Indian Journal of Agricultural Sciences **93** (8): 899–905, August 2023/Article
https://doi.org/10.56093/ijas.v93i8.133319

Performance of AquaCrop model for predicting yield and biomass of okra (*Abelmoschus esculentus*) crop

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Received: 15 February 2023; Accepted: 17 July 2023

ABSTRACT

The present study was carried out at Technology Park of College of Technology and Engineering, Udaipur, Rajasthan for two years (2019 and 2020) with 6 irrigation treatments and four replications in RBD. Among all the treatments, the treatment T_2 (Irrigation at 85% field capacity of soil, based on soil moisture sensor based drip irrigation system) was found best in selected areas for growing okra [*Abelmoschus esculentus* (L.) Moench] crop under sensor based drip irrigation with maximum crop yield and biomass. In other water scarce regions of Rajasthan, the use of a simulation model can be a better option to predict the crop yield and biomass with respect to different irrigation levels. Therefore, calibration and validation of the AquaCrop model was done with the help of various data which were collected from field experiments during the study period (2019–20). The cut off temperature and base temperature were set as 32.5–10^{0}C, respectively. The model was successfully calibrated and validated with minimum prediction error, mean absolute error (MAE: 0.34–0.56), root mean square error (RMSE: 0.38–0.60) and maximum model efficiency (E ranges 0.8–0.95) and coefficient of correlation ($R^2 > 0.9$). The overall result indicate good performance of the model and can help in decision making as well as for irrigation water management for okra crop under the given conditions of Udaipur district of Rajasthan. It can be used to assess the influence of various environmental factors and management practices on okra crop growth.

Keywords: AquaCrop model, Biomass, Crop yield, Drip system, Irrigation level

Water is a major input in agriculture. Growing population has increased water use per person, aggravating the water scarcity. This problem can be overcome by adopting water management techniques (Jain *et al.* 2021). Nowadays in India, climate change is a major factor which affects the selection of appropriate crop type in any specific area as per their available fresh water resources for producing significant crop yield and biomass. In order to select the appropriate crop, it is necessary to repeat research trials for various crops over years or at different locations in order to choose the best crop alternative that will boost crop yield, water use efficiency and, as a result, provide high returns to the farmers. It takes time and is too expensive. The implementation of a simulation model to forecast yield at various irrigation treatments for numerous growing seasons is a less time and resource-intensive option (Dhakar *et al.* 2021). The different models (such as CropSyst, DSSAT and CERES) that have so far been used to simulate the yield and biomass of various crops are typically complex models and require numerous input parameters. To date, and to our knowledge, there have been no attempts to model yield and biomass of okra [*Abelmoschus esculentus* (L.) Moench] in semi-arid region of Rajasthan using a water-driven crop model. The AquaCrop model mimics crop yield changes in response to the amount of water applied and is especially well adapted to address situations where irrigation water is a major constraint on crop production. Okra crop is very sensitive to the amount of water supplied during the growth period. Makinde (2022) has reported that okra plant survival depends on the magnitude of excess or deficit of the water. The yield of okra crop significantly varies with respect to different irrigation water management practices (Changade *et al.* 2023). So, there is an urgent need to simulate crop yield and biomass of okra at different levels of irrigation under modern irrigation techniques. Therefore, the effort was made to check the feasibility of the FAO-Aquacrop model to predict crop yield and biomass of okra crop in semi-arid conditions.

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MATERIALS AND METHODS

The present study was carried out at Technology Park of College of Technology and Engineering (CTAE), Maharana Pratap University of Agriculture and Technology (MPUAT)

Udaipur (24°35'31.5" N, 73°44'18.2" E, 582.17 m amsl), Rajasthan during 2019 and 2020.

Field experimental details: In this study six irrigation treatments were taken in four replications. The experimental design was random block design. The treatments comprised of T_1, Irrigation at 100% of field capacity of soil maintained by soil moisture sensor under automated drip irrigation; T_2, Irrigation at 85% of field capacity of soil maintained by soil moisture sensor under automated drip irrigation; T_3, Irrigation at 70% of field capacity of soil maintained by soil moisture sensor under automated drip irrigation; T_4, Irrigation at 100% of crop water requirement based on daily pan evaporation under manually operated drip irrigation; T_5, Irrigation at 85% of crop water requirement based on daily pan evaporation under manually operated drip irrigation and; T_6, flood irrigation as per farmer practice.

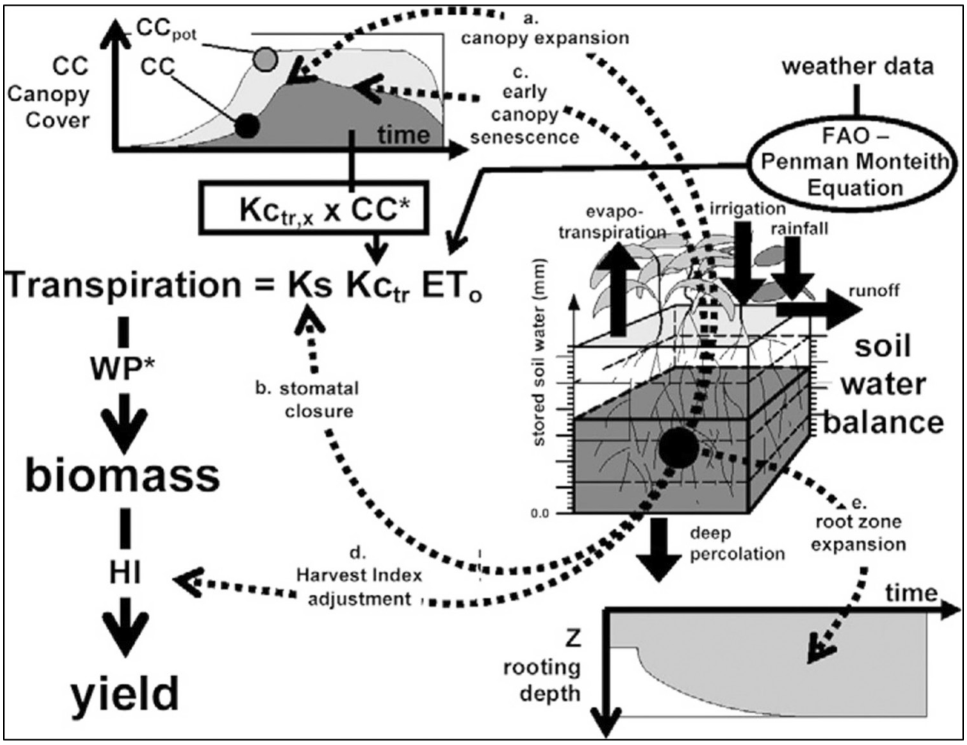

Fig 1 Representation of variables of AquaCrop model.

In this study, MAY-28 variety of okra [*Abelmoschus esculentus* (L.) Moench] crop was taken and pre-treated seeds were directly sown on 27th of February for both years (2019 and 2020) with the plant spacing 15 cm and row spacing of 50 cm on all treatments. Crop water requirement was calculated by pan evaporation data. The meteorological data such as temperature, relative humidity, wind speed, rainfall, pan evaporation and sunshine hours during the crop period was acquired from the meteorological observatory located at Instructional Farm, Udaipur, Rajasthan.

Estimation of crop water requirement: The total water applied to the okra crop under drip irrigation was calculated as:

$$V = \Sigma\ (Epan \times Kpan \times Kc \times C_a \times Wp)$$

Where V, Estimated irrigation water requirement (litre/day/plant); Epan, Pan evaporation (mm); Kpan, Pan coefficient (as per local condition); Kc, Crop coefficient (it is a developed crop coefficient as per local condition) and; C_a, Crop area (m^2). In this study, effective rainfall (ER) was calculated as:

$$ER = P_t \times \{125- (0.2 \times P_t) / 125) \text{ for } Pt < 250 \text{ mm}$$

Where P_t, total rainfall (mm) on monthly basis. In sensor based treatments, moisture content (as per treatment) was maintained automatically with the help of soil moisture sensor (resistivity based), microcontroller and solenoid valves. The field capacity (FC) of soil was estimated as 31% (on volume basis) for irrigation purposes under sensor-based drip irrigation treatments. In all the treatments, the recommended dose of fertilizer was applied.

Details of sensor based automatic drip irrigation system: The automated drip irrigation system was made up of an irrigation controller (24 VAC operated), relay, solenoid valves and a resistance based soil moisture sensor. Sensor moisture sensor was used to detect real time data of soil moisture in soil and to schedule the irrigation on the basis of threshold value (field capacity of soil). A probe was placed at the effective crop root zone. A timer cum relay was installed between the irrigation controller and pump starting panel. The 20 AWG wires were used to connect the soil moisture sensor module and controller.

Description of AquaCrop model: The FAO-AquaCrop model is basically a water driven simulation model which emphasizes on simulating the attainable crop yield and biomass as per water availability. In FAO-AquaCrop model, atmosphere, crop and soil are considered as a continuum (Fig 1). The input data such as climatic data (rainfall, temperature and evapotranspiration), crop growth data (growing cycle calendar) and management practices (irrigation amount, irrigation system type, mulching and fertility of soil) and soil data (soil horizon, field capacity) were taken during calibration and validation of model. Degree days were estimated as per methodology given in the AquaCrop reference manual. Testing of the AquaCrop model was performed with the help of data which were collected from field experiments during the first year (2019) and second year (2020), respectively.

Model performance measures: To check the feasibility of model to predict the yield and biomass of okra, the comparison between observed and predicted values of was done with the help of model efficiency (E), correlation coefficient (R^2)/prediction error (P_e), mean absolute error (MAE) and root mean square error (RMSE).

$$Pe = \frac{(Si - Oi)}{Oi} \times 100 \quad (1)$$

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

Where, S_i and O_i, simulated and actual (observed) data; O_i, average of O_i and; N, number of observations.

$$RMSE = \sqrt{\frac{1}{(N)}\sum_{i=1}^{N}(Si - Oi)^2} \quad (3)$$

$$MAE = \frac{1}{N}\sum_{a=1}^{N}|Sa - Oa| \quad (4)$$

Here, E and R^2 near to one and P_e, MAE and RMSE nearby zero will indicate better model performance.

Field observation and measurements: Phenological stages of the crop were identified visually through regular visit to the field and their dates were recorded. Canopy temperature was recorded by laser thermometer. In order to calibrate the AquaCrop model, water productivity and harvesting index were calculated on the basis of actual crop yield and biomass with respect to the amount of irrigation water applied for okra crop during field experiment.

RESULTS AND DISCUSSION

In this study during the time of simulation, the climatic data, harvesting index (HI), water productivity and depth of effective plant root zone were directly affecting the crop yield and biomass. AquaCrop model was calibrated first time for okra crop under given climatic conditions of Udaipur district of Rajasthan so some input data (like crop growth parameters, climatic data and water management data) were taken as per actual field experiment while remaining input data were selected from default files of AquaCrop model. During calibration the whole procedure was repeated so many times to select a set of input parameters that produced highly correlated results with the measured data under different treatments. The maximum canopy cover during calibration was taken as 95%. The flowering time period was taken as 45 days while the initial canopy cover (CC_0) as 0.33 (Table 1). The highest CC was in the middle of the flowering stage. In treatment T_3 and T_5 irrigation water was supplied at deficit level (irrigation at 70% of FC and 85% of volume of daily CWR) which create lack of optimum moisture content in plant root zone and directly affects the canopy development, early senescence and stomatal closure during crop growth period. Further, the underground root system may be blocked and interrupted from extracting larger amounts of deeply stored soil water, thereby limiting its ability to absorb water. It can be a possible reason for lowering the crop yield and biomass under T_3 and T_5 as compared to other drip irrigation or sensor-based drip irrigation treatments (T_1, T_2 and T_4). The result is in line with the finding of Wellen *et al.* (2013) for cabbage crop. They have noticed nearly same effect of water stress on crop data (development and stomata closer). Abedinpour *et al.* (2012) reported significantly more deviations under harsh water stress conditions, in comparison with well-watered treatments for maize crop simulated through AquaCrop model. The values of base and cut off temperature were taken as 32.40–100^{0}C, respectively. The calibrated value of water productivity was 19.3 g/m^2. The rootzone depth of the okra plant was considered as 0.45 m. Subsequently, in case of crop water stress, the different factors pertaining to expansion stress were calibrated to have the lower threshold, upper threshold and shape factor to be 0.76, 0.31 and 2.9, respectively. A CO_2 concentration data was taken from default data of AquaCrop model (measured at the Mauna Loa Observatory in Hawaii).

In the selected region the variation in daily weather data was observed during the whole growing period of okra. Therefore, the standard climatic data file (as input of model) was prepared by using actual daily weather data. This results in less error during calibration and validation of the model. The result obtained from pooled data indicates lower value of daily atmospheric temperature during initial and development growth stages of okra.

The daily sunshine hour was recorded almost the same during the whole growing period of okra. The average daily pan evaporation was recorded highest (8.4 mm/day) and lowest (4.5 mm/day) at mid stage and late stage of okra crop, respectively. This results in highest irrigation water requirement as 0.952 litre/plant/day (excluding ER) on daily average basis during mid stage of okra. The uneven trend of daily crop water requirement was recorded due to temporal variation in daily weather data in selected region which plays an important role for deciding the irrigation event during whole growing period of okra (Vikas 2020, Sharma and Yadav 2021). The crop yield was significantly affected at different irrigation levels as well as type of irrigation system [Automatic drip irrigation (ADI) and Traditional drip irrigation (DI)]. The actual as well as predicted crop yield and biomass were found maximum under T_2 [Irrigation at 85% FC, based on soil moisture sensors (SMS) under ADI]. The crop yield and biomass was highest due to presence of optimum moisture content in the plant root zone which indicates no water stress by the plant. Similar result was reported by Al-Gobari *et al.* (2017) as they reported that sensor based automated drip systems may be a valuable tool for fixation of irrigation events for tomato crop. Kumar *et al.* (2021) have reported that SMS based ADI systems can be used for effective water management in the broccoli crop. Result indicates that, in order to grow okra with high crop yield and biomass under Udaipur district of Rajasthan, farmer can irrigate their crop at 85% of field capacity of soil under sensor based automated drip irrigation

Calibration of model under different treatments: The model calibration result of crop yield for year 2019 shows acceptable correlation between actual and simulated yield.

Table 1 Input data for FAO-AquaCrop model

Crop parameter	Value	Unit
Base temperature	10	°C
Cutoff temperature	32.5	°C
Initial canopy cover (CC_0)	0.33	%
Canopy growth coefficient (CGC)	17.3	%/day
Canopy decline coefficient at senescence (CDC)	7.2	%/day
Reference harvesting index	69.8	%
Water productivity (WP)	19.3	gm/m^2
Time between sowing to emergence	7	Days
Time between sowing to start flowering	40	Days
Time between sowing to start senescence	90	Days
Time between sowing to maturity	112	Days
Flowering period	45	Days
Maximum effective rooting depth	0.45	M

In actual field conditions, the highest yield and biomass (observed) of okra crop were 11 and 7.2 tonnes/ha, respectively for T_2 and T_1. Similarly, minimum yield and biomass (observed) of okra crop were 6.1 and 3.7 tonnes/ha for the T_6 (control) and T_4, respectively (Table 2). The highest simulated yield and biomass of okra crop were 11.9 and 7.9 tonnes/ha for $T_2$and T_1 respectively. The minimum simulated yield and biomass of okra crop were 6.6 and 4 tonnes/ha for T_6 (control) and treatment T_4, respectively. The maximum values of errors in crop yield and biomass prediction were estimated as 10% and 14.3% for T_4 and T_6, respectively. The minimum values of errors in crop yield and biomass prediction were estimated 1.1 and 2.8% for the treatment T_1.

The model was calibrated for crop yield of okra with E and R^2 of 0.884 and 0.982, respectively (Table 3). The model was calibrated for biomass of okra crop with E of 0.890 and R^2 value of 0.980 (Fig 2). A similar result was reported by Magalhaes *et al.* (2019) for calibration of the AquaCrop model with $R^2 > 0.9$, which is good performance for simulating yield and biomass for bean crop. Kumar *et al.* (2020) reported R^2 values as 0.953 for biomass and 0.951 for grain yield for simulating biomass and grain yield of wheat crop. The result showed that a calibrated AquaCrop model was able to capture well the variability in crop yield and biomass of okra, in semi-arid conditions.

Validation of AquaCrop model: The model validation result of crop yield shows a good matching between observed and simulated yield (Fig 3). In actual field conditions the yield and biomass of okra were found highest as 8.6 and 7.3 tonnes/ha for the T_2 and T_4. Similarly, yield and biomass of okra were lowest as 4.1 and 3.2 tonnes/ha, respectively for T_6 and T_5 (Table 2). The maximum simulated/predicted yield and biomass were 9 and 7.5 tonnes/ha for the treatment T_2 and T_4. The minimum simulated yield and biomass of okra were 5 and 3.6 tonnes/ha, respectively for T_6 and T_5. The maximum values of errors in crop yield and biomass prediction were estimated 22 and 11.8% for T_6 and T_2, respectively. The prediction error was highest due to improper utilization of water under flood irrigation. The minimum errors in crop yield and biomass prediction were estimated 4.7 and 2.2% for T_2 and T_4.

The model was validated for crop yield of okra with E and R^2 of 0.932 and 0.984, respectively (Table 3). The model was validated for biomass of okra with E of 0.928 and R^2 value of 0.988 (Fig 4). Results after statistical analysis indicate the suitability of AquaCrop model in order to predict yield and biomass of okra at different levels and type of drip irrigation in semi-arid region of Udaipur, Rajasthan. In this study the obtained values of statistical parameters are supported by research finding of Kumar *et al.* (2014), they have validated AquaCrop model with prediction error statistics (index of agreement, model efficiency and coefficient of determination for grain yield, as 0.96, 0.85,

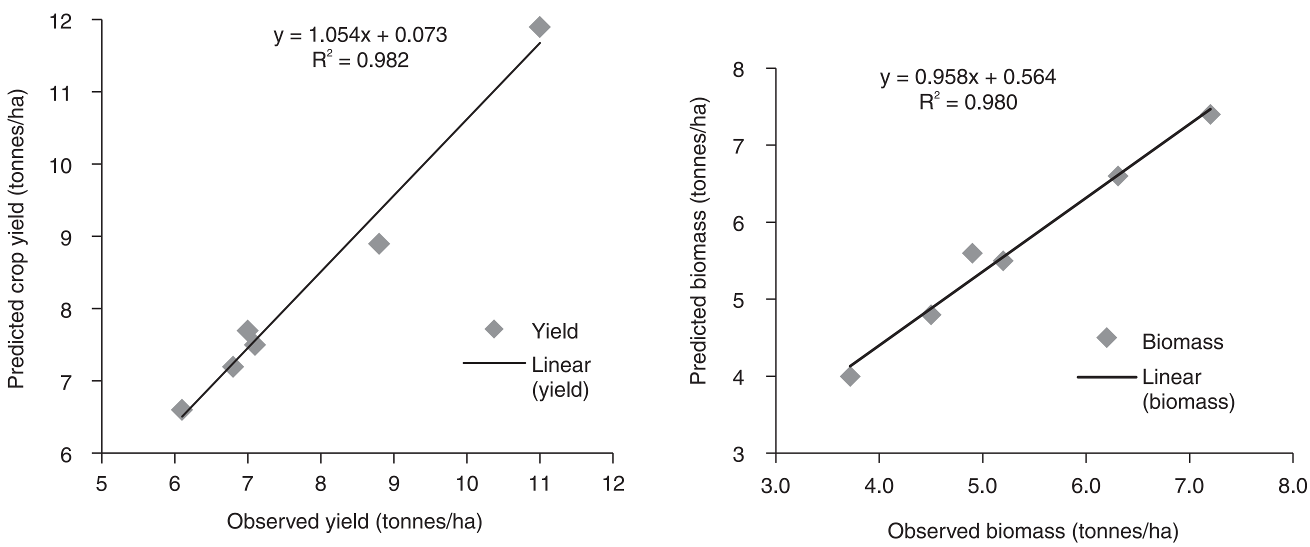

Fig 2 Correlation between observed and simulated okra yield and biomass during calibration.

Table 2 Calibration and Validation results under different treatments.

Treatment	Yield (tonnes/ha)		P_e (± %)	Biomass (tonnes/ha)		P_e (± %)
	Observed	Predicted		Observed	Predicted	
Calibration results						
T_1	8.8	8.9	1.1	7.2	7.4	2.8
T_2	11	11.9	8.2	4.5	4.8	6.7
T_3	7.1	7.5	5.6	6.3	6.6	4.6
T_4	7	7.7	10.0	3.7	4	7.5
T_5	6.8	7.2	5.9	5.2	5.5	5.8
T_6	6.1	6.6	8.2	4.9	5.6	14.3
Validation results						
T_1	7.3	7.8	6.8	6.7	7.4	10.4
T_2	8.6	9.0	4.7	3.4	3.8	11.8
T_3	5.6	6.4	14.3	6.1	6.6	7.5
T_4	5.9	6.2	5.1	7.3	7.5	2.2
T_5	4.9	5.4	10.2	3.2	3.6	11.8
T_6	4.1	5.0	22.0	4.8	5.0	4.6

Treatment details are given under Materials and Methods.

0.94 and for biomass as 0.95, 0.7, 0.95, respectively) under different irrigated saline regimes for wheat crop. Hong and Truong (2021) also observed that the AquaCrop model is suitable for forecasting the yield of cassava tuber throughout the water shortage region in Vietnam. Kumar *et al.* (2020) calibrate and validate AquaCrop model for winter wheat under Vindhyan region of Prayagraj, Uttar Pradesh and reported good predicting biomass and yield with correlation coefficient as 0.953 and 0.951, respectively.

Woodward *et al.* (2020) has reported the importance of deficit soil moisture content for ryegrass with the help of crop modeling. It was observed that the water scarcity in selected regions reduces leaf appearance, leaf expansion and flowering, irrespective of the availability of other resources.

The AquaCrop model was able to forecast the okra yield and biomass with respectable accuracy under various irrigation levels, although it was found that the simulated findings were slightly more appropriate for nearly full irrigation practice under conventional or sensor-based drip irrigation. The overall results indicate good performance of the model and can help in decision making and water management in okra crop under the given conditions of Udaipur district of Rajasthan. In this study, field conditions were assumed to be uniform without spatial variation in crop development, management, transpiration and soil characteristics but it is not practically possible in actual field conditions so some variation in predicted crop yield and biomass can be observed at farmer's field level. The spatial

Fig 3 View of AquaCrop interface and experimental site.

Table 3 Performance indicators during calibration and validation of AquaCrop model for okra.

Model output parameters	Mean		RMSE	MAE	Model efficiency	R^2
	Observed	Predicted				
Calibration results						
Crop yield (tonnes/ha)	7.8	8.3	0.559	0.500	0.884	0.982
Biomass (tonnes/ha)	5.30	5.48	0.381	0.345	0.890	0.980
Validation results						
Crop yield (tonnes/ha)	6.06	6.63	0.605	0.566	0.932	0.984
Biomass (tonnes/ha)	5.26	5.65	0.423	0.386	0.928	0.988

RMSE, Root mean square error; MAE, Mean absolute error; R^2, Coefficient of correlation.

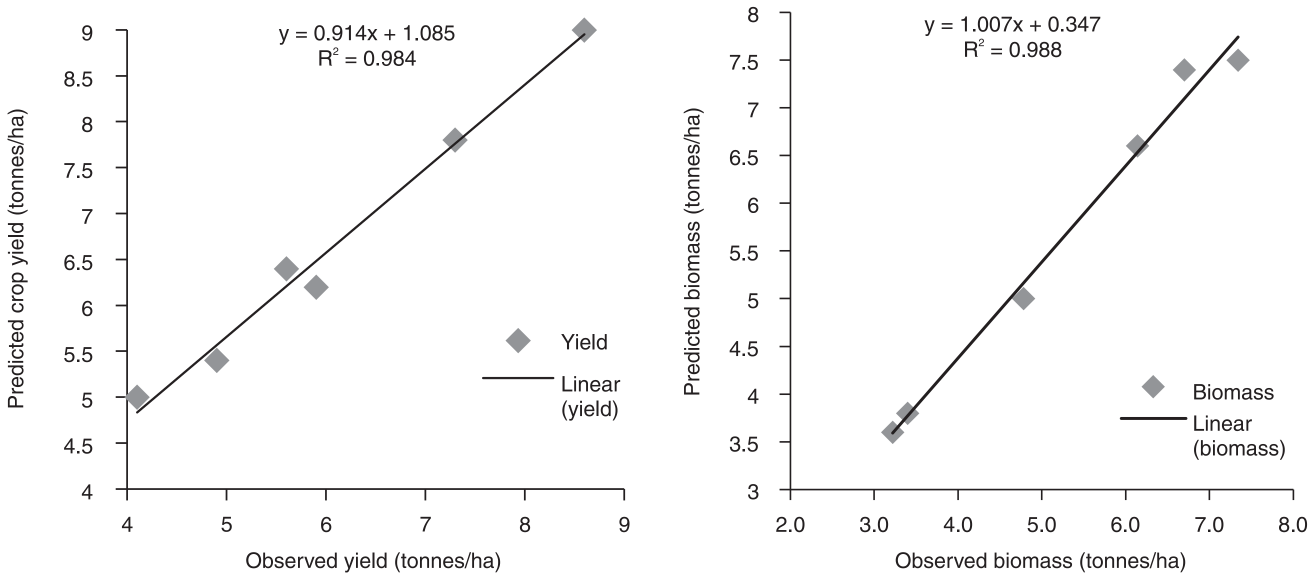

Fig 4 Correlation between observed and simulated okra yield and biomass during validation.

variation in crop and soil management can be considered a limitation in this model. The future studies should explore the sensitivity of our results to a much wider range of soil profile, environmental conditions and available water.

Overall, the good performance of the AquaCrop model was found for predicting yield and biomass of okra crop at various irrigation levels in semi-arid conditions of Udaipur, Rajasthan. Model is farmer friendly which requires only easily accessible input data for simulation of crop yield and biomass of okra. The model was successfully calibrated and validated with minimum values of errors and maximum values of model efficiency and coefficient of correlation. The treatment T_2 (Irrigation at 85% field capacity of soil maintained by soil moisture sensor based automatic drip irrigation system) was found best in selected areas for growing okra crop under drip irrigation with maximum crop yield and biomass which can also be used in other water scarce regions of Rajasthan. The results confirmed AquaCrop model's suitability for simulating crop response to water and can be used predict the yield and biomass of okra crop to different environmental conditions and crop as well as water management scenarios. Hence, model can be applied for undertaking different recommendations for farmers in the study region with a high level of confidence. In order to select the type of crop as per available fresh water resources, it will become a decision support tool for policy makers, agriculture advisers and practitioners in different regions of Rajasthan. Further testing of this model is required for other vegetables grown under different field conditions for better simulation accuracy.

ACKNOWLEDGEMENT

Authors are grateful to Dean, Technology Park of College of Technology and Engineering (CTAE), Udaipur, Rajasthan for providing a budget from the ICAR grant.

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