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Prediction of safflower yield under different saline irrigation strategies using AquaCrop model in semi-arid regions

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Abstract

The FAO AquaCrop is a crop water productivity model, which simulates yield response to water of herbaceous crops, and is particularly suited to address conditions, where water is a key limiting factor in crop production.
Although saline irrigation abounded yield for sensitive crops, its application can be noticeable for tolerant crops. In this study, different water quality and management strategies were used for Safflower irrigation in semi-arid regions of Iran. Three different irrigation water qualities with the average salinity levels of 3.4, 8.8 and 11.2 dS.m-1 (Q1, Q2 and Q3), two irrigation management strategies (GQ and GU), and two leaching levels, i.e. with no leaching (LR0) and with leaching (LR1), were considered during the year 2008. The experiment was laid out in a Split-Split plot with completely random blocks design with four replications. The model were generated for general case (case1) and detailed case (case2). Statistical analysis indices of the validated model in case1, including the model efficiency (EF), coefficient of residual mass (CRM) and index of agreement (d) for grain yield were 0.69, 0.1, 0.99; for biomass were 0.74, 0.08, 0.99 and for WP were 0.98, 0.11, 0.99, respectively. Statistical analysis indices of the validated model in case2, i.e. the model efficiency (EF), coefficient of residual mass (CRM) and index of agreement (d) for grain yield were 0.99, 0.02, 0.99 for biomass were 0.96, 0.04, 0.99 and for WP were 0.98, 0.02, 0.99, respectively. Final results showed good predicted outputs for both cases. In case1, the model could be helpful in any management decision uses, with acceptable risk errors, however, the detailed model in case2 seemed to be a better predictor model due to its more calibrated parameters. Therefore; statistical results of both cases were acceptable.

Keywords: AquaCrop model; Safflower yield; Saline irrigation; Irrigation management.

Abbreviations: CRM_coefficient of residual mass; d_index of agreement; EF_model efficiency; FC: Field Capacity; GQ_ management strategy, the irrigation water with the related salinity was applied uniformly in the cultivated season; GU_management strategy, fresh irrigation water (Q1) was applied for two first irrigations and until seedling establishment; LR0_without leaching requirement; LR1_with leaching requirement; PWP: Permanent Wilting Point.Q1, Q2 and Q3_Three irrigation water with different quality.

Introduction

Safflower (Carthamus tinctorius L.) is grown in over 60 countries. It is a C3 crop highly branched, herbaceous, thistle-like annual plant. Safflower is commercially cultivated for its vegetable oil extracted from the seeds. It is a minor crop today, with about 600,000 tons being produced commercially in more than sixty countries worldwide.
Safflower is one of the major economical products in Iran, and hence, its cropped area has been increased over last few years, reaching to about 10000 ha during 2008; whereas, its cultivated area was only 200-300 ha during 1997 (Omidi et al., 2009) . Safflower is an important oilseed crop with 35-40% oil. It has been used as a source of edible oil since ancient times (Kolsaric et al., 2005).
Safflower is mainly grown around the world for its edible oil for cooking, salad oil and margarine. The research linking health with diet has considered the increasing demands for the oil, which has the highest polyunsaturated/saturated ratios of any other available oil. It is nutritionally similar to olive oil, with high levels of linoleic or oleic acid, but much less costly (Weiss, 2000).
Safflower is a species moderately tolerant to salt stress and is cultivated in dry areas, where salinity can be a serious threat. Yeilaghi et al. (2012) examined the effects of salinity stress on seed oil content and fatty acid composition in 64 safflower genotypes grown under saline and non-saline (control) field experiments in two growing seasons. Salt tolerant genotypes were less affected by salinity than the salt-sensitive ones.
Simulation models have been used for decades to analyze various crop responses to environmental stresses and to test the alternate management practices (Boote et al., 1996; Sinclair and Seligman, 1996). The FAO AquaCrop is a crop water productivity model developed by the Land and Water Division of FAO. It simulates yield response to water of

herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in the crop production. AquaCrop model assures the appropriate balance of accuracy, simplicity, and robustness. It uses a relatively small number of explicit and mostly-intuitive parameters and input variables requiring simple methods for their determination (FAO, 2011). The FAO-AquaCrop model keeps a good balance between robustness and the output accuracy. It is a generic crop WP model and can be used for a large number of crops (Steduto et al., 2009). Todorovic et al. (2009) compared the performance of AquaCrop with CropSyst and WOFOST by simulating the sunflower (Helianthus annuus L.) growth under different water regimes in a Mediterranean environment. In their research, it was shown that although AquaCrop requires less input information than CropSyst and WOFOST, it performs similar to them in terms of simulating both biomass and yield at harvesting. Therefore, using different numbers of parameters and crop growth modules by the tested models did not substantially influence the simulation results.

Zhang et al. (2013) evaluated the performance of the FAO-AquaCrop model in winter wheat in the southern Loess Plateau in China. The results indicated that AquaCrop is capable of simulating the winter wheat yield under rain fed conditions. Further they suggested that improvements may be needed to capture the variation of different management practices such as fertility and irrigation levels in this region. Andarzian et al. (2011) evaluated the AquaCrop model by simulating the wheat yield under full and deficit irrigation in a hot dry environment in southern Iran. They reported that the model predictions of root zone soil moisture, biomass and grain yield were in line with the observed data, and with the normalized root mean square error (RMSE) less than 10%. Salemi et al. (2011) used the AquaCrop model for simulating the grain yield and water productivity of winter wheat grown in central Iran under deficit irrigation regimes, reporting that the model efficiency varied between 0.93 and 0.99 for water productivity. The water productivity of wheat varied from 0.91 to 1.49 kgm-1 and the maximum value was related to the crop grown under 40% deficit irrigation treatment. Kumar et al. (2014) evaluated the AquaCrop model in predicting the wheat yield and water productivity under the irrigated saline regimes. It was observed that the AquaCrop model was better at predicting the grain yield compared to the biomass and water productivity for all varieties and salinity levels. Singh et al. (2013) calibrated and validated the AquaCrop model of FAO to develop water management strategies for growing wheat under the normal water supply through surface irrigation systems in West Bengal, India. Good agreement was obtained by AquaCrop in simulating the wheat yields under full irrigation. Iqbal et al. (2014) tested the ability of the AquaCrop model (v3.1) to simulate winter wheat grain yield, biomass, actual evapotranspiration (ETa) and total soil water content. Field experiments were conducted under deficit irrigation. The overall results based on extensive validation and revalidation showed that AquaCrop is a valid model and can be used with a reliable degree of accuracy for optimizing winter wheat grain yield production and water requirement on the North China Plain (NCP).

The objectives of this study were therefore to evaluate the effects of different irrigation water salinity, leaching and water use management on safflower yield for a typical clay soil of semi-arid regions in central Iran.

Results and Discussion

The AquaCrop model was calibrated according to the observed values from the field experiment during the crop growth season. After the simulation, the predicted output values were compared with the observed yield, biomass and the water productivity. Subsequently, a trial and error approach was used for minimizing the differences between the predicted and the observed data. In this approach, this procedure was repeated to achieve the closest match between the simulated and the observed values for each treatment combination.

Some of the variables in AquaCrop model for Safflower are constant. These parameters have been illustrated from FAO irrigation and drainage No.56, and the observations in the field. These constant values are reported in Table 4.

Evaluation of case1

The results of calibrated and validated parameters in this case are presented in Table 6. Five parameters describe the development of the canopy cover, canopy growth coefficient (CGC), canopy decline coefficient (CDC), length of emergence from the sowing date, the duration of maturity from the sowing date, and the days to maturity. The CGC is related to canopy expansion rate and the CDC related to canopy decline rate at the end of growing season. Both CGC and CDC can be estimated through observations in the field. Canopy coverage in low saline water treatment (Q1) was calculated to be lower than its rate in Q2 and Q3 treatments. Although the senescence of canopy in Q2 and Q3 irrigation quality treatments reached earlier, in Q1, the maximum canopy cover occurred earlier than the two others. Likewise, the duration of flowering in low saline treatment of Q1 was longer.

It can be observed from the calibrated values that the ranges do not vary much in a salt-tolerant crop situation at different salinity sites (Rajput et al., 2009). Calibration was done to determine a good match between the simulated and observed output models, in a try and error approach based on the acceptable information from the observed situations, publications, etc. Four treatments Q1GQLR1, Q2GULR0, Q2GQLR1 and Q3GULR1 were used for the calibration steps, according to the results of the calibration parameters, as shown in Table 5. Simulated values of grain yield, biomass and water productivity based on observed data are given in Table 6.

As it is indicated in Table 6, the maximum prediction error is about 9% in saline water treatment of Q3 for the WP prediction. Except for Q3, the results illustrate less error in grain yield prediction as compared to biomass.

Q1 showed less error in the yield and biomass prediction. There is no more significant relationship between the salinity and prediction error. It can be observed from the findings that the prediction error in GQ management strategy is lower than that in the GU management. The calibrated model was validated using the data of irrigation depths and salinity of four other treatments Q1GQLR0, Q2GQLR0, Q2GULR1, and Q3GULR0, to predict the grain yield, biomass, and water productivity. The predicted value

Table 1. Average amount of chemical characteristics of irrigation water in irrigation season.

Treatment	Water source	EC_{iw} ($dS.m^{-1}$)	TDS ($mg.lit^{-1}$)	pH	Ions($mg.lit^{-1}$)					SAR
					HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}+Mg^{2+}	Na^+	
Q1	River	3.4	2144	7.8	4.4	25	61	14	31	11.7
Q2	Well	8.8	7016	7.6	4.9	50	41	26	96.6	19.3
Q3	Drainage	11.2	8968	7.7	5.2	73	52	35	15.2	22.8

TDS: total dissolved solids; SAR: sodium adsorption ratio; EC_{iw}: salinity of irrigation water (dS.m-1)

Table 2. Treatments' symbols and irrigation event according to the days after sowing.

Number	Treatment symbols	Irrigation water	Days after sowing for irrigation					
			1	32	51	64	75	90
1	Q1 GQ LR0	Ig(mm)	216	112	104	112	120	120
		EC_{iw}($dS.m^{-1}$)	1.5	1.5	3.4	3.9	4.8	5.1
2	Q1 GQ LR1	Ig(mm)	216	112	120	128	128	128
		EC_{iw}($dS.m^{-1}$)	1.5	1.5	3.4	3.9	4.8	5.1
3	Q2 GQ LR0	Ig(mm)	216	112	104	112	120	120
		EC_{iw}($dS.m^{-1}$)	8	8	7.5	8.5	10.3	10.3
4	Q2 GU LR0	Ig(mm)	216	112	104	112	120	120
		EC_{iw}($dS.m^{-1}$)	1.5	1.5	7.5	8.5	10.3	10.3
5	Q2 GQ LR1	Ig(mm)	216	112	136	152	160	144
		EC_{iw}($dS.m^{-1}$)	8	8	7.5	8.5	10.3	10.3
6	Q2 GU LR1	Ig(mm)	216	112	136	152	160	144
		EC_{iw}($dS.m^{-1}$)	1.5	1.5	7.5	8.5	10.3	10.3
7	Q3 GQ LR0	Ig(mm)	216	112	104	112	120	120
		EC_{iw}($dS.m^{-1}$)	11	12	10.3	10.5	11.4	12.1
8	Q3 GU LR0	Ig(mm)	216	112	104	112	120	120
		EC_{iw}($dS.m^{-1}$)	1.5	1.5	10.3	10.5	11.4	12.1
9	Q3 GQ LR1	Ig(mm)	216	112	160	176	168	176
		EC_{iw}($dS.m^{-1}$)	11	12	10.3	10.5	11.4	12.1
10	Q3 GU LR1	Ig(mm)	216	112	160	176	168	176
		EC_{iw}($dS.m^{-1}$)	1.5	1.5	10.3	10.5	11.4	12.1

Ig: irrigation gross water; EC_{iw}: salinity of irrigation water ($dS.m^{-1}$).

Table 3. Soil properties of three layers.

soil layer(cm)	FC%	PWP%	bulk density(gr/cm3)
0-30	28	18.3	1.45
30-60	28.8	19.5	1.6
60-90	30	18	1.75

FC: Field Capacity; PWP: Permanent Wilting Point.

Table 4. Constant value for safflower in the AquaCrop model.

Constant Parameter	Amount
ECe threshold (p_{upper}) ($dS.m^{-1}$)	14.5
ECe threshold (p_{lower}) ($dS.m^{-1}$)	5.3
Base temperature ˚c	5
Cut-off temperature ˚c	30
Maximum basal crop coefficient (K_{cb})	1.05
maximum root length (m)	1
Minimum root depth (m)	0.35
Seed germination rate (%)	70
Length of emergence from sowing(days)	8
Length of maturity from sowing (days)	110
Length of flowering from sowing (days)	70

Table 5. Calibrated value of the AquaCrop input model in case 1.

parameter	Water quality levels	calibrated value
maximum canopy coverage	Q1	95%
	Q2	75%
	Q3	70%
Canopy growth coefficient (CGC)	Q1	9.5
%day $^{-1}$	Q2	8.4
	Q3	8.5
Canopy decline coefficient at senescence (CDC)	Q1	8.3
%day $^{-1}$	Q2,Q3	6.1
Days from sowing to maximum canopy (days)	Q1	70
	Q2,Q3	76
Days from sowing to senescence (days)	Q1	80
	Q2,Q3	76
Duration of flowering stage (days)	Q1	20
	Q2,Q3	14
Crop water productivity (WP) (g/m^2)	Q1	18
	Q2,Q3	15
Harvest index (HI) (%)	Q1	30
	Q2	33
	Q3	37
Expansion stress threshold (P_{upper}) (%of total TAW)	Q1, Q2, Q3	0.25
Expansion stress threshold (P_{lower}) (%of total TAW)	Q1, Q2, Q3	0.25
Expansion stress coefficient shape factor (unit less)	Q1, Q2, Q3	3
Stomatal conductance threshold (P_{upper}) (unit less)	Q1, Q2, Q3	0.5
Stomatal conductance shape factor (unit less)	Q1, Q2, Q3	3
Early canopy senescence threshold (P_{upper}) (unit less)	Q1, Q2, Q3	0.85
Early canopy senescence shape factor (unit less)	Q1, Q2, Q3	3

Table 6. Calibration and validation result of grain yield, biomass and water productivity (WP) of safflower in case1.

Step	Treatment	Yield (t. ha-1)		Pe%	Biomass(t. ha-1)		Pe%	WP(t. ha-1)		Pe%
		Obs.	Pred.		Obs.	Pred.		Obs.	Pred.	
Calibration	Q1GQLR1	3.63	3.54	2.40	11.94	11.24	5.86	0.44	0.43	2.40
	Q2GULR0	2.28	2.44	6.71	5.81	6.24	7.56	0.29	0.31	6.71
	Q2GQLR1	1.88	1.96	4.00	5.58	5.98	7.30	0.20	0.21	4.00
	Q3GULR1	2.53	2.31	9.03	6.82	6.35	6.88	0.25	0.23	9.03
Validation	Q1GQLR0	3.35	3.62	8.28	10.14	11.46	12.94	0.43	0.46	8.28
	Q2GULR1	2.59	2.40	7.22	7.85	7.19	8.49	0.28	0.26	7.22
	Q2GQLR0	1.69	2.07	22.31	5.05	6.23	23.37	0.22	0.26	22.31
	Q3GULR0	2.01	2.50	24.29	6.18	6.72	8.60	0.26	0.32	24.29

Pe: prediction error; WP: water productivity

Table 7. Statistical analysis of calibrated and validated model in case1 for all regimes in different treatments.

Step	Model output parameter	EF	CRM	d
Calibration	Grain yield (t/ha)	0.95	-0.01	0.99
	Biomass (t /ha)	0.96	-0.01	0.99
	WP (Kg/m3)	0.96	0.00	0.99
validation	Grain yield (t/ha)	0.69	0.10	0.99
	Biomass (t /ha)	0.74	0.08	0.99
	WP (Kg/m3)	0.98	0.10	0.99

EF: model efficiency; CRM: coefficient of residual mass; d: index of agreement

Table 8. Calibrated value of AquaCrop input model in case 2.

parameters	Quality levels	Calibrated value
Maximum canopy cover	Q1	99-90%
	Q2	61-86%
	Q3	67-81%
Canopy growth coefficient (CGC)	Q1	8.9-9
%day -1	Q2	8-8.8
	Q3	8.1-8.3
Canopy decline coefficient at senescence (CDC)	Q1	8.5
%day -1	Q2	6.1
	Q3	5.9
Days from sowing to maximum canopy (days)	Q1	70
	Q2	75-78
	Q3	78

Days from sowing to senescence (days)	Q1	80
	Q2	80
	Q3	80
Duration of flowering stage (days)	Q1	20
	Q2	18
	Q3	17
Crop water productivity (WP) (g/m2)	Q1	16
	Q2	15
	Q3	16
Harvest index (HI) (%)	Q1	31
	Q2	33
	Q3	32-37
Expansion stress threshold (P_{upper}) (% of TAW)	Q1	0.3
	Q2	0.2-0.21
	Q3	0.19
Expansion stress threshold (P_{lower}) (% of TAW)	Q1	0.6
	Q2	0.55
	Q3	0.54
Expansion stress coefficient shape factor (unit less)	Q1	4.6
	Q2	3
	Q3	2.8
Stomatal coductance threshold (P_{upper}) (unit less)	Q1	0.35
	Q2	0.49-0.5
	Q3	0.49
Stomatal coductance shape factor (unit less)	Q1	4.2
	Q2	4
	Q3	3.8
Early canopy senescence threshold (P_{upper}) (unit less)	Q1	0.7
	Q2	0.65-0.67
	Q3	0.64
Early canopy senescence shape factor (unit less)	Q1	3
	Q2	3
	Q3	3

Table 9. Calibration and validation results of grain yield, biomass and water productivity (WP) of safflower in case2.

Step	Treatment	Yield (t /ha)		Pe%	Biomass (t /ha)		Pe%	WP (Kg/m3)		Pe%
		Obs.	Pred.		Obs.	Pred.		Obs.	Pred.	
Calibration	Q1GQLR1	3.63	3.60	0.83	11.94	11.72	1.83	0.44	0.43	0.83
	Q2GULR0	2.28	2.22	2.79	5.81	5.75	0.95	0.29	0.23	20.30
	Q2GQLR1	1.88	1.82	3.43	5.58	5.55	0.48	0.20	0.28	38.23
	Q3GULR1	2.53	2.51	0.94	6.82	6.90	1.19	0.25	0.25	0.94
Validation	Q1GQLR0	3.35	3.33	0.45	10.14	10.90	7.46	0.43	0.42	0.45
	Q2GULR1	2.59	2.66	2.66	7.85	7.85	0.04	0.28	0.19	30.91
	Q2GQLR0	1.69	1.79	5.92	5.05	5.25	3.98	0.22	0.26	22.42
	Q3GULR0	2.01	2.03	1.05	6.18	6.37	3.01	0.26	0.26	1.05

Table 10. Average prediction errors (Pe%) in calibration and validation steps in case1 and case2.

Case	Step	Yield (t /ha)	Biomass (t /ha)	WP (Kg/m3)
Case1	calibration	5.54	6.90	5.54
	validation	15.52	13.35	15.52
Case2	calibration	2.00	1.11	15.07
	validation	2.52	3.62	13.71

Table 11. Statistical analysis of calibrated and validated model in case2 for all regimes in different treatments.

Step	Model output parameter	EF	CRM	d
Calibration	Grain yield (t /ha)	0.994	-0.02	0.99
	Biomass (t /ha)	0.998	-0.01	0.99
	WP (Kg/m3)	0.994	-0.02	0.99
Validation	Grain yield (t /ha)	0.99	0.02	0.99
	Biomass (t /ha)	0.96	0.04	0.99
	WP (Kg/m3)	0.98	0.02	0.99

EF: model efficiency; CRM: coefficient of residual mass; d: index of agreement.

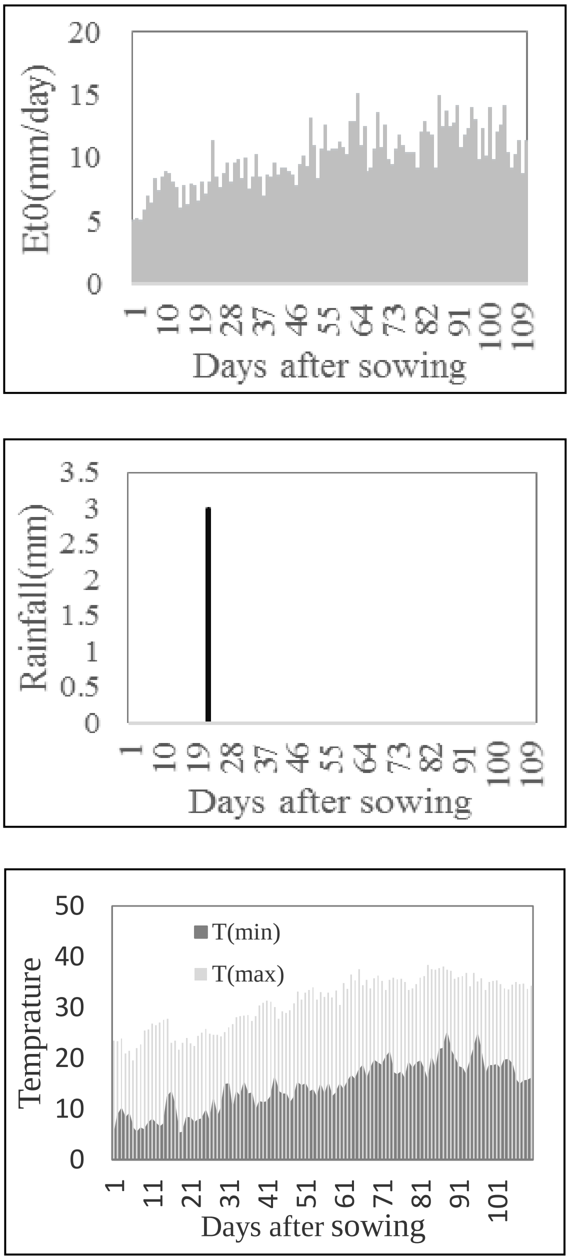

Fig 1. Weather parameters during the crop growth season.

was compared with the observed values. Table 6 shows the observed values from the experiment in line with the simulated values of the model and the prediction error in each treatment. The maximum prediction error is about 24% in saline irrigation water of Q3 for predicting WP. The yield prediction error is less in biomass in all treatments except for Q3, where the biomass prediction error is about 8.6% and the yield prediction error the same and 24%. On the other hand, minimum error in the yield prediction of Q2GULR1 is 7.22%.

Statistical evaluations

Statistical analysis was done to assess the appropriation of the calibration and validation steps, and the results are shown in Tables 7.

For a perfect fit between the observed and the simulated data, values of EF, CRM and d should be equal to 1, 0 and 1, respectively. The CRM is a measurement of the tendency of the model to overestimate or underestimate the measurements. Positive values of CRM indicate that the model underestimates the measurements and negative values of CRM indicate the tendency to overestimate.
The efficiency of the model in the calibration steps normally indicates a higher value as compared with the validation steps. Maximum EF was reported for the water productivity validated value, and it was approximately 0.98 (table 7). Minimum EF was seen in the grain yield validated value, which was about 0.69. The best result of validation was related to the WP prediction. The EF value indicates the model efficiency in the simulation. Considering the EF, it can be understood that in this case, the model is more suitable for the water productivity than the biomass prediction, and the grain yield (biomass prediction results better than the grain yield prediction). Kumar et al. (2014) evaluated the AquaCrop model for predicting wheat under irrigated saline water. According to the results, it was notified that AquaCrop Model is more successful in the grain yield prediction and water productivity. According to Kumar et al. (2014), the reported EF rates for the validated model were 0.85, 0.7, -0.04 for the grain yield, biomass, and WP, respectively. Generally, the validated safflower for validated wheat model used in this research illustrates better results as compared to the study by Kumar et al. However, regarding the prediction of WP in their research, there was a mismatch of total reference evapotranspiration calculated with formula as compared to the total measured water usage. Whereas, in this study the water usage in each irrigation was calculated based on the measured evapotranspiration in pan-class "A". Hence, a suitable WP prediction is expected in the current study.

Evaluation of case2

Statistical analysis was done to assess the appropriate calibration and validation steps. Calibration and validation results are shown in Table 9.

According to Tables 8 and 9, the maximum prediction errors for both calibration and validation steps are seen in the simulation results of WP in Q2 water quality level. Q2 water quality level is the only water quality that both management strategies could be coupled with it. Thus, the calibration procedure was more sensitive in this level. The average prediction errors of grain yield, both in calibration and validation steps were less than average prediction error of biomass. The prediction error in the calibration steps demonstrates better result for the biomass in comparison with the grain yield. Additionally, in validation step, the exception is perceived in Q2GQ treatment, where the biomass prediction error is less than the grain yield prediction error.
Ultimately, the prediction errors indicate good predictions by AquaCrop model. Regarding case 2, the prediction errors of the grain yield, biomass and WP were less than the prediction errors measured in case1. Hence, it can be said that AquaCrop model in case2 is assumed to be a better predictor. However, more calibrated parameters are needed to achieve even better results. Average prediction errors in

calibration and validation steps (Pe %) in case1 and case2 are shown in Table 13.

Evaluation of model

To evaluate the model, some statistical analyses were used, similar to the ones applied in case1. As it was mentioned earlier, for a perfect fit between the observed and simulated data, values of EF, CRM and d should be equal to 1, 0 and 1, respectively. Statistical analysis of the calibrated and validated model for all the regimes and treatments in case2 are indicated in Table 14 and Table 15. In a proper manner, evaluation results led to a proper simulation. Similarly, the model efficiency (EF) was high in all the three desired output grain yield, biomass and WP. Furthermore, the EF of biomass output in the calibrated model was higher than the grain yield and WP; nonetheless, the EF of biomass output in the validated model was lower. However, the differences of EF in various outputs were negligible. CRM in the calibrated model indicate the trend to be underestimated. Also, the tendency of CRM values from zero was not considerable. The differences between the observed and the simulated values for the calibration steps in each treatment are revealed in Table11. Comparing the parameters in Tables 8 and 9 with parameters in Tables 14 and 15, it can be seen that although the statistical analysis of case1 is appropriate and reliable having more calibrated parameters, but as a whole, case2 is a better predictor model for the grain yield, biomass, and water productivity of Safflower.

Conclusion

The AquaCrop model was calibrated and validated for the grain yield, biomass, and water productivity of Safflower under different irrigation water quality levels and different management strategies in Rudasht region of Isfahan province in Iran. The prime advantage of AquaCrop is its lower input data requirement compared to other crop models. Considering this advantage, the model was prepared for two cases. In case1 (general model), it was tried to emphasize on less calibrated values, so that the model could be helpful in any management decision uses, with acceptable risk errors. In case2 (detailed model), a complete model was generated. To do so, a wide range of input data was calibrated. Final results showed good predicted outputs for both cases; however, the detailed model in case2 seemed to be a better predictor model due to its more calibrated parameters. Based on the aims in using the model for predictions, estimation, or bringing about more accurate outputs, each of these two cases are recommended. Regarding the findings based on the statistical analysis, the model validation results for grain yield, biomass and water productivity were all in line with the observed data. Therefore, it is concluded that the FAO AquaCrop model could be used to predict the safflower yield with acceptable accuracy in semi-arid regions of Iran.

Materials and methods

Experimental site

This research was carried out in order to simulate safflower yield in different irrigation strategies, using the AquaCrop model. The required data were collected from Rudasht Research Experiment Station of Isfahan Agricultural and Natural Resource Research Center, located at 65 km southeast of Isfahan city, in the central part of Iran. Rudasht region is characterized by a semi-arid climate with the mean precipitation of 100 mm/yr. The experimental site lies at longitude 52º20′, and latitude 32º30′ and the height of the area is 1510 m above sea-level. The field data for this study was collected during 2008.

Cultivar practices

Zayandeh-Rood safflower cultivar was sown on 17th April 2008 (Feizi et al., 2010). The growth season of safflower in this situation is 110 days; so, 4th of August is the harvesting time. The experiment was laid out in a Split-Split plot with completely random blocks design with four replications. The experimental plots with the area of 5*25 m were selected to collect the data. The plots were irrigated six times during the growing season. A certain volume of water was applied according to crop requirement using class "A" evaporation pan. The irrigation intervals were based on about 100 mm evaporation from the pan, and soil texture of experimental field was clay.

Treatments and management strategies

Three types of irrigation waters with average salinity levels of 3.4, 8.8 and 11.2 dS.m-1 (Q1, Q2 and Q3), with two irrigation management strategies (GQ and GU), and two leaching levels, i.e. without leaching (LR0) and with leaching (LR1), were used in four replications. Some average chemical characteristics of the irrigation waters are given in Table 1.
The leaching levels were determined based on the following equation [17]:

$$LR = \frac{EC_{iw}}{5EC_e - EC_{iw}} \quad (1)$$

Where LR = leaching requirement, ECiw = EC of irrigation water (dS.m-1), and ECe = electrical conductivity of the saturated extract in dS.m-1.
Irrigation water for Q1 treatment was supplied from Zayandeh-Rood River as fresh water. Irrigation water in Q2 and Q3 were supplied in the site from a surface well and also drained water, respectively. Regarding the GU management strategy, fresh irrigation water (Q1) was used for the first two irrigations before the seedlings establishment. Other irrigations continued according to water salinity in irrigation water treatments. For the GQ management strategy, the irrigation water with the related salinity was applied uniformly in the cultivated season. Finally, 10 different treatment combinations were determined. The treatment symbols, irrigation quantities, and the salinity of each event are given in table 2.

AquaCrop model

AquaCrop model, version 4.0 (August 2012) was used to predict the safflower yield under different irrigation regimes. Some fundamental inputs should have been determined to prepare the model. These inputs are described below:

Climate data

The required data for AquaCrop model include: daily values of maximum and minimum air temperature, rainfall, mean value for annual carbon dioxide (CO2), and the reference crop evapotranspiration (ET0). The climatic data, which is used in the model are gathered from Rudasht Climatology Station near the experimental field. The average values of minimum and maximum air temperature and ET0 in crop season are 14˚C, 31˚C and 10 mm/day, respectively. The total rainfall during the experiment was 3 mm. The reference CO2 concentration was 369.41 ppm, as the default of the model. The rate of the rainfall, and variation of the temperature and ET0 are shown in Fig. 2.

Crop parameters

FAO has prepared crop parameters in AquaCrop model for some crops and some regions. Nevertheless, there is no evidence in Aquacrop for crop parameters of safflower. Therefore, the whole set of calibrated and validated crop parameters in this research were used in the study. Safflower was sown on 17th April 2008. Safflower was planted in rows with 0.5m distance from each other, and within 0.05 m in the rows. Seed rate was 27.5 kg/ha and the seeds germination was about 70%. Maximum root depth was 0.85 m. The mass of 1000 seeds was 31.4, 32.56, 32.67 and 31g in Q1GQ, Q2GQ, Q2GU and Q3GU, respectively.
The durations of the crop growth from sowing to emergence, and to maturity were 8 and 110 days, respectively.

Irrigation management

The irrigation method was the basin irrigation. Six times of irrigations were applied during the crop growth season. The rate of irrigation and the salinity of each irrigation interval in each treatment are reported in Table 2.

Field management

The type of mulches and the fraction of soil surface covered by the mulches, the soil fertility level, and practices that affect the surface run-off (soil bunds and field surface practices) are generally specified in the field management file. However, using surface' mulches were not considered in this research, and the fertility is assumed to be unlimited. Moreover, the occurrence of runoff seemed to be negligible.

Soil profile

The soil texture was clay, and its salinity was about 6 dS.m-1. The soil water content at field capacity (FC), the permanent wilting point (PWP), and the bulk density were measured for three layers in the experimental soil of the field. Results of this measurement are reported in Table 3.

Groundwater characteristics

The considered characteristics in the groundwater base include its depth below the soil surface (i) and its salinity (ii). In this study, the groundwater base is constant and is three meters below the surface, with 15dS.m-1 salinity.

Model construction

Two cases were considered in order to create the model: i) a general model for safflower crop, which could be used for any condition in a simple situation, and ii) a detailed model, which would be more accurate.

Case1: General model

It was attempted to emphasize on less calibrated value in this study. So, the model would be helpful for any management decisions with acceptable risk errors. Kumar et al. (2014) reported the range of sensitive input parameters of the model. According to the crop salinity rating and plant, some ranges are considered. For instance, while safflower is a C3 crop, based on CO2 concentration, the range of crop water productivity (WP) is 15-20 g/m2.
The main purpose of considering this case is presenting a user friendly aspect of the model to get an estimated output. In this regard, treatments were separated to two equal parts for calibration and validation. The effect of two treatments was not considered in this procedure (treatments No. 7 and No.9 in Table 2). Drainage of the saline irrigation water was applied throughout the growing season in both treatments. Consequently, the seeds germinated and established during the first irrigation, but the leaves were seriously injured after the second irrigation, due to the direct contact to saline water, and almost all newly developed plants died. Under this turbulent condition, the plants were severely damaged, since the observed yield and the biomass were very little and nearly negligible.

Case2: detailed model

A complete model was considered for this case. As the climate situation was common in all treatments, calibration was implemented according to the irrigation management and crop parameters. Furthermore, the soil profile, field management, and groundwater were the same in all the treatments. The crop file in AquaCrop contained crop-specific parameters of seven phonological crop growth stages with canopy and root development, evapotranspiration, water, fertility and temperature stress parameters (Steduto et al., 2009). As it was mentioned before in case1, in order to determine a good match between simulated and observed models, the output calibration was accomplished in a try and error approach. Again, four treatments Q1GQLR1, Q2GULR0, Q2GQLR1 and Q3GULR1 were used for the calibration. Thereafter, the calibrated model was validated using the data for irrigation depths and salinity of four other treatments Q1GQLR0, Q2GQLR0, Q2GULR1, and Q3GULR0, to predict the grain yield, biomass, and water productivity. The calibrated value of the input model was derived considering the quality levels of the irrigation water. The irrigation management and leaching condition were remarked in the calibration procedure. The calibrated values of AquaCrop input model for this case are presented in Table10. The irrigation management (GQ and GU) and leaching condition (LR0 and LR1) for each parameter were considered in the calibration. Maximum canopy coverage was related to LR1 treatments in the Q1 quality level, and was calibrated to about 99%. In the Q2 quality level, the higher maximum canopy was calibrated in the GU irrigation management and LR1 leaching condition. In this regard, the maximum canopy coverage was calibrated up to 86%. For the GQ-LR1 calibration, the maximum canopy coverage was 75%; whereas, the lower amount was related to LR0 leaching condition. In Q3, the water quality level of the maximum canopy coverage was related to LR1 treatments, and it was calibrated to about 81%. Obviously, the maximum canopy coverage in LR1 treatments is greater than LR0. Also the GU irrigation management leads maximum canopy to a higher value in comparison with the GQ management. The rate of canopy expansion is controlled by the canopy growth coefficient (CGC). The value of CGC was changed by changing the amount of maximum canopy coverage. The value of CGC was higher in LR1 treatment and GU management, than LR0 and GQ management.

The calibration results, from sowing to the maximum canopy, showed 70, 75-78, and 78 days in Q1, Q2, and Q3 quality level, respectively. For the Q2 quality level, the lower amount was reached in GU management and LR1 treatment after 75days from sowing. In Q2 quality level, the maximum amount of expansion stress threshold (Pupper) was reached in GU management and LR1 treatment up to 0.21% TAW and the minimum amount of stomata conductance threshold (Pupper) was reached in GU management and LR1 treatment, which was 0.49. Also, in this quality level (Q2), the maximum amount of early canopy senescence threshold (Pupper) was reached in GU management and LR1 treatment, and it was 0.67 %. The amount of the harvest index (HI) is an observed parameter in any treatment. In Q3, HI was observed to be lower in LR1 treatment.

Statistical analysis

The appropriateness of the fit between the simulated and observed values in calibration of validation steps was evaluated using prediction error statistics. The prediction error (PE), model efficiency (FE), coefficient of residual mass (CRM), and the index of agreement (d) were used for the model analysis in prediction. PE, EF, CRM and d, were formulated according to the following equations:

$$EF=1-\frac{\sum_{i=1}^{N}(O_i-P_i)^2}{\sum_{i=1}^{N}(O_i-\bar{O})^2} \quad (2)$$

$$CRM=\frac{\sum_{i=1}^{N}(p_i-O_i)}{\sum_{i=1}^{N}O_i} \quad (3)$$

$$d=1-\frac{\sum_{i=1}^{N}(S_i-O_i)^2}{\sum_{i=1}^{N}(|S_i-\bar{O}|+|O_i-\bar{O}|)^2} \quad (4)$$

Where, Oi and Pi indicate the observed and simulated values, respectively. In addition $\bar{O}$ indicates the average value of observed data.

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