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Soil water content simulation under different irrigation and nitrogen strategies using AquaCrop model

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ABSTRACT:

The purpose of this research was to study the efficiency and accuracy of AquaCrop model, in estimating soil moisture and soybean crop water consumption based on Evapotranspiration (ET). A field sprinkler irrigation system was conducted under full and deficit irrigation using different nitrogen fertilizer applications (40%, 80%, and 100%) during two cropping seasons for soybean at Gorgan province in Iran. The simulation results showed a reasonably accurate prediction of soil moisture content and actual crop Evapotranspiration (ETc) under different irrigation water application and nitrogen treatments. The Root Mean Square Error (RMSE) of ETc estimation for calibration and validation sets were 14.5 mm and 23.2 mm, respectively. Based on optimization, the required amount of irrigation water to achieve optimum WUE was equal to 200 mm and 275 mm for the first and second year of study, respectively. The simulated soil moisture data can be used in subsequent studies to develop a drought indicator for agricultural drought monitoring.

Keywords:

Soil moisture contents, Evapotranspiration, Deficit irrigation, Water use efficiency, Soybeans.

Abbreviation:

ΔS-The change in the Soil moisture content; CC-Canopy Cover; cc_o-Canopy Cover per seedling; CC_x-Maximum Canopy Cover; CGC-Canopy Growth Coefficient; D-Drainage Water; ET-Evapotranspiration; ET_c-Crop Evapotranspiration; FC-Field Capacity; I-Irrigation; K_{sat}-Saturated Hydraulic Conductivity; N-Nitrogen; P-Effective Rainfall; PWP-Permanent Wilting Point; R-Runoff; RH_{max}-Maximum Relative Humidity; RH_{min}-Minimum Relative Humidity; RKN-Root-Knot Nematode; RMSE-Root Mean Square Error; SWC-Soil Water Content; T_{max}-Maximum Air Temperature; T_{min}-Minimum Air Temperature; T_r-Transpiration; WP-Water Productivity; WUE-Water Use Efficiency; θ_{FC}-Field Capacity; θ_{PWP}-Permanent Wilting Point; θ_{sat}-Volumetric Water Content at Saturation; Pb-Soil Bulk Density; ISWC-Initial Soil Water Content

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INTRODUCTION

On universal balance, cultivated irrigation water put away nearby 72% of available fresh water resources (Geerts *et al*., 2009). In Iran, agriculture consumes 94% of available water (Alizadeh and Keshavarz, 2005). Since agriculture (mainly irrigation) is the major sector of water consumption, improving agricultural water management is quite vital. Rahimi *et al*. (2015) and Valipour (2014, 2015a, 2015b) illustrated the prominence of watered and waterless agriculture in the world. In addition, they pronounced benefits and shortcomings of irrigation methods and significance of apprising irrigation information to pick out optimum decision. Deficit irrigation has been investigated as a useful strategy for arid and semiarid regions where water is the limiting factor in crop cultivation. Soil moisture can be one of the principal factors that affect Root-Knot Nematode (RKN) illness expansion (Mohawesh and Muwaffaq, 2014). Soil moisture is a key parameter in numerous environmental studies, including hydrology, meteorology, and agriculture (Shi *et al*., 2002). Soil Water Content (SWC) and nutrient availability are two main factors limiting plant growth and productivity (Matson *et al*., 1997). Soil moisture controls the infiltration rate during precipitation events, runoff production, and Evapotranspiration (ET). Thus it affects both global water and energy balances.

To quantify the yield decline caused by water discrepancy, an accurate simulation of the soil water balance constituents is required. This is mainly because the mechanistic crop growth simulation models use transpiration as an input to calculate the indices of water stress affecting crop growth and development (Faria *et al*., 2003).

In Gorgan domain, in northern Iran, soybean is the key cultivated yield and commonly planted unaccompanied or in alternation with wheat yield. In Gorgan the amount of observed grain yield for irrigated and dry farming is 4.3 and 1.6 ton ha^{-1}, respectively. Soybean is established in virtually all over of the world for human consumption, trade and animal feed (Boydak *et al*., 2002). Foroud *et al*. (1993) indicated that soybean is quite susceptible to water stress during grain filling, flowering and vegetative stages. The maximum available water for plant water uptake is the difference between the soil moisture content at field capacity and permanent wilting point. Water source is also essential for crop production as far as possible nitrogen (Mansouri-Far *et al*., 2010). Nitrogen accessibility or uptake might too be adapted by water source. Fertilization is assumed to mitigate the negative effects of water deficit by improving root growth, plant height, leaf area, photosynthesis and water use efficiency (Mahmoud and Younis, 2009).

Irrigation and fertilization are extensively realistic by farmers to attain high plant development and harvest. More residual nitrate residues in the soil at the finale of the cropping season when soil water is deficient as likened to when it is acceptable (Fapohunda and Hussain 1990). Soil fertility restrictions are correspondingly more stringent for well-watered situations (Heng *et al*., 2007). Recently, researchers have been interested

Table 1. Notation of the treatments used in the experiment

S.No.	Treatments	First year	Second year
1	I_1	100% of soil deficit was accomplished	100% of soil deficit was accomplished
2	I_2	75% of soil deficit was accomplished	67% of soil deficit was accomplished
3	I_3	52% of soil deficit was accomplished	35% of soil deficit was accomplished
4	I_4	24% of soil deficit was accomplished	No irrigation
5	N_1	100% of the required nitrogen was applied	100% of the required nitrogen was applied
6	N_2	80% of the required nitrogen was applied	80% of the required nitrogen was applied
7	N_3	40% of the required nitrogen was applied	40% of the required nitrogen was applied

Table 2. Some physical characteristics of soil in the experimental field

S.No.	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	FC (%)	PWP (%)	ρ_b (g cm^{-3})	K_{sat} (mm day^{-})
1	0-20	34.2	53.2	12.6	Silty Clay	27	14	1.3	150
	SD	±1.3	±1.2	±1.5	Loam	±0.5	±1.6	±0.07	±1.3
2	20-40	22.6	63.1	14.3	Silt Loam	26	15	1.35	350
	SD	±1.2	±1.5	±0.5		±0.6	±1.5	±0.06	±1.2
3	40-60	23.1	62.5	14.4	Silt Loam	26	15	1.35	350
	SD	±1.4	±1.5	±0.4		±0.5	±1.3	±0.04	±2.2
4	60-80	23.4	64.2	12.4	Silt Loam	26	15	1.4	350
	SD	±1.4	±1.5	±0.6		±0.5	±1.4	±0.07	±4.5
5	80-120	24.8	61.6	13.6	Silt Loam	26	15	1.35	350
	SD	±1.2	±1.5	±0.7		±0.5	±1.1	±0.03	±3.3

in the application of fertilizers for soybean production. Wesley *et al*. (1999) reported that application of nitrogen at the beginning pod of growth stage increased yield, but had no effect on the content of seed protein or oil. The low yield of irrigated farming due to low levels of nitrogen.

Investigating the yield comeback to diverse amount of water and nitrogen submissions in field and/ or controlled treatments is difficult and luxurious. Since such restrictions, modeling can be a beneficial appliance to investigation and improve promising shortage irrigation plans (Heng *et al*. 2007; Geerts and Raes, 2009). Simulation models permit a combined assessment of diverse influences affecting yield in order to develop finest irrigation amounts for altered irrigation and nitrogen situations (Liu *et al*., 2007). Crop growth models based on plant physiology (mechanistic models)

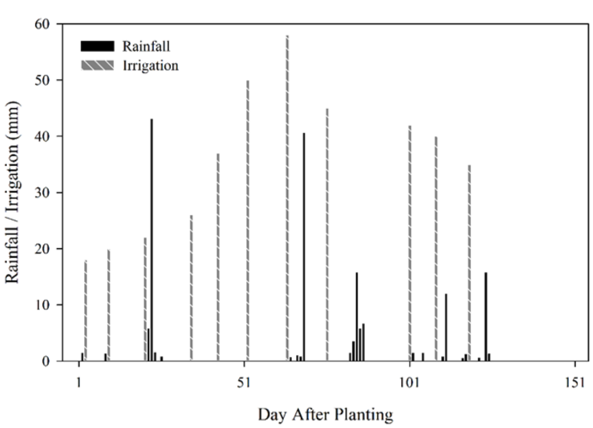

Figure 1. Daily rainfall and applied irrigation during the growing seasons in second year

provide a good understanding of the combined influence of environment and plant characteristics on crop development (Yang *et al*. 2004; Bannayan *et al*. 2007), but it is difficult to apply them on large scale due to large amount of required inputs that are often difficult to acquire. AquaCrop model expanded from the basic yield response to water process in Doorenbos and Kassam (1979) to a daily-step, process-based crop growth model with little intricacy. The FAO- AquaCrop classical is a novel, perfect and strong model and necessitates fewer input data associated with the other models (Hsiao *et al*. 2009; Steduto *et al*. 2009). AquaCrop encompasses a water-driven growth-engine for field crops with a growth-module that trusts on the traditional performance of biomass per component Transpiration (Tr) association (Steduto *et al*., 2007).

Steduto *et al*. (2009) stated that AquaCrop is an attempt to develop a simple, versatile, and robust model that used to determine the optimal water application in cotton under different sets of conditions. Farahani *et al*. (2009) and Garcia-Vila *et al*. (2009) investigated AquaCrop model for cotton under full and deficit irrigation regimes in Syria and Spain. They indicated that the main factors such as standardized water production, canopy cover and total biomass, for calibration must be verified under diverse climate, soil, cultivars, irrigation procedures and field management. In Italy, sunflower was considered using AquaCrop, CropSyst, and WOFOST models for association of model accurate-

Table 3. Calibration values for selected parameters of the crop data file in AquaCrop

S.No.	Description	Value	Units or meaning
1	Base temperature	5	°C
2	Cut-off temperature	35	°C
3	Canopy cover per seedling at 90% emergence	5	cm^2
4	Canopy growth coefficient (CGC)	11.9% (0.503%)	Per day or GDD
5	Maximum canopy cover (CC_x)	95	%
6	Canopy decline coefficient (CDC) at senescence	3% (0.163%)	Per day or GDD
	Water stress response parameters		
1	Leaf growth threshold (p_{upper})	0.15	Above this leaf growth is inhibited
2	Leaf growth threshold (p_{lower})	0.65	Leaf growth stops completely at this p
3	Coefficient curve shape	4	Moderately convex curve
4	Stomatal conductance threshold (p_{upper})	0.5	Above this stomata begin to close
5	Senescence stress coefficient (p_{upper})	0.7	Above this early canopy senescence begins
	Soil fertility stress response parameters		
1	Canopy growth coefficient reduction	8	%
2	Maximum canopy cover reduction	15	%
3	Normalized water productivity reduction	5	%
4	Average canopy cover decline	0.41	% day^{-1}
	Crop production parameters		
1	Normalized water productivity	14	g m^{-2}
2	Reference harvest index (HI_o)	40	%

ness. AquaCrop consequences indicated less discrepancy between experimental and simulated grain yields than did the others. They stated that AquaCrop model introduced notable simplifications and required fewer input parameters than the other two models, without affecting negatively its performances in terms of final biomass and yield (Todorovic *et al*., 2009).

Evapotranspiration is an important component of the hydrologic budget because it expresses the exchange of mass and energy between the soil-water-vegetation system and the atmosphere. Accurate estimation of Evapotranspiration is a very important step to achieve the soil water budget. Simulation of the effects of deficit irrigation and fertility (N) stress using AquaCrop model along with a sprinkler irrigation system for soybean has not been reported yet. The main objective of this study was the estimating of soil moisture content under full and deficit irrigation in interaction with full and deficit fertility effects on Soybean yield. Also, the grain yield, biomass and water use efficiency investigated under different conditions .

MATERIALS AND METHODS

Site description

This study was performed in an experimental farm located at Hashemabad (36°51' N, 54°16' E), north part of Iran, for two cropping seasons at two different years.

Field experiments

In this study soybean was cultivated under full and deficit irrigation and under full and deficit nitrogen conditions. Soybean was grown in the field under a

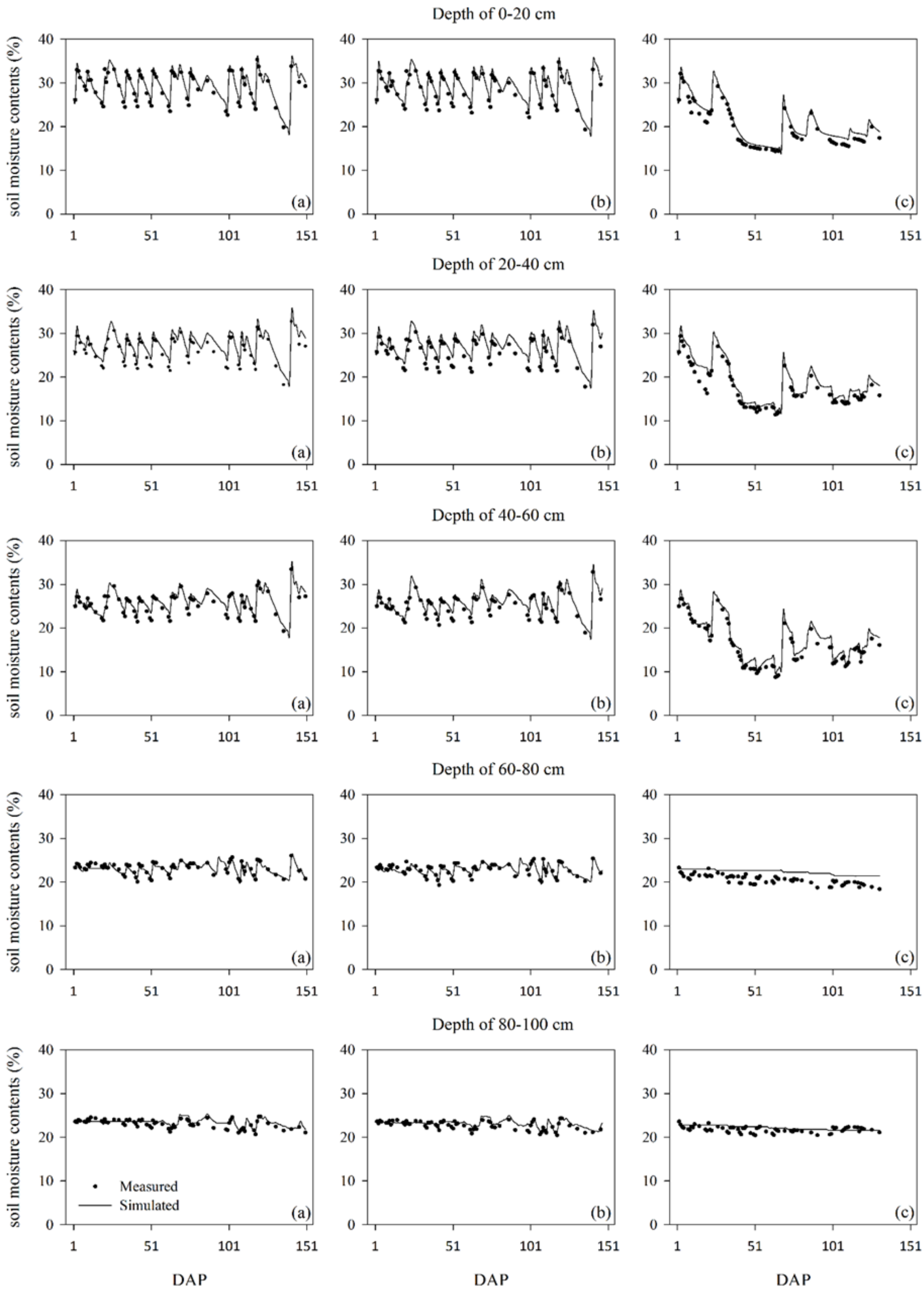

Figure 2. Observed and simulated soil moisture contents for each of 20 cm soil layers for (a) I_1N_1 (b) I_1N_3 and (c) I_4N_1 irrigation treatments. DAP is days after planting

Table 4. Statistical indices derived for evaluating the performance of the model for soil moisture

S.No.	Treatment	I_1N_1	I_1N_2	I_1N_3	I_2N_1	I_2N_2	I_2N_3	I_3N_1	I_3N_2	I_3N_3	I_4N_1	I_4N_2	I_4N_3
1	RMSE	0.94	1.12	1.16	1.25	1.38	1.41	1.38	1.38	1.40	1.58	1.53	1.81
2	R^2	0.98	0.96	0.97	0.97	0.96	0.97	0.96	0.96	0.95	0.95	0.94	0.95
3	E	0.95	0.96	0.94	0.92	0.93	0.91	0.91	0.89	0.88	0.88	0.89	0.85
4	d	0.98	0.97	0.97	0.96	0.96	0.94	0.96	0.93	0.92	0.92	0.90	0.91

sprinkler irrigation system. Irrigation was started at maximum allowable depletion of 50% in the I_1 treatment and water was applied until soil reaches to the field capacity.

The treatments that were used in this study are shown in Table 1. Four levels of irrigation application of I_1, I_2, I_3 and I_4 were used as main treatment and three levels of nitrogen application of N_1, N_2 and N_3 were used as sub-treatment. For treatments of N_1, N_2 and N_3, the amount of 120, 96 and 48 kg ha^{-1} nitrogen were applied. The experimental design was split-plot with four replications. (Heng *et al.,* 2009)

The planting date for soybean was June 2 and the harvesting time was 10 days after physiological maturity which was October 29. Soybean was cultivated with a row spacing of 0.5 m and plant spacing of 0.12 m apart. All plots were uniformly irrigated by sprinklers two days after planting to ensure good germination, and the irrigation treatments were imposed afterward. The type and amount of the required fertilizers were determined based on soil analysis. The nitrogen application was 120 kg ha^{-1} of nitrogen (urea at 46% N) for each year which was applied at three different times during the growing season (before planting, 30 days after planting and 60 days after planting). Field was monitored for pests and weeds, and they were effectively controlled using herbicides, or pesticides as needed (Heng *et al.,* 2009).

Data analysis

In order to simulate soil moisture content using AquaCrop model for soybean crop, parameters such as Field Capacity (FC), Permanent Wilting Point (PWP), Saturated Hydraulic Conductivity (K_{sat}), Initial Soil Water Content (ISWC), Soil Bulk Density (P_b) and Canopy Cover (CC) were measured. The values of K_{sat} were determined based on existing data of Guelph permeameter. Soil water contents were measured at soil depths of 0-20, 20-40, 40-60, 60-80 and 80-100 cm using gravimetric method. The soil water content in the root zone was recorded throughout the season. The soil physical characteristics for the experimental field were shown in Table 2. The FC and PWP were determined based on measurement of soil moisture mass content for each soil sample. To determine FC, after each irrigation, soil samples were taken until soil moisture content becomes nearly constant which occurred about 24 hours after irrigation. PWP estimated as the soil water content held in the soil at -1.5 MPa matric potential using porous ceramic plate (Heng *et al.,* 2009).

Irrigation application

For the first and second year of experiment, the evaporation was 852.4 and 970.4 mm, respectively.

Table 5. Statistical indices derived for evaluating the performance of the model for calibration and validation

S.No.	Parameter	First year			Second year		
		RMSE	E	d	RMSE	E	d
1	GY	0.202	0.94	0.98	0.306	0.93	0.98
2	B	0.424	0.95	0.98	0.648	0.93	0.98
3	ETc	14.52	0.98	0.99	23.19	0.98	0.99

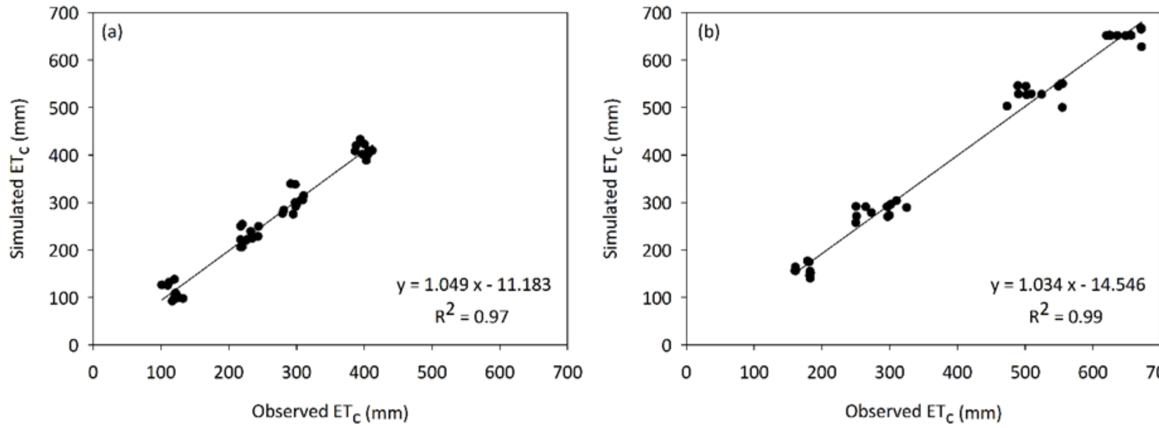

Figure 3. Simulated vs. observed values of soybean ETc used for model (a) calibration and (b) validation

Totally, 11 irrigations were applied during the whole growing season. In full irrigation (I_1) and deficit irrigations (I_2, I_3 and I_4), 393, 265, 138 and 17 mm irrigation water were applied, respectively. Irrigations were imposed in approximately 8-12 day intervals started from two days after planting until 10 days prior to harvest. The soil water content profile at planting was almost near to the field capacity for all treatments. The diameter of the soil sampling tube was 8 cm and three replications were used for sampling. The soil samples were taken before irrigation and day after irrigation and thereafter, every two or three days until the start of next irrigation. The volume of water applied was measured in the field by catch cans and three catch cans were used for each application level. The measurements were made early in the morning, so Evapo Transpiration from each can was negligible.

The source of irrigation water was groundwater which its quality was good (pH: 7.6; EC: 0.66 dS m^{-1}; SAR: 1.08). Rainfall and irrigation during the growing seasons in second year are shown in Figure 1. (Heng *et al.,* 2009)

AquaCrop model

Since the model uses Canopy Ground Cover (CC) instead of LAI, the CC was monitored at the field. The differentiation of ET into Transpiration (Tr) and Evaporation (E) eludes the dissenting effect of the non-productive consumptive use of water (E), which is important especially during incomplete ground cover, and led to the conceptual equation at the core of the AquaCrop growth engine:

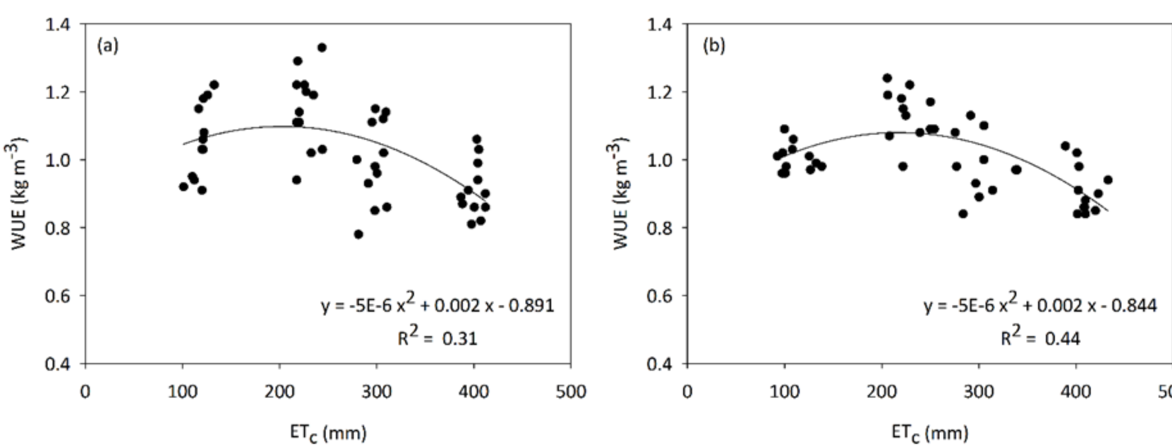

Figure 4. Relationship between observed (a) and simulated (b) ETc and water use efficiency for calibration set

Table 6. Comparison of simulated and observed values of aboveground biomass and grain yield of soybean under various irrigation and nitrogen treatments in two cropping season

Year	Treatment	Final biomass (t ha^{-1})			Grain yield (t ha^{-1})		
		Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
First year	I_1N_1	9.16	8.87	-3.20	4.38	3.94	-10.00
	I_2N_1	7.59	7.08	-6.67	3.22	3.25	1.05
	I_3N_1	6.35	5.72	-9.89	2.65	2.62	-1.01
	I_4N_1	4.12	3.92	-4.77	1.61	1.71	6.19
	I_1N_2	8.48	8.16	-3.77	3.54	3.51	-0.76
	I_2N_2	6.82	6.62	-2.87	2.82	2.99	5.87
	I_3N_2	5.64	5.31	-5.83	2.37	2.43	2.35
	I_4N_2	3.94	3.69	-6.36	1.57	1.62	3.24
	I_1N_3	7.80	8.06	3.40	3.25	3.47	6.57
	I_2N_3	5.94	6.60	10.96	2.59	2.97	14.89
	I_3N_3	4.78	5.26	9.90	2.06	2.40	16.16
	I_4N_3	3.14	3.70	17.93	1.30	1.61	23.88
Second year	I_1N_1	12.40	11.32	-8.71	5.15	4.89	-5.04
	I_2N_1	9.01	8.62	-4.28	3.77	3.66	-2.99
	I_3N_1	5.83	5.63	-3.39	2.45	2.40	-2.20
	I_4N_1	4.45	4.00	-10.05	1.72	1.71	-0.46
	I_1N_2	10.48	9.81	-6.4	4.34	4.24	-2.27
	I_2N_2	7.54	7.83	3.87	3.19	3.37	5.47
	I_3N_2	5.28	5.31	0.58	2.18	2.27	4.02
	I_4N_2	4.42	3.85	-12.71	1.52	1.67	9.88
	I_1N_3	9.48	9.71	2.44	4.02	4.22	4.92
	I_2N_3	7.00	7.68	9.63	2.94	3.34	13.45
	I_3N_3	4.75	5.26	10.59	1.97	2.26	14.77
	I_4N_3	3.27	3.80	16.29	1.19	1.66	39.13

$$B = WP \times \sum Tr \qquad (1)$$

Water Productivity (*WP*) is the biomass per unit of cumulative Transpiration (*Tr*), which inclines to be persistent for a assumed climatic situation (Hanks 1983). By fittingly regularizing for different climatic situations, Water Productivity grows into a conventional parameter (Steduto *et al*., 2007). Computer simulation runs of AquaCrop are implemented with daily time steps, using both schedule days and Growing Degree Days.

Soil data

The soil profile can be composed of up to five different horizons, each with its own physical characteristics. The required soil data are: K_{sat}, volumetric water content at saturation (θ_{sat}), field capacity (θ_{FC}), and permanent wilting point (θ_{PWP}). In AquaCrop, the soil input data were used to simulate water balance (Raes *et al*., 2009).

Canopy parameters

Another key feature of AquaCrop (Steduto *et al*. 2009) is the simulation of green crop CC instead of leaf area. AquaCrop runs by first calculating the crop canopy development from emergence time with the conservative parameters of initial Canopy Cover per seedling (cco), Canopy Growth Coefficient (CGC), and Maximum Canopy Cover (CCx). Water stress is triggered through the soil water content in the root zone, including three stress response functions: canopy growth reduction, stomata closure, and acceleration of canopy senescence.

ETo calculation

The input values of daily weather parameters were Maximum Air Temperature (Tmax), Minimum Air

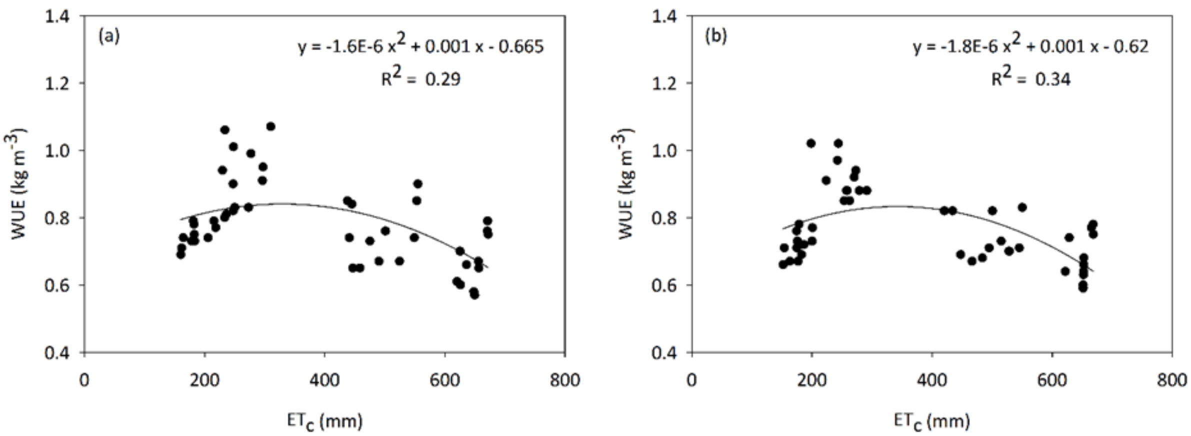

Figure 5. Relationship between observed (a) and simulated (b) ETc and water use efficiency for validation

Temperature (Tmin), Maximum Relative Humidity (RHmax), Minimum Relative Humidity (RHmin), sunshine hours (n/N) and wind speed at a height of two meter (u2) based on the weather station data and ETo Calculator was also used.

The daily soil water balance was calculated during the growing period of soybean. Evapotranspiration was calculated using a simple soil water balance model proposed by Doorenbos and Kassam (1979):

$$ET = I + P - D - R \pm \Delta S \qquad (2)$$

where 'ET' is the Evapotranspiration , 'I' is Irrigation, 'P' is the effective rainfall, 'D' is the drainage water, 'R' is the amount of runoff, and 'ΔS' is the change in the soil moisture content determined by gravimetric method. All terms in this equation are expressed in mm. After irrigation, the excess water from FC was used to simulate D. For the model, since the model simulates soil moisture, the excess water from FC was also used to simulate D. The water balance equation (Equation 2) was used to simulate ET between two irrigations.

Soil moisture sampling was performed by an auger before irrigation to calculate the soil moisture deficit. Moisture content in the 0-100 cm soil profile was measured gravimetrically on the one and two days before and one and two days after irrigation for all treatments. Before the start of the experiment, we took several samples from the field and the results showed that the soil of the experimental field is uniform. After soil sampling, the holes were filled with the same soil of experimental field and the holes were compacted until its soil bulk density reached to the same value of the surrounding soil. Since there was no observed runoff during the experiment and the water bench was 10 m depth, capillary flow to the root zone and runoff flow were assumed to be negligible in the calculation of ET.

RESULTS

Model calibration

Before expending AquaCrop for evolving the reaction to water and fertility disturbance in soybean, the model must be calibrated and validated for the applicable situations. Two years experimental field data collected at the north of Iran were used to calibrate and validate the model. The primarily year information where used for calibration and the second year experimental measure where used for validation. The biomass of fully nitrogen and fully irrigation water requirement were used for calibration. For model correction, the first year experimental measure details were used, while the second year information was employed for model verification.

The calibration was performed through an iterative process using the observed crop growth variables, observed phenological stages parameters simulated from available data and derived growing coefficients.

The calibration was performed until the simulated soil water content matches the observed one. The final phase of calibration consisted in the refinement of other parameters so that simulated values (B and Y) fit well with observed data. Table 3 shows some of the consequences of the parameterization of AquaCrop simulation model for soybean yield. Based on field data, maximum canopy cover were determined and it was 95%. The development of soybean with AquaCrop was modeled based on calendar days and growing degree days.

Model evaluation

The proof of AquaCrop model for faking soybean progress, expansion and profit was shown using independent records sets of the cropping period of the second year. In confirming the model, the experimental soil water content and grain yield with the conforming pretend values under diverse managements were matched. The truthfulness of the fake data was assessed realistically and statistically. Goodness of fit of the simulation consequences of the calibration and the validation were evaluated on the origin of statistic indices including Coefficient of Determination (R^2) and Root Mean Square Error (RMSE).

Soil moisture

AquaCrop provides the set of daily output from each simulation such as soil moisture content, biomass production rate and cumulative biomass. Figure 2 shows the simulated soil moisture content as compared with the measured values for soil layers of 20 cm thick for validation of three treatments of I_1N_1, I_1N_3 and I_4N_1. The simulation results of soil moisture contents were compared with the observed values and the results followed nearly the same trend for all treatments. The model overestimates the soil moisture content at the depths of 0-20, 20-40, 40-60, 60-80 and 80-100 cm for all irrigation treatments of N_1, N_2 and N_3 (Figure 2).

The increase of nitrogen (N_1) for soybean caused the soil moisture content to increase as compared to the N_2 and N_3 treatments but this effect was not significant. At lower soil depths the difference in soil moisture between I_1N_1 and I_1N_3 treatments become less. As the irrigation and nitrogen levels decreased, the forecasting error increased. Soil moisture content decreased from soil surface by increasing soil depth. In case of increasing soil depth, soil moisture content decreased and the forecasting error increased because the model is sensitive to soil moisture deficit.

The lowest and highest RMSE belonged to I_1N_1 and I_4N_3 treatments, respectively. In general, there was a good agreement between observed and simulated soil moisture content. As the irrigation and nitrogen levels decreased, the R^2, d and E indices for relation between simulated and observed SWC also decreased (Table 4). High irrigation treatment improved soil moisture and thus promote the growth and development of soybean, resulting higher yield. As shown in Figure 2, for the water stress treatments, the SWC were overestimated. The results for the validation with field experiment data for second year were similar to the first.

Water balance and ET estimation

As mentioned before, ET was calculated using soil water balance model (Doorenbos and Kassam 1979) and it was 404 and 670.3 mm for I_1N_1 treatment for the first and second year of study, respectively. The actual crop Evapotranspiration was simulated using AquaCrop model and it was 403.2 and 669 mm for I_1N_1 treatment for the first and second years of study, respectively. Errors in soil moisture content estimation had minimal effect on simulated ETa as a major component of the soil water balance (Farahani *et al*., 2009). The runoff was simulated using AquaCrop model and its value was zero. The highest seasonal ET was recorded for the I_1 water treatment while the least seasonal ET was recorded for the I_4 water treatment during all seasons. The drainage values were 4.9 and 26.5 mm for I_1N_1 treatment for the first and second years of study, respectively. The amount of drainage was simulated using AquaCrop model and it was 5.5 and 28 mm for I_1N_1 treatment in the first and second years of study, respectively.

To assess AquaCrop presentation, a linear regression was fixed between the experimental and simulated data of Evapotranspiration (ETc) (Figure 3). The simulated ETc closely corresponded with the observed values for most of the water and fertilizer treatments. The simulated ETc was reduced with decrease in irrigation water depth. Figure 3 shows the comparison between simulated and observed ETc. The amount of ETc for soybean was in the range of 101 to 404 mm and 160.2 to 671.6 mm for calibration and validation, respectively. The results showed the model underestimated ETc for N_1 and N_2 treatments and overestimated for N_3 treatment. The ETc increased as the nitrogen increased.

The simulated values of ETc fit the observed data with good accuracy. The values for validation are summarized in Table 5. There was a good agreement between observed and simulated data with low RMSE. The RMSE for calibration and validation were 14.52 and 23.19, respectively. Generally, the RMSE was low for all treatments. In general, the statistical analysis results showed that the model simulates satisfactorily ETc and soil moisture content for all treatments.

As a summary of the result of the estimations, the simulated grain yield and final biomass of the different irrigation and nitrogen treatments were compared with the observed values. The results showed a deviation of the simulated biomass (0.58% to 17.93%) and grain yield (0.46% to 39.13%) from their corresponding observed data. Figure 4 and Figure 5 show the relationship between ETc and water use efficiency for calibration and validation, respectively. The amounts of irrigation water and ETc decreased with distance from the sprinkler pipeline. The results showed that the effect of irrigation water and nitrogen on ETc was significant ($P < 0.05$). WUE was determined from the ratio of yield to ET. Figure 4 and Figure 5 show that for low irrigation water application, WUE increased and then reached to a maximum value and then started to decrease. The optimization can be made to determine maximum WUE.

DISCUSSION

The results indicated that, the most susceptible agronomic finiteness in AquaCrop model are crop coefficient for transpiration, crop water productivity, time to canopy senescence, HI_0, time to flowering and time to Maximum Canopy Cover (CC_x) (Table 3). Similar results were obtained by Geerts *et al.* (2009). The most sensitive initial conditions parameters in AquaCrop model are PWP and FC. In this study, the model sensitivity decreased with increasing of fertility stress level. The model showed less sensitivity to Initial Soil Water Content (ISWC) and K_{sat} but showed more sensitivity to ET_0. Generally, model productions were highly thoughtful to the depth of irrigation water and were diverse in irrigation treatments so that, the reactivity was declined with reducing of water stress level.

The model overestimates the soil moisture content at all depths for all irrigation treatments of N_1, N_2 and N_3. Farahani *et al*. (2009) found that there was a tendency for the AquaCrop model to consistently overestimate soil water storage in the deficit irrigated plots. At lower soil depths the soil moisture becomes more uniform. The mean RMSE for the first soil moisture layer was 1.22 for the model. While, for the fifth soil layer the mean error was 0.91. Farahani *et al*. (2009) found a tendency to overestimate the surface layer and underestimate in the deeper layers for cotton which the results are consistent with the results of this study. In the deeper layer, soil moisture content was almost uniform.

The I_4 treatment had less soil moisture content because this treatment received less irrigation water. The simulated soil moisture content was nearly close to the observed values in the early days after irrigation (RMSE=0.65%) and thereafter the differences increased (RMSE= 1.04%). Similar results were obtained by

Hsiao *et al*. (2009) for full irrigation and moderate water stress because the discrepancy was cumulative; therefore the overestimation was observed at the end of season.

Under low irrigation and low nitrogen level treatments, error between simulated and observed values was less than 10% except for the I_4N_3 treatment that the error was about 20%. Errors in initializing soil moisture in AquaCrop model tend to cause errors in ETc predictions. Farahani *et al*. (2009) found that AquaCrop simulated ETa within 11% of the observed values for all irrigation levels.

In this study, there was strong relationship between measured and simulated data with low RMSE. The low values of RMSE indicated the good performance of the model. Also, there was strong relationship between the measured and simulated biomass (R^2 > 0.94). Hsiao *et al.* (2009) in their study showed that the RMSE was about two and the Index of Agreement (d) was 0.98 for maize. Andarzian *et al.* (2011) using AquaCrop model under full and deficit irrigated wheat showed that RMSE, index of agreement (d) and R^2 for yield were 0.27 t ha^{-1}, 0.97 and 0.95, respectively. Araya *et al.* (2010) showed that this relationship between the observed and simulated biomass was 0.8. Cabelguenne *et al.* (1999) studied the effect of water and nitrogen stress on biomass and yield of soybean using EPIC model. They showed that the RMSE and R^2 values for biomass were 2.94 and 0.23, respectively. Also, the RMSE and R^2 values for grain yield were 0.65 and 0.47, respectively.

Water stress and nitrogen stress is the most important limitation of the AquaCrop model. Farahani *et al*. (2009) investigated AquaCrop model for cotton under full and deficit irrigation regimes. They showed that yield predictions were within 10% of the observed values in the 40 and 100% irrigation treatment and the highest error in yield was observed in the 80% irrigation treatments (Table 6). Generally, the grain yield was better simulated by the model when compared with the biomass.

In this study the amount of irrigation water to achieve optimum WUE was equal to 200 and 275 mm for the first and second year of study, respectively. As the irrigation water application increases beyond the optimum amount, the yield might increase but the value of WUE will decrease. Soil moisture storage has significant effect on producing crop yield under deficit irrigation, especially in arid and semi- arid regions. In this research, AquaCrop model accurately simulated soil water content and crop's water requirements under different deficit irrigation. Based on the results of this study, this model can be employed in regions with water limitation in order to evaluate and optimize the best possible management options and to achieve higher yield.

CONCLUSION

This study was performed to simulate soil moisture, ETc and water use efficiency for soybean using AquaCrop model under a range of nitrogen fertilizer and irrigation water application. The evaluation of the AquaCrop model illustrated that the model was able to simulate soil water content and ETc accurately. It was concluded that with less input parameters and less complex calibration procedures, AquaCrop model can be applied for simulating and evaluating the effect of nitrogen and water management on ETc, yield and water use efficiency of soybean. The results indicated that the WUE was strongly influenced by irrigation and nitrogen fertilizer strategies. Using simulation model to predict soybean yield under different water stress conditions could be very helpful for researchers, field engineers and water managers to evaluate and interpret variable responses due to management factors. Irrigation and nitrogen fertilizer management improves water use efficiency, and thus reduces the impact of water limitation.

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