Thus, it can be concluded that the results obtained in the statistical evaluation of AquaCrop calibration are within those reported in applications for soybean, indicating that AquaCrop can be used for predicting yield when adequately calibrated.

In this regard, Heng et al., (2009) found better performance of the AquaCrop model under full and mild water stress conditions, compared to under severe water stress conditions. Therefore, finally the simulation results of AquaCrop model for water productivity (WP), biomass and grain yield of soybean crop indicated a close match with the measured data under different irrigation and planting dates regimes.

Validation of AquaCrop Model

The performance of AquaCrop in simulating ET, WP, biomass and grain yield for different irrigation regimes and planting dates was evaluated. The validation of the model was performed using the calibrated model and data from the second field experimental year (2015). The same conservative parameters used in the calibration were used in the validation model. The statistical parameters obtained from the regression of measured and simulated values are presented in Table 6. The validation model was used to evaluate the effect of different irrigation water management and planting dates on soybean WP and yields.

The measured and simulated WP of all treatments is plotted as shown in Fig. 6. AquaCrop simulated the WP with reasonable accuracy (R^2 = 0.89, RMSE of 0.87 kg mm^{-1} ha^{-1}, and E of 90%) (Table 7). The model slightly underestimated the lower values as indicated by a high slope of the regression equation while higher values were correctly simulated.

As shown in Fig. 7 and Table 7, except for slight underestimation of higher values, the aboveground biomass was adequately simulated with an average deviation of 4.86%, RMSE = 0.40 t ha^{-1}, R^2 = 0.95, E = 0.96, and close to unity slope. Fig. 8 shows that AquaCrop has simulated the most important output, grain yield, with acceptable accuracy under varying environmental and management conditions with the average deviation between the simulated and observed yield of 5.48%, RMSE = 0.22 t ha^{-1}, R^2 = 0.92, and E = 0.93 (Table 7). In addition, the model was validated for cumulative ET with E of 0.92, Pe of 4.7% and R^2 of 0.91.

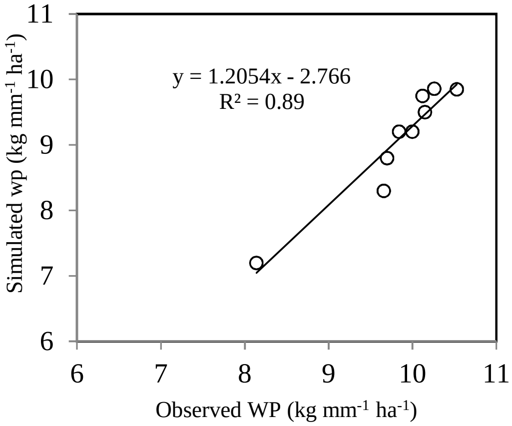

Fig. 6. Model validation results in simulating WP of soybean

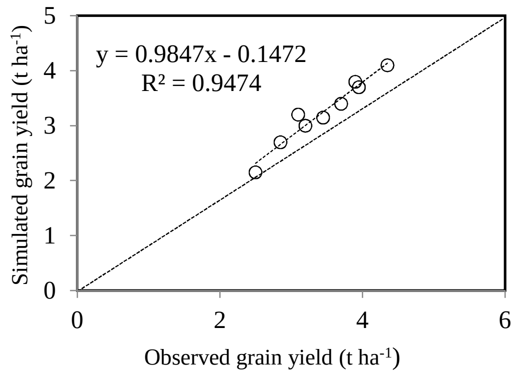

Fig. 8. Model validation results in simulating grain yield of soybean

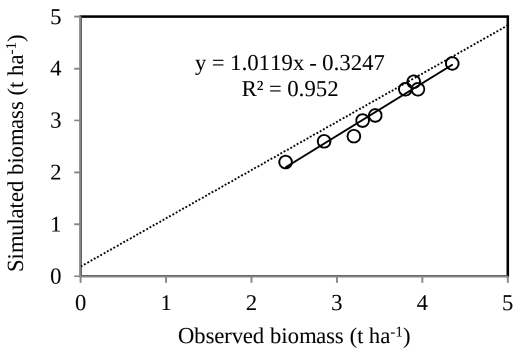

Fig. 7. Model validation results in simulating biomass yield of soybean

Regarding validation, the non-stressed or full irrigation treatment (I_1) showed slight underestimation of simulated yield over the measured yield. Also, same result was achieved for deficit irrigation treatments I_2 and I_3 under all planting dates (Table 6).

These results also indicated that the model had better performance in the simulation for the condition of no water deficit throughout the early planting date.Similar results were obtained by Silva et al., (2018) when they calibrated and validated the AquaCrop model to obtain soybean yield under different irrigation depths in the geographic region of Matopiba in Brazil.

Table 6. Validation results of GY, Bi, WP and ET under different planting dates and water treatments (2015)

Water Treatment	Grain yield ($t\ ha^{-1}$)		Pe (%)	Biomass ($t\ ha^{-1}$)		Pe (%)	WP ($kg\ mm^{-1}\ ha^{-1}$)		Pe (%)	ET (mm)		Pe (%)
	M	S		M	S		M	S		M	S	
						Planting date: 15 April (PD_1)						
100 % FI (I_1)	4.35	4.20	3.4	8.60	8.40	2.3	10.12	9.75	4.3	430	420	2.3
80 % FI (I_2)	3.95	3.70	6.3	8.20	7.75	5.5	10.53	9.85	6.4	375	360	4.1
60% FI (I_3)	3.20	3.00	6.3	7.50	7.05	6.0	9.84	9.20	6.5	325	310	4.6
						Planting date: 30 April (PD2)						
100 % FI (I_1)	3.90	3.75	3.8	8.40	8.00	4.8	10.26	9.86	3.9	380	370	2.7
80 % FI (I_2)	3.45	3.25	5.8	7.45	6.95	6.7	10.15	9.50	6.5	340	325	4.6
60% FI (I_3)	2.85	2.60	8.8	6.40	5.90	7.8	9.66	8.30	8.6	295	275	6.7
						Planting date: 15 May (PD_3)						
100 % FI (I_1)	3.80	3.60	5.3	8.00	7.65	4.4	10.00	9.20	8.0	380	365	4.1
80 % FI (I_2)	3.30	3.05	7.6	6.65	6.20	6.0	9.7	8.8	9.3	340	320	6.2
60% FI (I_3)	2.40	2.20	8.3	5.90	5.40	8.5	8.14	7.20	11.5	295	275	7.3

M, measured; S, simulated; P_e, prediction error

Table 7. Prediction error statistics of the validated AquaCrop model for all treatments

Model output parameter	Mean		RMSE	E	P_e(%)	R^2
	Obs.	Sim.				
Grain yield, ($t\ ha^{-1}$)	3.47	3.28	0.22	0.93	5.48	0.92
Biomass, ($t\ ha^{-1}$)	7.41	7.10	0.40	0.96	4.86	0.95
WP, ($kg\ ha^{-1}\ mm^{-1}$)	9.82	9.12	0.87	0.90	7.43	0.89
ET (mm)	351	335	0.48	0.92	4.7	0.91

CONCLUSIONS

AquaCrop was able to predict the impacts of different management decisions on soybean grain and biomass yields, reasonably well. The model estimated soybean yield with acceptable accuracy (P_e= 5.4%, R^2 = 0.92, E = 0.93 and RMSE = 0.22 t ha^{-1}). From the results of this study, it is possible to recommend that AquaCrop model could be used to estimate biomass, grain yield, and water productivity of soybean with a reasonably high degree of confidence for different irrigation levels and planting dates. Overall, it could be concluded that AquaCrop can be a useful tool to help decision making for soybean irrigation management and evaluation in different planting dates to maximize yield.

REFERENCES

Adeboye, O. B., Schultz, B., Adekalu, K. O., & Prasad, K. C. (2019). Performance evaluation of AquaCrop in simulating soil water storage, yield, and water productivity of rain fed soybeans (Glycine max L. merr) in Ile-Ife, Nigeria. *Agricultural Water Management*, 213, 1130-1146.

Battisti, R., Sentelhas, P. C., & Boote, K. J. (2017). Inter-comparison of performance of soybean crop simulation model and their ensemble in southern Brazil. *Field Crop Research*, 200, 28–37.

Comlekcioglu, N., & Simsek, M. (2011). Effects of deficit irrigation on yield and yield components of vegetable soybean [Glycine max L. (Merr.)] in semi-arid conditions. *African Journal of Biotechnology*, 10 (33), 6227-6234.

Doorenbos, J., & Kasssam, A. H. (1979). *Yield response to Water*. FAO Irrigation and Drainage Paper no 33. Rome, Italy: FAO.

FAO. (2013). FAOSTAT. Retrieved from: http://www.fao.org/nr/water/cropinfo_soybean.html.

Farahani, H. J., Izzi, G., & Oweis, T. Y. (2009). Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton. *Agronomy Journal*, 101, 469-476.

Heng, L. K., Hsiao, T. C., Evett, S., Howell, T., & Steduto, P. (2009). Validating the FAO AquaCrop model for irrigated and water deficient field maize. *Agronomy. Journal*101, 488–498.

Hsiao, T. C., Heng, L.K., Steduto, P., Rojas-Lara, B., Raes, D., & Fereres, E. (2009). AquaCrop—Th e FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. *Agronomy Journal*, 101:448– 459.

Jensen, M. E. (1973). *Consumptive use of water and irrigation water requirements*. New York, NY, USA: ASCE.

Jones, C. A., & Kiniry, J. R. (1986). *CERES-maize: A simulation model of maize growth and development*. Texas: A & M University Press, College Station.

Kawasaki, Y., Yamazaki, R., & Katsuyuki, K. (2018). Effects of late sowing on soybean yields and yield components in southwestern Japan. *Plant Production Science*, 21, 339-348.

Keating, B. A., Carberry, P. S., & Hammer, G. L. (2003). An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy*, 18, 267-288.

Kresović, B., Gajić, B., Tapanarova, A., Pejić, B., Dugalić, G., & Sredojević, Z. (2017). Impact of deficit irrigation on yield and chemical properties of soybean seeds in temperate climate. *Contemporary Agriculture*, 66(1-2), 14-20.

Mazaheri, D. H., Zeinali, H., & Madani, A. (2005). Influence of planting dates and plant densities on photosynthesis capacity, grain and biological yield of soybean in Karaj, Iran. *Journal. of Agronomy*, 4, 230-237.

Nehbandani, A., Soltani, A., Zeinali, E., & Hoseini, F. (2017). Analyzing soybean yield constraints in Gorgan and Aliabad katul using CPA method. *Journal of Agroecology*. 7(1), 109-123.

Paredes, P., Wei, Z., Liu, Y., Xu, D., Xin, Y., Zhang, B., & Pereira, L. S. (2015). Performance assessment of the FAO AquaCrop model for soil water, soil evaporation, biomass and yield of soybeans in north China plain. *Agricultural Water Management*, 152, 57-71.

Raes, D., Steduto, P., Hsiao, T. C., & Fereres, E. (2009). AquaCrop - the FAO crop model to simulate yield response to water: II. Main algorithms and software description. *Agronomy Journal*, 101, 438-447.

Raja, W., Habib Kanth, R., & Singh, P. (2018). Validating the AquaCrop model for maize under different sowing dates. *Water Policy*, 20, 826-840.

Silva, V. de P. R., Silva, R. A. E., Maciel, G. F., Braga, C. C., Silva Júnior, J. L. C. da, Souza, E. P. de., Rodrigues, R. S., Silva, M. T., & Holanda, R. M. de. (2018). Calibration and validation of the AquaCrop model for the soybean crop grown under different levels of irrigation in the Motopiba region, Brazil. *Ciência Rural*, 48, 1-8.

Steduto, P. (2003). Biomass water- productivity. Comparing the growth- engines of crop models. FAO expert consultation on crop water productivity under deficient water supply, Rome, Italy, 26 - 28 February.

Steduto, P., Hsiao, T. C., & Fereres, E. (2007). On the conservative behavior of biomass water productivity. *Irrigation Science*, 25, 189-207.

Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. (2009). AquaCrop: The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. *Agronomy Journal*, 101, 426-437.

Stockle, C. O., Donatelli, M., & Nelson, R. (2003). CropSyst a cropping systems simulation model. *European Journal of Agronomy*, 18, 289–307.

Yuba, R. K., Kiersten, A. W., Carl, A. B., Albert, U. T., & Daren, S. M. (2016). Effect of planting date, seed treatment, and cultivar on plant population, sudden death syndrome, and yield of soybean. *Plant Disease*, 100, 1735-1743.

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مقاله علمی- پژوهشی

ارزیابی مدل AquaCrop در زراعت سویا تحت تاریخ های مختلف کاشت و کم آبیاری

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چکیده- تنش آبی به عنوان یکی از مهم ترین عامل مؤثر بررشد و تولید سویا در مناطق نیمه خشک بشمار می رود. تاریخ کاشت و مدیریت آبیاری از کلیدی ترین عملیات زراعی است که بر رشد سویا و تولید محصول اقتصادی تأثیر فراوانی دارد. امروزه، جهت بررسی تأثیرات مخرب تنش های محیطی، از مدل های واسنجی شده برای شبیه سازی و ارزیابی رشد محصولات زراعی تحت سناریوهای مختلف استفاده می شود. در این تحقیق، مدل AquaCrop برای شبیه سازی عملکرد و کارآیی مصرف آب گیاه سویا درسطوح مختلف آبیاری و تاریخ کاشت در شمال شرقی ایران مورد ارزیابی قرار گرفت. برای ارزیابی کارآیی مدل از میانگین مربعات خطای ریشه (RMSE) ، راندمان مدل(E) ، ضریب تعیین (R^2) و خطای پیش بینی (Pe) استفاده شد. در مرحله واسنجی مدل AquaCrop عملکرد دانه سویا و زیست توده برای کلیه تیمارها با خطای $0.27<RMSE<0.41\ t\ ha^{-1}$، $2.1<Pe<5.6\%$، $0.9<R^2<0.92$ و $0.88<E<0.94$ پیش بینی شد. سپس، نتایج اعتبارسنجی مدل شامل $0.93<E<0.96$ ، $0.92<R^2<0.95$ و RMSE به ترتیب برای عملکرد دانه و زیست توده ۰/۲۲و ۰/۴ تن در هکتار حاصل شد. عملکرد سویا و پاسخ رشد به آب آبیاری تکمیلی و تاریخ کاشت با دقت قابل قبولی توسط مدل پیش بینی شد. به طور کلی، مدل AquaCrop یک ابزار پشتیبانی کننده مناسب جهت تصمیم گیران برای شبیه سازی بهره وری آب (WP) ، عملکرد دانه (GY) و زیست توده (Bi) در زراعت سویا تحت مدیریت متفاوت مزرعه در محیط نیمه خشک توصیه می گردد.