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Testing of AquaCrop Model for Maize under Different Water and Nitrogen Managements

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Abstract—*AquaCrop model was calibrated and validated for grain maize (Single Cross 260) under varying irrigation and nitrogen levels. The experiment was conducted at the Gorgan city during summer season 2011 and 2012. Irrigation treatments consisted of different levels of depletion of available soil water. The four levels of moisture depletions considered in the study were 20, 40, 60 and 80 percent. Nitrogen application levels were 150 (N_1), 200 (N_2), 250 (N_3) and 300 kg ha^{-1}. Root Mean Square error (RMSE), Prediction error (Pe), coefficient of determination (R^2) and normalized root mean square error ($RMSE_n$) were used to test the model performance. The model was calibrated for simulating maize grain and biomass yield for all treatment levels with the prediction error 4<Pe<5 percent, $0.64<R^2<0.81$ and 469<RMSE<786 t ha^{-1}. Upon validation, Pe between 10 and 6; R^2 between 0.65 and 0.76 and RMSE between 1062 and 1293 for grain and biomass yield, respectively. The results of the present study show that the AquaCrop model simulates aboveground biomass more accurately than grain yield. Also, model cannot provide satisfactory results under severe water stress conditions.*

1. INTRODUCTION

Water withdrawal for agricultural purposes accounts for about 75 per cent of all usages in developing countries and the FAO has predicted a 14 per cent net increase in use of water to meet the food demands by the year 2030 as compared to year 2000 [1]. At the same time, irrigation is widely criticized as a wasteful user of water, especially in the water-scarce regions. Hence, search for sustainable methods to increase crop water productivity is gaining importance in arid and semiarid regions [2]. [3] evaluated the AquaCrop model under rainfed and supplemental irrigated maize, sugar beet and sunflower in Serbia. They reported that the maximum prediction error for maize was 3.6% and for sugarbeat 12.2%. However, they concluded that the AquaCrop model can be used in impartial decision-making and in the selection of crops to be given irrigation priority in areas where water resources are limited. [4] indicated that, the Aquacrop model was more accurate in predicitng the maize yield under full and 75% FC as compared to the rainfed and 50% FC. AquaCrop model required lesser number of inputs data in simulating the maize growth and yield under different water and fertilizer availability scenarios, as compared to other crop models. Therefore, investigation was undertaken to calibrate and validate AquaCrop model for maize grown in Gorgan plain and evaluate its performance under different irrigation and nitrogen irrigation scenarios.

2. MATERIAL AND METHODS

The experimental fields of 3000 m^2 block in the research field at Gorgan city in Iran, during season of 2011 and 2012. The research field is located between 54° 36′ E longitude and 36° 33′ N latitude at an average elevation of 1810 m above mean sea level. The experiment was laid in randomized complete block design (RCBD) with a split plot layout comprised I_1; MAD 20 % i.e., irrigation after 20 % moisture depleted of field capacity (FC): I_2; MAD 40%: I_3; MAD 60% and I_4; MAD 80% (W_4). The Nitrogen application levels were 150 Kg N ha^{-1}: N_1; 200 Kg N ha^{-1}: N_2; 250 Kg N ha^{-1} N_3 and 300 Kg N ha^{-1}: (N_4). There were five furrows in each plot of 6 × 3.75 m size and the replications were separated by 2 m to ensure that the treatments in plots were independent to each other. The furrows were 75 cm apart with plant spacing of 20cm in each furrow. The maize hybrid Single Cross 260 cultivar was sown on 1st July for both years. Soil moisture content of 15cm profiles and up to crop root zone were monitored periodically for irrigation scheduling *i.e.* deciding the date and quantity of irrigation water during the crop growth period. Irrigation scheduling was based on the percentage depletion of available soil water in the root zone. The available soil water was taken as the difference between root zone water storage at field capacity and permanent wilting point. The maximum allowable depletion of the available soil water was fixed at 20, 40, 60 and 80 %. Using the data of soil moisture measured by gravimetric measurements, the percentage depletion of available soil water in the effective root zone was estimated by the equation (1),

$$\text{Depletion}=\frac{1}{n}\sum_{1}^{n}\frac{\theta_{Fci}-\theta i}{\theta_{Fci}-\theta_{wp}}\times 100 \tag{1}$$

Where n is the number of sub-divisions of the effective rooting depth used in the soil moisture sampling, Θ_{Fci} is the soil moisture at field capacity for i^{th} layer, □i is the soil moisture in i^{th} layer and Θ_{wp} is the soil moisture at permanent wilting point. The amount of water applied after the attainment of predefined *MAD* was calculated as eq. (2):

$$V_i = \frac{(\theta_{Fc} - \theta_{wp}) \times R_z \times MAD \times A}{100} \quad (2)$$

Where:

V: Volume of water applied for each treatment (lit), θ_{fc}: Soil water content at field capacity, θ_{wp}: Soil water content before irrigation (weight percent basis), R_z: Depth of root development (mm), A: irrigated area (m^2). The surface area of each plot was 21 m^2.

Calibration of AquaCrop model

Calibration or fine tuning of the AquaCrop model was accomplished by using the observed values from the field experiment during 2011 as model input and then simulating the model to predict the output *viz.* the yield, biomass and canopy cover (CC). Subsequently, the predicted output values were compared with the observed yield and biomass of the experimental plot. The difference between the model predicted and experimental data were minimized by using 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 is repeated to arrive at the closest match between the model simulated and observed value of the experiment for each treatment combination.

Validation of AquaCrop model

AquaCrop model was validated using data of 2012 to predict grain yield and biomass under different water and N-fertilizer application levels in the experiment. Calibrated AquaCrop model was simulated with the input data of the experiment during the year 2012 to predict the grain yield, biomass and water productivity. Further, these predicted values were compared with the observed values of the experiment and the model validation performance statistics were analyzed.

Model evaluation criterion

AquaCrop model simulation results of maize yield, biomass and WP were compared with the observed values form the experiment during both calibration and validation processes. The goodness of fit between the simulated and observed values was corroborated by using the prediction error statistics. The prediction error (P_e), coefficient of determination (R^2), root mean square error (RMSE) and normalized root mean square error ($RMSE_n$) were used as the error statistics to evaluate both the calibration and validation results of the model. The R^2 was used to access the predictive power of the model while the Pe, $RMSE_n$ and RMSE indicated the error in model prediction. In this study, the model output in terms of prediction for grain yield and above ground biomass during harvest was considered for evaluation of the model. The following statistical indicators were used to compare the measured and simulated values.

$$P_e = \frac{(S_i - O_i)}{Oi} \times 100 \quad (4)$$

Where:

S_i and O_i are predicted and actual (observed) data, $\bar{O}_i$ is mean value of O_i and N is the number of observations.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Oi - Si)^2} \quad (5)$$

$$RMSE_n = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Oi - Si)^2} \times \frac{100}{\bar{O}i} \quad (6)$$

The prediction is considered excellent with the

$RMSE_n$ <10 %, good if 10–20 %, fair if 20–30 % and if $RMSE_n$ >30 % is poor.

3. RESULTS AND DISCUSSION

Grain yield, above ground biomass, under non limiting fertilized (N_1), moderate fertilized (N_2 and N_3) and poor fertilized (N_4) conditions for 2011 and 2012 experiments are shown in Tables 1 and 2. It was observed from the Table 1 that during two years of experiment, the lowest grain yields and biomass was observed to be 5500 and 11585 kg ha^{-1} in irrigation at MAD 80% (I_4) and poor-fertilized (N_4) treatment and the highest was 9611 and 17875 kg ha^{-1} under irrigation at 20% MAD (I_1) and recommended dose of nitrogen (N_4), respectively. These results were the average of three replications pertaining to the experiments conducted during 2011 and 2012. This could possibly be due to the fact that the senescence of the canopy accelerates under severe water stress, and the underground root system may be restricted and prevented from extracting more deeply stored soil water, thereby limiting its water uptake. Several authors [4, 5] reported much greater deviations under severe water stress or rainfed treatments, as compared to well-watered treatments for maize, teff and canola crops simulated by AquaCrop.

AquaCrop model calibration results

AquaCrop model was calibrated using experiment data of 2011 to predict grain yield and biomass under different water and fertilizer application levels in the experiment.

Table 1: Calibration results of biomass, grain yield of maize Obs.–Observed; Sim. - Simulated; P_e–Prediction error

Treatments	Yield (t ha^{-1})		P_e	Biomass (t ha^{-1})		P_e
	Obs.	Sim.	(±%)	Obs.	Sim.	(±%)
Non-limiting fertilized dose (N_4)						
I_1	8.998	9.085	-0.97	15.17	16.06	5.87
I_2	8.660	8.902	-2.8	14.925	16.024	7.36
I_3	7.828	8.674	10.81	14.505	15.194	4.75
I_4	7.316	8.219	12.34	13.152	14.479	10.1
Moderate-limiting fertilizer level (N_3)						
I_1	8.544	8.749	2.4	15.030	15.54	3.42
I_2	8.432	8.578	1.73	14.840	15.50	4.51
I_3	7.937	8.433	6.25	14.052	14.75	5.02
I_4	7.283	8.016	10.06	12.916	14.10	9.21
Moderate-limiting fertilizer level (N_2)						

I_1	8.482	8.355	-1.5	14.850	14.90	0.36
I_2	8.355	8.196	-1.9	14.412	14.87	3.18
I_3	7.820	8.197	4.8	13.660	14.32	4.9
I_4	7.158	7.815	9.18	12.694	13.73	8.23
Poor fertilizer level (N_1)						
I_1	8.006	7.903	-1.28	14.182	14.15	-0.16
I_2	7.829	7.754	-0.90	13.840	14.12	2.04
I_3	7.587	7.934	4.57	13.227	13.86	4.79
I_4	7.032	7.604	8.13	12.472	13.35	7.07

Model simulated and measured above ground biomass under all treatment combinations Fig. 1. It was observed from these figure that the model predictions for above ground biomass were close to the observed values of all treatment combinations, (i.e. R^2 = 0.81). This may be attributed to the less irrigation water condition during the crop growth period. The model was callibrated for grain yiled with R^2 of 0.64. It was observed that, the maximum and minimum error in grain yield prediction was in I_4 and I_1 treatments amounting to 12% and 1%, respectively (Table 1). The prediction error in biomass for I_4 and I_1 treatments were 0% and 10%, respectively (Table 1).

AquaCrop model validation results

AquaCrop model valibrated for grain yield under irrigation after 20 and 40 per cent depletion of available soil water ($I_1$and I_2) and all nitrogen levels resulted in prediction error ranging from 1.84% to 4.41%. Whereas model valibrated for grain yield under irrigation after 60 and 80 per cen soil moisturet depletion (I_3 and I_4) with all nitrogen levels resulted in prediction error ranging from 15.85% to 31.7% (Table 2). It was observed that the maximum error of grain yield prediction during model validation with the data of 2012 was for I_4N_1 treatments amounting to 31.7% .

Table 2: Validation results of biomass and grain yield of maize under different irrigation water and nitrogen regimes

Treatments	Yield (t ha^{-1})		P_e	Biomass (t ha^{-1})		P_e
	Obs.	Sim.	(±%)	Obs.	Sim.	(±%)
Non-limiting fertilized dose (N_4)						
I_1	9.611	9.200	-4.3	17.875	16.578	-7.25
I_2	9.000	8.750	2.88	15.973	16.292	2.0
I_3	7.708	8.930	15.85	14.350	15.699	9.4
I_4	6.833	7.986	16.87	13.034	14.079	8.02
Moderate-limiting fertilizer level (N_3)						
I_1	9.083	8.840	-2.67	15.665	16.017	2.25
I_2	8.625	8.822	2.28	15.355	15.766	2.68
I_3	7.535	8.695	15.40	13.643	15.274	11.95
I_4	6.083	7.811	28.40	11.688	13.755	17.68
Moderate-limiting fertilizer level (N_2)						
I_1	8.166	8.348	2.23	14.624	15.200	3.94
I_2	8.125	8.480	4.37	14.470	15.213	5.13
I_3	6.744	8.461	25.46	12.535	14.854	18.50
I_4	5.958	7.639	28.21	12.283	13.442	9.43
Poor fertilizer level (N_1)						
I_1	7.666	7.525	-1.84	13.989	13.793	-1.4
I_2	7.458	7.143	4.41	13.695	13.346	-2.6
I_3	6.464	7.734	19.64	12.078	13.581	12.44
I_4	5.500	7.243	31.7	11.585	12.734	9.92

Obs.–Observed; Sim. - Simulated; P_e–Prediction error

Morever, AquaCrop model valibrated for above ground biomass under irrigation after 20 and 40 per cent depletion of available soil water ($I_1$and I_2) and all nitrogen levels resulted in prediction error ranging from 1.4% to 7.25%. Whereas model valibrated for above ground biomass under irrigation after 60 and 80 per cen soil moisturet depletion (I_3 and I_4) with all nitrogen levels resulted in prediction error ranging from 8.02% to 18.5% (Table 2).

Table 3: Prediction error statistics of the validated AquaCrop

Model output parameters	Mean		RMSE	RMSE$_n$ (%)	Pe	R^2
	Measured	Simulated				
yield, t ha^{-1}	7.535	8.276	1062	14	10	0.6
Biomass, t ha^{-1}	13.928	14.745	1293	9	6	0.7

It was observed that, the AquaCrop model validated biomass with the prediction error statistics of 9<Pe<14, 1062<RMSE<1293 t ha^{-1} for irrigation and nitrogen treatment levels (Table 3). Overall, the simulation results of AquaCrop model for biomass and grain yield of Maize showed a close match with the observed values under 20 and 40 % ($I_1$and I_2) moisture depletion of (FC) for all nirogen regimes.

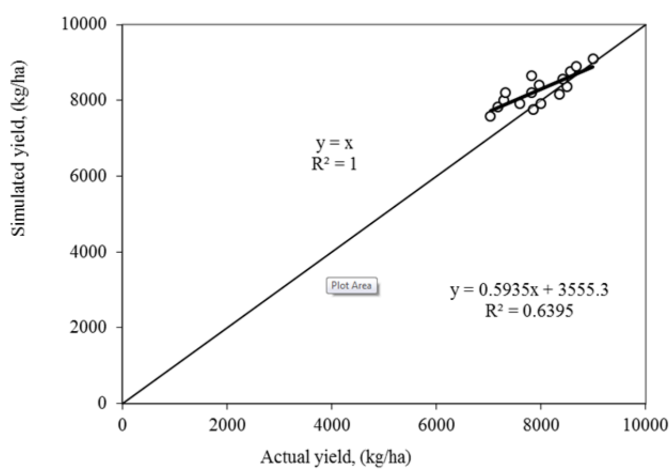

Fig. 1: Model calibration results for grain yield under all irrigation and nitrogen levels

4. CONCLUSION

AquaCrop model required lesser number of inputs data in simulating the maize growth and yield under different water and fertilizer availability scenarios, as compared to other crop models. The results of the present study show that the AquaCrop model simulates aboveground biomass more accurate than grain yield. Also, model cannot provide satisfactory results under severe water stress conditions.

Nonetheless, from the results of field experiment and modeling, it can be concluded that the water driven FAO AquaCrop model could be used to predict the maize yield with acceptable accuracy under variable irrigation and field management situations.

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