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Evaluation of the AquaCrop Model in the simulation of the simultaneous effect of different water regimes and salinity on soybean's productivity and yield in the North of Iran

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ABSTRACT

Objective: This study investigates the feasibility of integration using Caspian Sea water and different fresh groundwater levels for soybean irrigation and performance evaluation of the Aqua Crop model at the Gorgan University of Agricultural Science and Natural Resources research field in the Golestan Province, northern Iran

Material and Methods: Irrigation applications comprised irrigation at 75% of field capacity (FC) (I1), 100 % FC (I2), and over irrigation at 125% FC (I3). Experiments were conducted during two consecutive seasons. It was done by grain yield (GY), biomass yield (BY), and water productivity (WP) under varying irrigation depths and saline water regimes. Model efficiency (E), coefficient of determination (R2), Root Mean Square error (RMSE), and Mean Absolute Error (MAE) were used to evaluate the model performance.

Results and Discussion: The calibration results for (GY) and (BY) were in line with observed data, with the estimation error statistics $0.97<E<0.99$, $0.11<RMSE<1.51$, $0.92<R2<0.96$, and $0.33<MAE<1.02$ t ha-1. The model prediction error in simulating the soybean WP varied from 2.35% to 27.5% for all treatments. Therefore, the AquaCrop model accurately estimated soybean yield under different saline water and irrigation levels.

Conclusions: According to the results of this study, Caspian Sea water can be considered an alternative irrigation water resource in combination with fresh groundwater for soybean crop irrigation at a ratio of 14 percent in the dry years.

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1. Introduction

Declining availability of fresh water because of climate change and recent years' drought is a worldwide problem, which has convinced humans to use deficit irrigation strategy and new water alternatives such as secondary quality water resources, especially saline water for agricultural consumption (Wallace, 2000). Low-quality waters are recycled and reused for irrigation in many areas of the globe. When using saline water for field irrigation, factors such as plant tolerance, irrigation system, and field irrigation management techniques, irrigation intervals, and soil properties must be considered (Fasakhodi et al., 2010). On the other hand, as a result of the reduction in the world's fresh water resources, so farmers have to use saline water or waste waters. Water scarcity originates from the physical limitations of water resources and their inefficient use and poor management (Abedinpour et al, 2012). Judicious management is essential to enhancing crop water productivity (WP). Hence, search for sustainable methods to increase (WP) is an important goal in arid and semi-arid regions (Debaeke and Aboudrare, 2004), such as Iran's East North provinces. Using crop models could be helpful in achieving this goal. Current crop models are developed to simulate the crop growth (GY)[1], (BY)[2] and (WP)[3] using some parameters, including water, radiation, and energy. Crop models have been extended for estimating the complex effects of soil, water, nutrients, salinity, carbon *dioxide*, and solar radiation on (GY), (BY), and (WP) of different crops (Azam et al., 1994). Simulation models are designed to indicate the system behavior. For time-variant systems, the time step of operating the corresponding simulation model should match the real lifetime intervals during which there is a measurable and meaningful variation in the causative factors that determine the output. The short simulation time-step demands that a wide number of input values (viz., climate, soil, and crop parameters) be used for the model to run. Generally, these models suggest the possibility of specifying management options, and they can be used to study a wide range of management scenarios at low costs (Kumar and Ahlawat, 2004). The Aqua Crop model, as a water-driven crop growth model, assumes a linear relationship exists between biomass yield and crop transpiration through a (WP) value (Tanner and Sinclair, 1983; Steduto and Albrizio, 2005). This approach avoids subdivision into different hierarchical levels, which results in a less complex structure and *reduces the* amount of input data (Steduto et al., 2009). A major merit of the water-driven module over radiation-driven is the opportunity to normalize the WP parameter for the evaporative demand and the atmospheric CO2 concentration in the former, which, therefore, has a greater scripting in different areas under varying space-time settings (Steduto and Albrizio, 2005; Steduto et al., 2007). Compared to other crop models, this model requires minimal input data. Its new version 4.0 (June, 2012) has a salinity module used in this research to simulate the GY and WP of soybean under deficit and saline water irrigation. Hsiao et al. (2009) stated the capability of AquaCrop to simulate the biomass development, grain yield, and Canopy cover (CC) of maize cultivars over six different crop years that differed in planting date and plant density. Araya et al. (2010) reported good model efficiency varying from 0.5 to 0.95 for simulating biomass and yield of irrigated barley under water-deficient conditions in northern Ethiopia. Evaluation of the AquaCrop model under rain-fed and supplemental irrigated sugar beet in Serbia by Stricevic et al. (2011) showed that the maximum prediction error for maize was 3.6% and for sugar beet was 12.2%. Mkhabala and Bullock (2012) validated the AquaCrop model (v3.0) and simulated the yield of spring wheat and soil water content in Western Canada (Canadian Prairies). They reported only 3% difference between actual and predicted GY, while the difference between observed and simulated soil moisture was 2%. Andarzian et al. (2011) simulate wheat growth under irrigation depths in south Iran with the AquaCrop model.

[1] . Grain yield (GY)
[2] . Biomass yield (BY)
[3] . Water productivity (WP)

Their results showed that the model estimations of soil water content at the root zone, BY and GY, were in line with actual data, with (NRMSE) less than 10%. Simulations of GY and WP of wheat crop under deficit irrigation levels in central Iran were done by Salemi et al. (2011) after AquaCrop model evaluation. They reported that the E varied between 0.93 and 0.99 for WP. Many researchers (Heng et al., 2009; Iqbal et al., 2010; Abedinpour et al., 2012; Araya et al., 2010; Stricevic et al., 2011; Hsiao et al., 2009; Hussein et al., 2011) used the AquaCrop model to simulate different crop growth under varying agro-climatic conditions. Evett and Tolk (2009), after performance evaluation of different crop models (AquaCrop, CERESMaize, CropSyst, DSSAT 4.0, and WOFOST in simulating) for water use efficiency (WUE) in some crops (cotton, maize, sunflower, soybean, dry bean, and peanut etc), revealed that the WUE was primarily governed by the evaporation (E) and transpiration (T) components of crop evapotranspiration. It was suggested that the WUE simulation should include E or T measurements to study the effects of conservation agriculture technologies that reduce E. By comparing the performance of AquaCrop (as a water-driven model) and CropSyst and WOFOST (as carbon-driven models) for sunflower using deficit irrigation methods in Southern Italy, Todorovic et al. (2009), suggested that the simpler model AquaCrop using limited input information should be preferred due to its minimal input data and prediction accuracy about crop yield and WUE. Some researchers also used AquaCrop for other crops such as wheat and maize and reported good performance of the model to predict water content and grain yield (Khorsand et al., 2014; Ziaii et al., 2014). About 12% of surface waters and some of the alluvial underground water of Iran are saline, so the role of saline and brackish (semi-saline) water in the future would be undeniable (Khorsandi et al, 2010). Also, one of the most important agricultural productions in Golestan province is soybean, which provides more than 50 percent of total soybean production in Iran (the first soybean producer in Iran's provinces). Furthermore, the AquaCrop model has not been tested further to simulate soybean yield under saline conditions in the semi-arid climate region of Golestan province. Therefore, the objectives of this study were: a) to calibrate and validate the AquaCrop model ver. 4.0 under different irrigation water depths and salinity levels, b) to evaluate the model performance in estimating GY, BY, and WP for soybean under varying depths of irrigation and salinity levels, and the possibility of applying Caspian Sea water as an alternative water resource for irrigation, due to the water scarcity condition.

2. Materials and Methods

2.1. Site description

The experimental area was in the research farm of Gorgan Agricultural Science and Natural Resource University, during the summer season of 2013 and 2014. The experimental farm was located between 54° 27′ 06″ E longitude and 36° 58′ 25″ N latitude at an average elevation of 13 m above sea level (Figure 1). Weather parameters were collected from the Hashem Abad synoptic weather station located near the experimental site. Reference evapotranspiration (ETO), temperature, and rainfall are presented in Figures 2 and 3 for 2013 and 2014, respectively.

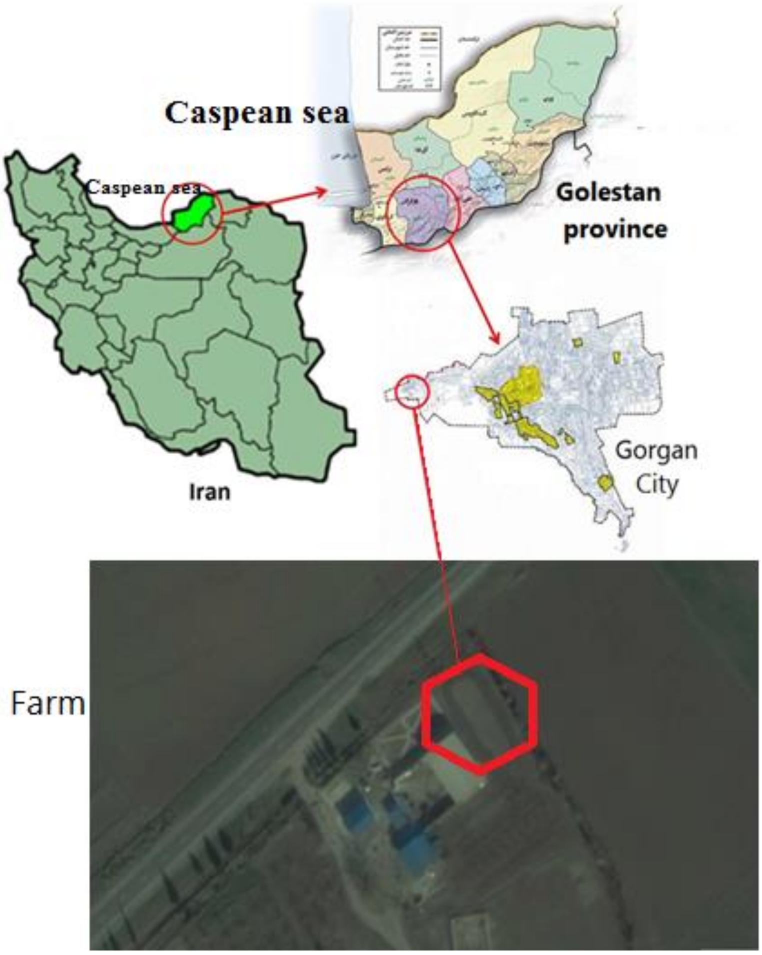
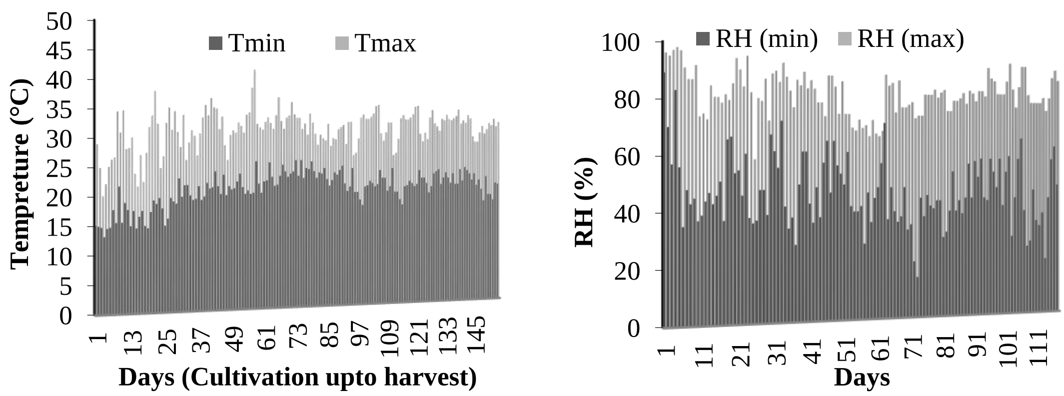


Figure 1- Location of field experiment site at Gorgan Agricultural Sciences and Natural Resources University in North of Iran.



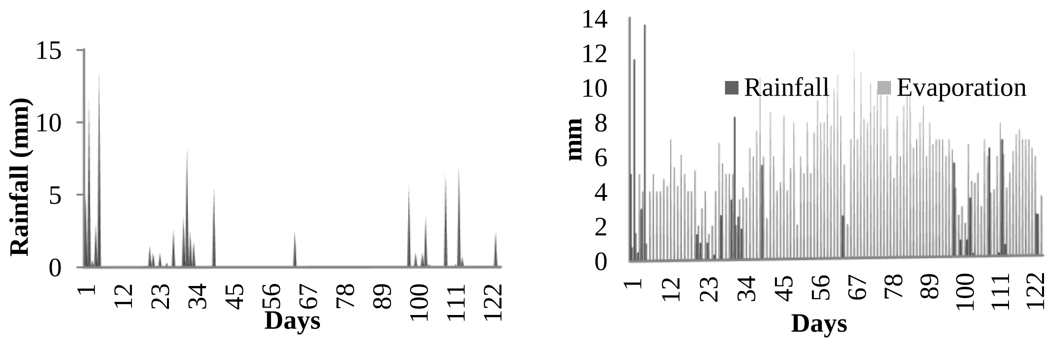


Figure 2- Weather parameters during the crop growth period during 2013

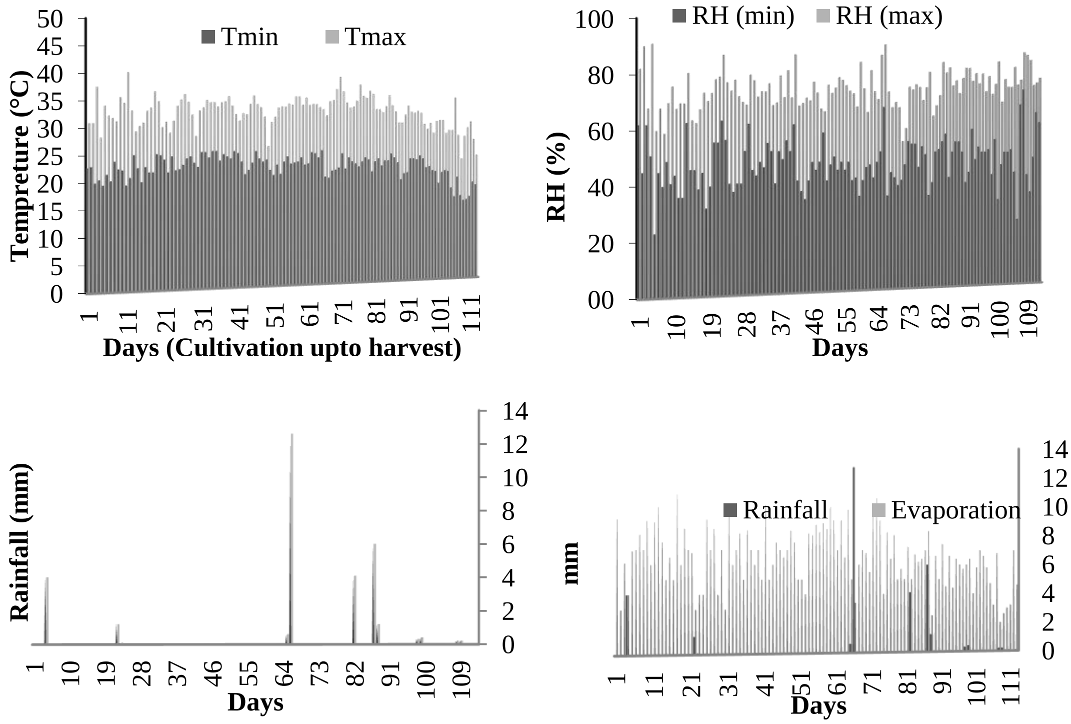


Figure 3- Weather parameters during the crop growth period during 2014

2.2. Field managements

The experiment was laid out in a split-plot design (SPD) over a randomized complete block design (RCBD), which included three irrigation depth treatments (viz. 75 % (I1), 100% (I2), 125% percent of crop water requirement (I3)) and three irrigation water salinity level treatments (viz. Control (farm's well water) (S1), 5 (S2); and 8 dS m-1 (S3). All treatments have 3 replications and a total of 27 square plots with 9 m2 area were in this study. Soybean (Williams variety) seeds were sown on 5th May during the spring season, the spacing between plants in each row was 35-40 cm, and the spacing between rows was 7 cm. Also, the distance between plots was around 1 m. The soil's physical and chemical characteristics are shown in Table 1.

Table 1- Soil physical and chemical characteristics

		Soil Depth (Cm)		
		0-30	30-60	60-90
Physical	Clay (%)	36	35	34
	Sand (%)	6	5	5
	Silt (%)	58	60	59
	Soil Texture	Si.C.L	Si.C.L	Si.C.L
	FC (cm^3 cm^{-3})	44	44.5	45.2
	Bd (gm/cm-3)	1.35	1.33	1.32
	PWP (cm^3 cm^{-3})	23	23.2	23.4
	θs (cm^3 cm^{-3})	55.3	55	55.2
Chemical	EC (ds/m)	1.86	1.86	1.24
	pH	7.9	7.9	7.8
	OM (%)	1.3	1.4	1.6
	N (ppm)	155	168	174
	P (ppm)	9.5	10	10.2
	K (ppm)	200	205	208

θs: Saturated water content, Bd: Bulk Density, FC: Field Capacity, PWP: Permanent Wilting Point, EC: Electrical Conductivity, OM: Organic Matter, Si.C.L: Silty clay loam

The Caspian Sea water (ECw: 26.5 dS m-1) mixed with an appropriate proportion (around 14 and 28 percent respectively) with tube well water (ECw: 0.86 dS m-1) to prepare the water of desired salinity (5 and 8 dS m-1). The properties of groundwater and seawater are presented in Table 2.

Table 2- Chemical properties of tube well water (Control) and source of saline water (Caspian Sea water)

Water	EC (dS/m)	pH	SAR	Na^+	Ca^{2+}	Mg^{2+}	K^+	$SO4^{+2}$	HCO3	Cl^-
				meq/l						
Well	0.86	7	0.14	0.27	4.4	2.8	0.48	0.7	7	1
Sea	26.6	8	36	237.9	25.2	61.71	8.21	24.5	31.5	221

Table 3- Soybean parameters for non-stressed well-managed crops (FAO 56) in sub-humid climates.

Crop stage	Crop growth stages				Crop growth (Days)	Planting date	Height of crop (m)
	Initial	Develop	Mild	Late			
Days	20	25	75	30	150	May	
KC	0.5	0.8	1.15	0.5			1

The control plots were irrigated using groundwater 0.86 dS m-1 during the experiment period. The measured quantity of irrigation water based on soil moisture content was directly applied to the plots using a flow meter. The P fertilizer and one split of nitrogen fertilizer were applied before sowing, and the second split of nitrogen fertilizer was applied at the mid-stage of soybean growth. The yield was measured at the late crop growth stage by selecting 50 plants in the middle points of each plot. After harvesting, the plants were air-dried, and the grains were separated from the soybean pod. Further, the grain weight was measured for each plot, and the yield per ha was estimated.

2.3. Irrigation Scheduling and Salinity Implementation

Soil water content of 0-100 cm profiles of the crop root zone was determined periodically for irrigation scheduling, i.e., deciding the date and quantity of irrigation water. The plots were irrigated when the soil moisture of the root zone reached 50% of the water holding capacity (WHC), (half the soil moisture between the (FC) and (PWP) to be depleted). Depth of irrigation for treatments was calculated according to the soil water content before irrigation and soybean root depth using Eq. (1).

$$SMD = (\theta_{FC} - \theta_i) \times D_{rz} \times B_d \times f \qquad (1)$$

Where, SMD: Soil moisture deficit (mm), θFC: Soil moisture at FC, θi: Soil moisture before irrigation (weight basis in %), Drz: Depth of root zone (mm), Bd: Bulk density of the given soil layer (g cm-3), and f: irrigation treatment coefficient. The soil moisture allowed depletion (MAD) of 50% was determined as the initial condition in the model, and a similar condition was practiced in the plots using SMD-based irrigation planning. Hence, the irrigation information was used as input to the model by determining the date and depth of irrigation.

The irrigation treatment coefficient of each treatment f (I1) = 0.75, f (I2) =1(without any deficit), and f(I3)= 1.25, was used to estimate the quantity of water. The soybean salinity threshold (ECt) is about 5 ds/m. So, we selected 3 salinity ranges (S1, S2 and S3). First salinity treatment was selected as a control or freshwater, the second salinity treatment was selected 5 ds/m in the range of threshold for soybean, and the third treatment was selected 8 ds/m more than the threshold. Overall, in both water and salinity treatments, we selected less, equal, and more than the soybean water requirement and salinity threshold. The height and canopy of the crop were measured at some stages of the crop season.

2.4. Model description

AquaCrop is designed to be widely applicable under different climate and soil conditions, without the need for local calibration, once it has been properly parameterized for a particular crop species. To this end, the model is constructed with parameters falling into two groups. One group is considered conservative, in that the parameters should remain basically constant under different growing conditions and water regimes. The other group encompasses parameters that are dependent on location, crop cultivar, and management practices, and must be specified by the user. A critical stipulation for many of the conservative parameters is that their values are based on data obtained from modern high-yielding cultivars grown with optimal soil fertility without limitation by any mineral nutrient, particularly nitrogen. With some notable exceptions, it is also stipulated that values are based on data obtained when water is not limiting. It follows that, if the conservative parameters already calibrated for a given crop do not provide simulated results that match measured data for a crop in a particular case, the first thing to check is that mineral nutrients are not limiting the growth of the crop. To keep the model relatively simple, AquaCrop does not simulate nutrient cycles and nutritional effects on the crop directly. Instead, a way is provided in the 'Biomass' tab sheet to account for nutritional effects after calibration based on the reduction of biomass produced by a nutrient-deficient treatment.

2.5. Calibration of the AquaCrop model

In this study, the AquaCrop model was evaluated through calibration to estimate yield, biomass, and water productivity under different irrigation amounts and salinity levels. Calibration of the AquaCrop model was accomplished by using the observed values from the field experiment during 2013 as model input and then simulating the output parameters containing the yield, biomass, and water productivity. Subsequently, the predicted output values were compared with the observed yield, biomass, and water productivity. The difference between the predicted and observed data was minimized by using a trial-and-error approach in which one specific input variable was chosen as the reference variable at a time and adjusting only those parameters that were known to influence the reference variable the most. The procedure was repeated to arrive at the closest match between the simulated and observed value for each treatment combination (Table 4).

Table 4- Calibrated values of AquaCrop model input parameters for different irrigation depths under varying salinity levels

Parameters	Treatment	Calibrated values	Unit
Water productivity (WP*)	I1S2	15	gr/m3
Reference harvest index (HI0)		65	%
Max. crop canopy (CCX)		68	%
Water productivity (WP*)	I1S3	15	gr/m3
Reference harvest index (HI0)		64	%
Max. crop canopy (CCX)		60	%
Water productivity (WP*)	I2S2	19	gr/m3
Reference harvest index (HI0)		63	%
Max. crop canopy (CCX)		69	%
Water productivity (WP*)	I2S3	16	gr/m3
Reference harvest index (HI0)		57	%
Max. crop canopy (CCX)		57	%
Water productivity (WP*)	I3S2	15	gr/m3
Reference harvest index (HI0)		70	%
Max. crop canopy (CCX)		65	%
Water productivity (WP*)	I3S3	15	gr/m3
Reference harvest index (HI0)		70	%
Max. crop canopy (CCX)		60	%

2.6. Field management calibration

Furrow irrigation was applied to different treatments based on soil moisture deficit criteria. The soil moisture allowed depletion (MAD) of 50% was determined as the initial condition in the model, and a similar condition was practiced in the plots using SMD-based irrigation planning. Hence, the irrigation information was used as input to the model by determining the date and depth of irrigation.

Irrigation water was applied through three depths of 176, 220, and 268 mm in irrigation levels of 75, 100 and 125 %, respectively. Effective rainfall was 38.75 mm during crop growth in 2013. Irrigation water was applied through five depths of 187, 250, and 312 mm in irrigation levels of 75, 100 and 125 %, respectively. Effective rainfall was 38.8 mm during crop growth in 2014.

2.7. Validation of the Aqua Crop model

The Aqua Crop model was validated using data from 2014 to estimate GY and BY under different irrigation levels and saline water. In other words, the calibrated AquaCrop model was simulated with the input data of the experiment during the year 2014 to estimate the GY, BY and WP. Further, these estimated data were compared with the actual data of the field experiment and the model validation performance statistics were analyzed.

2.8. Model evaluation criterion

The model simulation results of soybean GY, BY, and WP were compared with the actual data from the field experiment during both calibration and validation processes. The goodness of fit between the simulated and actual data was confirmed by using the prediction error statistics. The coefficient of determination (R2), prediction error (Pe), mean absolute error (MAE), root mean square error (RMSE), and model efficiency (E) were applied as the model evaluation for the calibration and validation process. The R2 and E were applied to achieve the predictive power of the model, while the Pe, MAE, and RMSE indicated the error in model estimation. The model output in terms of estimation for canopy cover, grain yield, and above-ground biomass during harvest was considered for the evaluation of the model. The following statistical indicators were applied to compare the observed and simulated data. Model performance was evaluated using the following statistical parameters, such as (E) (Nash and Sutcliffe, 1970), given by:

$$P_e = \frac{(P_i - O_i)}{O_i} \quad (2)$$

$$\mathrm{E} = 1 - \frac{\sum_{i=1}^{N}(\mathrm{Oi}-\mathrm{Si})^2}{\sum_{i=1}^{N}(\mathrm{Oi}-\bar{\mathrm{O}})^2} \quad (3)$$

Where:

Si and Oi are predicted and actual (observed) data, Ōi is the mean value of Oi, and N is the number of observations.

$$RMSE = \sqrt{1/(\mathrm{N}) \sum_{i=1}^{N}(\mathrm{Oi}-\mathrm{Si})}^{\,2} \quad (4)$$

$$MAE = \sqrt{\sum_{i=1}^{n}(\mathrm{Pi}-\mathrm{Oi})/\mathrm{n}} \quad (5)$$

Model efficiency (E) and R2 approaching one, and Pe, MAE, and RMSE close to zero were indicators for better model performance.

3. Results and discussion

Irrigation water depth, crop water use, grain yield, above Aerial biomass (WP), and irrigation water use efficiency (IWUE) under different irrigation levels (75, 100 and 125 percent) for 2013 and 2014 experiments are shown in Table 5. It was observed that during 2 years of experiment, the lowest grain yields and biomass were observed to be 2.03 and 2.63 ton ha−1 in I3S3 treatment (2014), and the highest was 8.14 and 13.4 ton ha−1under I2S1 treatment (2014), respectively. Water productivity (WP) ranged from a minimum of 6.06 kg ha−1mm−1to a maximum of 29.82 kg ha−1mm−1 in 2013 and 2014. Water productivity for full irrigation with no salinity (I2S1) was the highest (29.82 percent), whereas this parameter for I3S3 treatment was the lowest (6.06 percent). The irrigation water use efficiency (IWUE) ranged from a minimum of 13.69 kg ha−1mm−1 (I3S3) to a maximum of 31.99 kg ha−1mm−1 (I1S1) in 2013. However, in 2014, the irrigation water use efficiency ranged from a minimum of 6.51 kg ha−1mm−1 to a maximum of 32.56 kg ha−1mm−1 obtained for I3S3 and I2S1 treatment, respectively. These results were the average of three replications of the experiments conducted during 2013and 2014.

Table 5- Irrigation water depths, crop water use, grain yield, above ground biomass, water productivity (WP), irrigation water use efficiency (IWUE), and harvest index (HI) under different irrigation levels and salinity during 2013 and 2014

Parameters		**Irrigation water**	**Crop water use**	**Grain yield**	**Biomass**	**Wp**	**IWUE**
		(mm)	(mm)	ton ha^{-1}	ton ha^{-1}	kg $ha^{-1}mm^{-1}$	kg $ha^{-1}mm^{-1}$
Irrigation level 75%(I1)							
	S1	176	214.75	5.63	6.96	26.22	31.99
2013	S2	176	214.75	4.19	5.69	19.51	23.81
	S3	176	214.75	3.45	3.78	16.07	19.60
	S1	187	210	6.01	7.87	28.62	32.14
2014	S2	187	210	3.84	4.57	18.29	20.53
	S3	187	210	3.25	3.71	15.48	17.38
Irrigation level 100%(I2)							
	S1	220	258.75	6.9	10.27	26.67	31.36
2013	S2	220	258.75	5.4	9.9	20.87	24.55
	S3	220	258.75	4.45	7.03	17.20	20.23
	S1	250	273	8.14	13.4	29.82	32.56
2014	S2	250	273	6.82	11.15	24.98	27.28
	S3	250	273	6.15	10.02	22.53	24.60
Irrigation level 125%(I3)							
	S1	268	306.75	5.79	6.78	18.88	21.60
2013	S2	268	306.75	4.27	4.58	13.92	15.93
	S3	268	306.75	3.67	4/.7	11.96	13.69
	S1	312	335	6.07	7.13	18.12	19.46
2014	S2	312	335	4.47	5.01	13.34	14.33
	S3	312	335	2.03	2.63	6.06	6.51

The results of grain yield showed that there were significant variations in soybean grain yield at 0.01 and probability levels of significance (P) amongst different irrigation and saline water treatments during 2013. Analysis of variations and comparison of means for main effects and their interaction in 2013 and 2014 is shown in Table 6. It was found from Table 6 that the variations in yield due to different irrigation treatments were significant at a 0.01 probability level. However, the effect of salinity on GY and BY variation was significant at a 0.01 probability level in 2013.

Table 6 -Analysis of variance for yield, ground biomass, and 1000 grain weight in 2013, 2014

Source	df	Year	Mean Square		
			Yield (Kg ha^{-1})	Biomass (Kg ha^{-1})	1000 grain weight (gr)
Irrigation (I)	2	2013	28.08**	542.94**	225.83**
		2014	6.57*	0.78**	1345.44**
Salinity (S)	2	2013	91.24**	486.94**	490.67**
		2014	34.62**	0.23**	4845.14**
I*S	4	2013	0.08 NS	11.18NS	40.93**
		2014	16.29**	0.0045 NS	61.2**
Error (N)	18	2013	1.48NS	4.68NS	6.26NS
		2014	1.59 NS	0.024 NS	52.26NS
CV (%)		2013	1.25	2.15	2.54
		2014	1.35	2.08	3.35

3.1. Grain Yield and biomass

Irrigation treatment results in 2013 and 2014 for GY and BY variations under different irrigation and saline water levels are presented in Figures 4 and 5. It was observed that the maximum grain yield was obtained at full irrigation with non-saline water treatment (I2S1) 6.9 ton ha-1 (2013) and 8.14 ton ha-1 (2014), and also the minimum grain yield was obtained 3.45 ton ha-1 and 2.10 ton ha-1 for I1S3 treatment (2013) and treatment I3S3 around (2014), respectively. The soybean biomass (above-ground parts of the soybean) was measured and taken from each experimental plot. Irrigation treatments also affected the biomass yields under varying salinity levels, as shown in Figures 4 and 5. The maximum biomass was measured at full irrigation and non-saline water as control treatment I2S1 (10.27 and 13.38 ton ha-1 in 2013 and 2014, respectively), and the minimum biomass was observed 3.78 (I1 S3) and 2.63ton ha-1(I3S3) in 2013 and 2014, respectively.

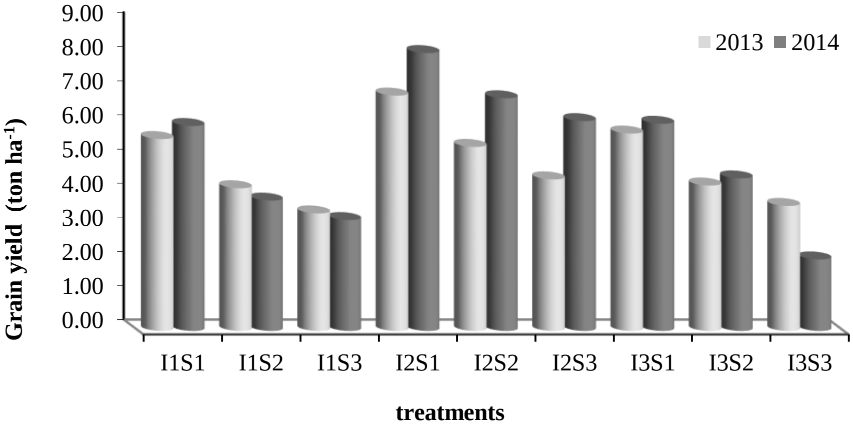


Figure 4- Effect of irrigation depths and saline water levels on grain yield in 2013, 2014

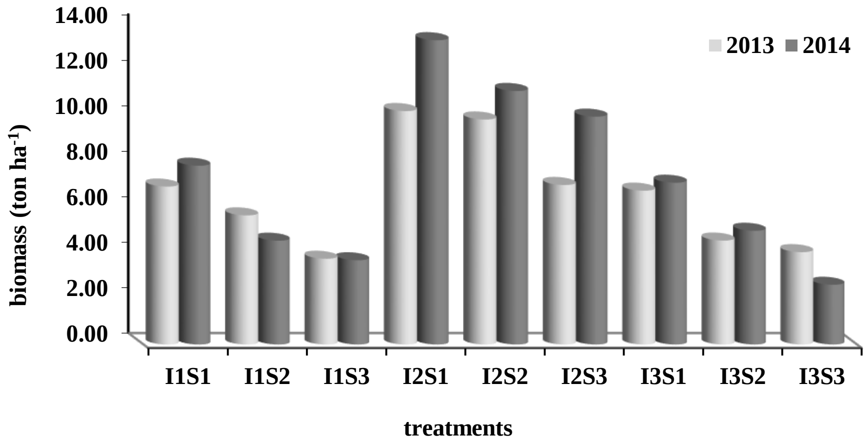


Figure 5- Effect of irrigation depths and saline water levels on biomass in 2013, 2014

3.2. AquaCrop model calibration performance

The AquaCrop model was calibrated using field experiment data to estimate GY and BY under different water and saline water application levels. It was found that the highest and lowest errors in grain yield estimation were in I3S3 (2014) and I3S1 (2014) treatments, amounting to 24.63% and 1.81 %, respectively (Table 7). The prediction error in biomass for I3S3 (2014) and I2S1 treatments was 35.36 and 1.42 (in absolute) %, respectively (Table 7). The best grain yield simulation of the AquaCrop model was obtained in 2014 with average prediction error ranging from a minimum of 5.05, 7.67, and 10.31 % for the 75, 100, and 125% of FC irrigation treatment, respectively, for all salinity levels, while this prediction error in 2013 was 7.36, 11.88, and 14.29 %. Moreover, for biomass simulation, the minimum of average prediction error 9 % was computed in I2(100% FC) and 15.44% and 18.88 % in 75% FC treatment (I1) and 125% treatment (I3), respectively, at all salinity levels in 2013.

Table 7- Calibration result of grain yield and biomass of soybean under different irrigation depths and saline water regimes

	Treatment	Observed data		Simulated data		Model predicted error for grain yield (%)	Model predicted error for biomass (%)
		Grain yield (ton ha^{-1})	Biomass (ton ha^{-1})	Grain yield (ton ha^{-1})	Biomass (ton ha^{-1})		
2013	I1S1	5.63	6.96	5.94	7.43	5.51	6.75
2014	I1S1	6.01	7.87	6.26	8.26	4.16	4.96
2013	I1S2	4.19	5.7	4.52	6.19	7.88	8.60
2014	I1S2	3.83	4.57	4.18	5.57	9.14	21.88
2013	I1S3	3.45	3.78	3.75	4.22	8.70	11.64
2014	I1S3	3.25	3.71	3.31	4.88	1.85	31.54
2013	I2S1	6.9	10.27	7.58	12.8	9.86	24.63
2014	I2S1	8.14	13.4	8.35	13.21	2.58	-1.42
2013	I2S2	5.4	9.9	6.1	10.71	12.96	8.18
2014	I2S2	6.82	11.15	7.56	11.94	10.85	7.09
2013	I2S3	4.45	7.03	5.02	7.98	12.81	13.51
2014	I2S3	6.15	10.02	6.74	10.63	9.59	6.09
2013	I3S1	5.79	6.78	6.31	7.32	8.98	7.96
2014	I3S1	6.07	7.13	6.18	8.4	1.81	17.81
2013	I3S2	4.27	4.58	4.74	5.38	11.01	17.47
2014	I3S2	4.47	5.01	4.67	6.47	4.47	29.14
2013	I3S3	3.67	4.07	4.51	5.34	22.89	31.20
2014	I3S3	2.03	2.63	2.53	3.56	24.63	35.36

Also, the graphs of the model-calibrated and observed values for all treatment combinations pertaining to grain yield are presented in the Figures. 6 and for biomass are shown in Figure 7, respectively.

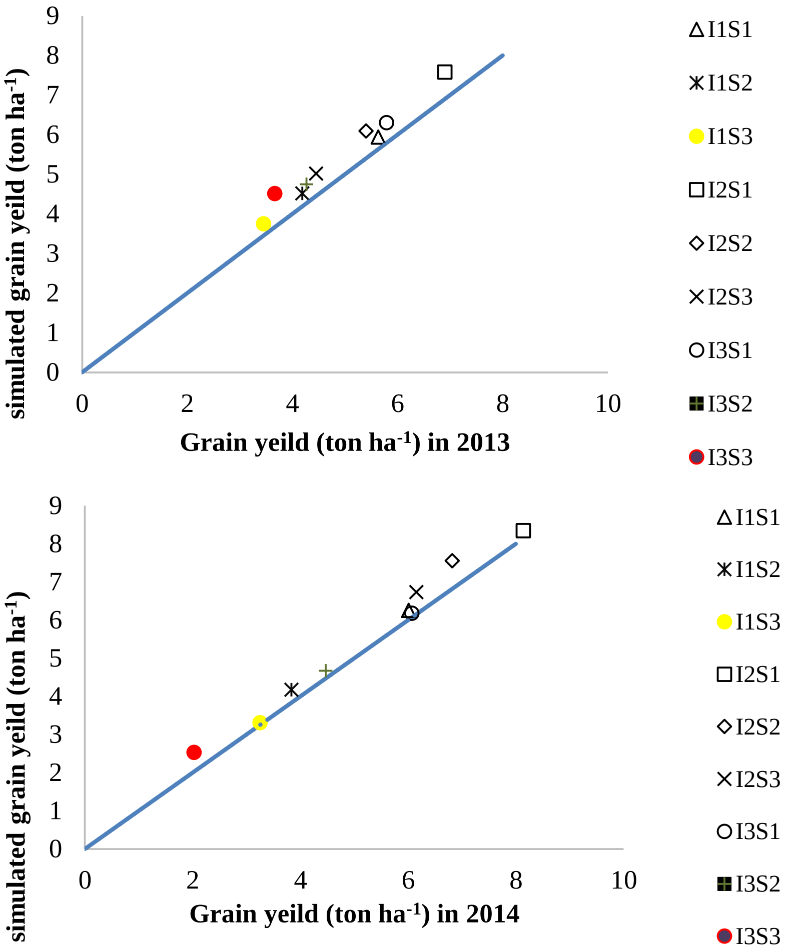
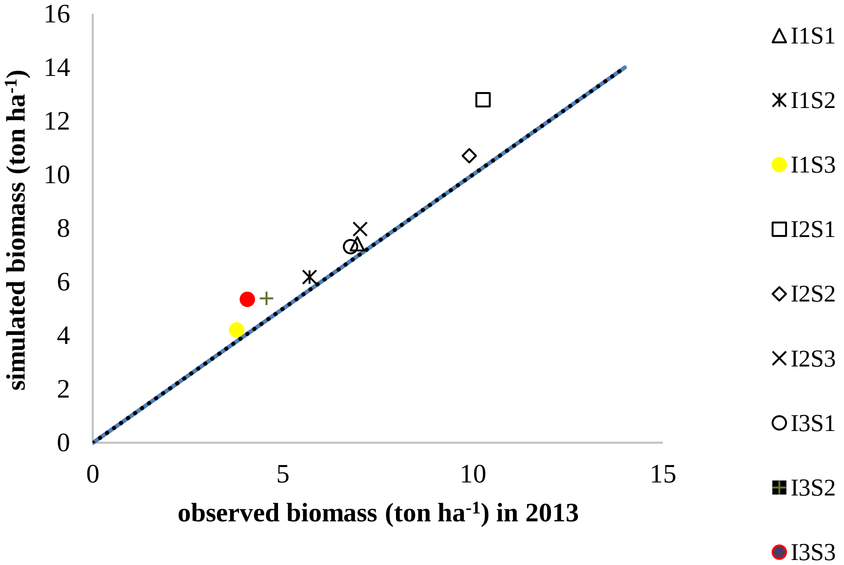


Figure 6- Model calibration results for grain yield under all treatments in 2013 and 2014



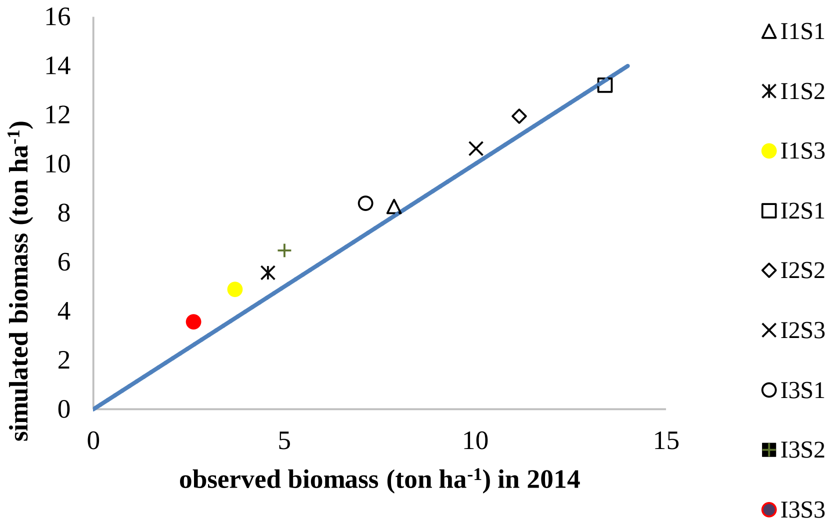


Figure 7- Model calibration results for biomass under all treatments in 2013 and 2014

Also, the results of AquaCrop calibration for biomass, grain yield, and WP for different treatments is shown in table 8 for 2013. It is represented that the minimum and maximum prediction error (Pe %) of GY was 5.51 and 22.89 % for I1S1 and I3S3 treatment, respectively. The minimum and maximum of Pe for biomass and WP also occurred in similar treatments. So it can be concluded that the error of simulation is increased in the salinity condition (I3S3 treatment) and also the salinity effect on prediction error is more than only the water stress condition (I1S1 treatment). It is known that water use efficiency (WP) decreased with increasing salinity stress, so the minimum and maximum values of WP were obtained in I3S3 and I2S1 treatment, respectively. These results are in agreement with the results of Rostamihir et al (2024).

Table 8- Calibration results of biomass, grain yield, and Wp of soybean under different irrigation water and salinity treatment using 2013 data

Treatment	Grain yield (ton ha^{-1})		Pe	Biomass(ton ha^{-1})		Pe	Wp kg ha^{-1}mm^{-1}		Pe
	Observed	Simulated	(%)	Observed	Simulated	(%)	Observed	Simulated	(%)
I1S1	5.63	5.94	5.51	6.96	7.43	6.75	26.22	27.66	5.51
I1S2	4.19	4.52	7.88	5.7	6.19	8.60	19.51	21.05	7.88
I1S3	3.45	3.75	8.70	3.78	4.22	11.64	16.07	17.46	8.70
I2S1	6.9	7.58	9.86	10.27	12.8	24.63	26.67	29.29	9.86
I2S2	5.4	6.1	12.96	9.9	10.71	8.18	20.87	23.57	12.96
I2S3	4.45	5.02	12.81	7.03	7.98	13.51	17.20	19.40	12.81
I3S1	5.79	6.31	8.98	6.78	7.32	7.96	18.88	20.57	8.98
I3S2	4.27	4.74	11.01	4.58	5.38	17.47	13.92	15.45	11.01
I3S3	3.67	4.51	22.89	4.07	5.34	31.20	11.96	14.70	22.89

Pe: percent error rate between measured and simulation data

AquaCrop model estimations for GY and BY were in line with the actual data, corroborated by E and R2 values around. The observed and simulated data of GY for all treatment combinations are shown in Table 9. It was observed from Table 9 that the model was calibrated for simulation of GY and BY for all treatment levels with the prediction error statistics 0.73<E<0.75, 0.55<RMSE<1.11, 0.52<MAE<0.92ton ha-1, and 0.957<R2<0.969. This result is also shown for Wp (kg ha-1mm-1) equal to 2.06, 0.81, 1.98, and 0.987, respectively.

Table 9-Prediction error statistics in calibration Aquacrop model with 2013 data

Model output parameters	Mean		RMSE	E	MAE	R^2
	Observed	Simulated				
Grain yield (ton ha^{-1})	4.86	5.39	0.55	0.73	0.52	0.9697
Biomass (ton ha^{-1})	6.56	7.49	1.11	0.75	0.92	0.9575
Wp (kg $ha^{-1}mm^{-1}$)	19.03	21.02	2.06	0.81	1.98	0.987

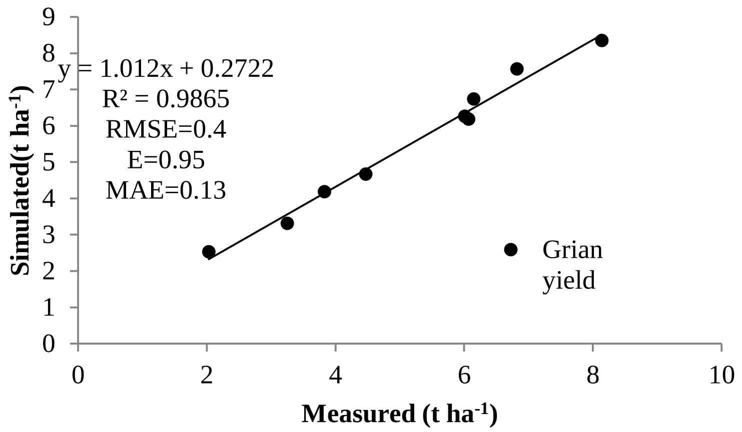


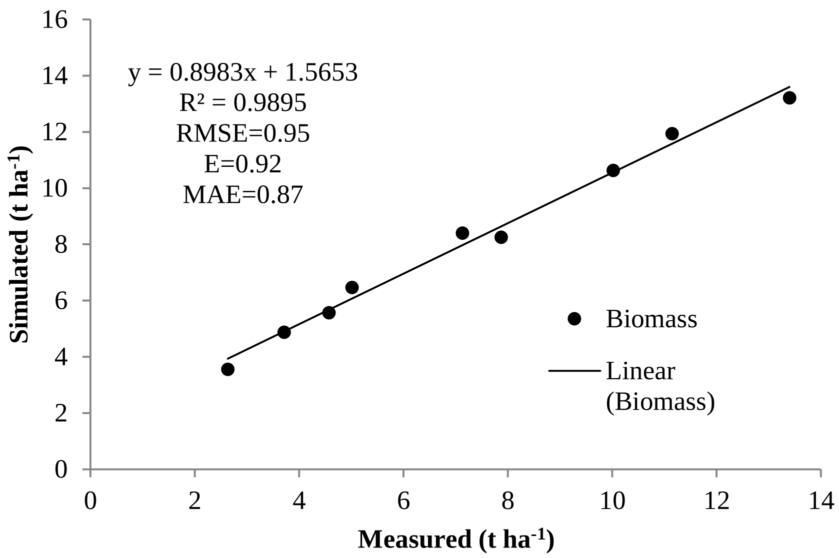
Figure 8- Model validation results in simulating the grain yield of soybean

3.3. AquaCrop model validation results

The results showed that the error of GY prediction (using experiment-generated data of 2014) was obtained in I3S3 and I3S1 treatments at the rate of 24.63 (max) and 1.81(min) %, respectively. Moreover, this prediction was observed for biomass in the I2S1 and I3S3 treatments by 35.36% and 1.41%, respectively (Table 10). The model was validated for simulation of yield and biomass for all treatment combinations with the prediction error statistics 0.93<E<0.97, 0.4<RMSE<0.95, 0.986<R2<0.989, and 0.16<MAE<0.91 t ha-1 in simulating the GY and BY for all irrigation treatments.

Table 10- Validation results of grain yield, biomass, and Wp of soybean under different irrigation water and salinity treatments (2014)

Treatment	Grain yield (tonha^{-1})		Pe	Biomass (tonha^{-1})		Pe	Wp (kg ha^{-1}mm^{-1})		Pe
	Observed	Simulated	(%)	Observed	Simulated	(%)	Observed	Simulated	(%)
I1S1	6.01	6.26	4.16	7.87	8.26	4.96	28.62	29.81	4.16
I1S2	3.83	4.18	9.14	4.57	5.57	21.88	18.29	19.90	8.8
I1S3	3.25	3.31	1.85	3.71	4.88	31.54	15.48	15.76	1.81
I2S1	8.14	8.35	2.58	13.4	13.21	-1.42	29.82	30.59	2.58
I2S2	6.82	7.56	10.85	11.15	11.94	7.09	24.98	27.69	10.85
I2S3	6.15	6.74	9.59	10.02	10.63	6.09	22.53	24.69	9.59
I3S1	6.07	6.18	1.81	7.13	8.4	17.81	18.12	18.45	1.81
I3S2	4.47	4.67	4.47	5.01	6.47	29.14	13.34	13.94	4.5
I3S3	2.03	2.53	24.63	2.63	3.56	35.36	6.06	7.55	24.59



Figurer9-Model validation results in simulating biomass yield of soybean.

The result of model evaluation is presented in Table 11. The AquaCrop model was able to predict the grain yield, accurately had a linear regression slope of 1.01 and R2 = 0.98, (Fig. 8). Moreover, these values obtained for biomass prediction at the rate of 0.89 and 0.99, for slope and R2, respectively, Fig. (9). Furthermore, the validated model for simulating of Wp with the Pe values was observed 1.81 and 24.59 % for I1S3 and I3S3 treatments respectively.

Table 11-Prediction error statistics in the validated Aquacrop model with 2014 data

Model output parameters	Mean		RMSE	E	MAE	R^2
	Observed	Simulated				
Grain yield (tonha^{-1})	5.20	5.53	0.4	0.95	0.33	0.9865
Biomass(tonha^{-1})	7.28	8.10	0.95	0.92	0.87	0.9895
Wp (kg ha^{-1}mm^{-1})	19.69	20.93	1.46	0.95	1.24	0.9892

The prediction error statistics of the validation stage of the model according to the 2014 data are shown in Table 11. The RMSE parameter has a range between 0.4 and 0.95 ton ha-1 for grain yield and biomass, but for WP is observed to be 1.46 kgha-1mm-1. According to the results of Table 11, it appears that the simulation of grain yield has higher accuracy compared to biomass; these results are consistent with the results of Babazadeh and Sarei (2012). They evaluated the model under water stress and announced the amount of yield in addition to the amount of water, which depends on various factors such as the amount and timing of the fertilizer, the soil, and the fertility of the farm, the farm situation in terms of the type of cultivation in the previous year, and pests and diseases. According to Table 10, most of the prediction errors are positive; furthermore, the simulation result of the model overestimates the grain yield, biomass, and WP. Also, by increasing the applied stress level, the simulation error of the model would be higher So that the prediction error in treatment I1S3, I2S3, and I3S3 is greatest and totally the best simulation in grain yield and biomass is for the I2S1 treatment (2.58, 1.42 in absolute %) and I3S3 treatment has the most fouls (35.36 %), respectively. In other words, the simulation of grain yield is more accurate than the simulation of biomass. The effect of salinity on the decline more accurately simulates the effects of drought. Generally, about the average prediction error, it can be concluded that the effect of salinity stress on seed yield and biomass is greater than the effect of drought stress. The Prediction error statistics in the validated AquaCrop model with 2014 data for grain yield and biomass were obtained: $0.4<RMSE<0.95$, $0.92<E<0.95$, $0.33<MAE<0.87$-ton ha-1, and $0.986<R2<0.989$. These parameters for WP were 1.46, 0.96, 1.24, and 0.989, respectively. These values are less than the calibration stage, which is shown in Table 9. Also, it can be said that the prediction error of grain yield is less than its value for biomass. Moreover, the model validation results and the observed values of GY, BY, and WP for all treatments were presented in the Figures. 8 –10, respectively. It was found from the E and R2 values that the GY and BY estimations by the model under all treatments were in line with the actual data, but were largely overestimated. This result is reported in the study of Hassanli et al. (2016). Moreover, the water productivity predictions by AquaCrop for all treatments were with E and R2 of 0.99 and 0.989, respectively (Figure 10). The reason for a little overestimation of the results of AquaCrop compared to values measured in the field may be the simultaneous occurrence of environmental stresses on the same site, which is not considered when developing the model.

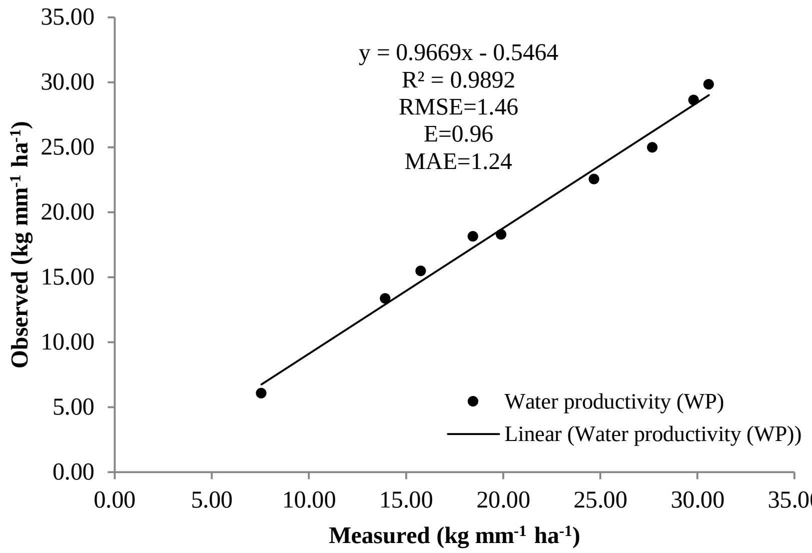


Figure 10- Model validation results in simulating the water productivity of soybean

4. Conclusions

The AquaCrop model was calibrated for GY and BY under different irrigated saline levels and three irrigation depths. The model calibration results for GY and BY were in line with the actual values, as evidenced by the prediction error statistics. However, the GY and BY for all treatments were over-predicted by the AuqaCrop model. According to the prediction error (%), we conclude that the accuracy of the AuqaCrop model for GY and BY simulation in water stress conditions was better than in salinity stress conditions. Nonetheless, from the comparison between the results of the experiment and modeling, it can be concluded that the AquaCrop model can be used to estimate the soybean yield with appropriate accuracy under varying depth and saline irrigation water. Also, Caspian Sea water can be considered as an alternative irrigation water resource in drought years in combination with fresh groundwater for soybean crop irrigation at a ratio of 14 percent. However, this issue requires further investigation of the long-term effects of soil salinity and the economic feasibility of using Caspian Sea water in agricultural lands at different distances from it.

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