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Performance evaluation of AquaCrop model for *Okra* crop under *Tarai* condition of Indo-Gangetic Plain

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ABSTRACT

Crop growth simulation models are used for predicting the effects of soil, water and nutrients on grain yield and biomass. The impact of deficit irrigation on crop growth and yield was simulated using AquaCrop model with a view to conserve irrigation water and energy. These models are tested for a given region using the data generated from field experiments. In this study a water driven crop growth model was tested for *Okra* crop under varying irrigation regimes. The study area comes under climatic zone of western Himalayan region and is located in the Shivalik foothills of the Himalayas and represents the *Tarai* region of Uttarakhand state. The field experiment was conducted at the experimental farm of College of Technology, GBPUA&T Pantnagar, Uttarakhand during 2014. The irrigation treatments comprised of all possible combinations of full irrigation or limited irrigation is such that T_1 (full Irrigation *i.e.* 100% level of estimated crop water requirement through drip), T_2 (80% of level of estimated crop water requirement through drip), T_3 (60% of level of estimated crop water requirement through drip) and T_4 (Furrow Irrigation). The performance of the model was tested using statistical parameters like model efficiency (E), coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE). It was observed that the model was calibrated for yield and biomass with the prediction statistics $0.96 < E < 0.97$, $0.34 < RMSE < 0.50$ and $0.19 < MAE < 0.30$ t ha^{-1} for different irrigation levels. The model was validated for fruit yield and biomass with all treatment combinations with prediction error statistics values $0.90 < E < 0.91$, $0.30 < RMSE < 0.42$, $0.89 < R^2 < 0.91$ and $0.11 < MAE < 0.25$ t ha^{-1}. It was observed that the AquaCrop model was more accurate in predicting the *Okra* yield under full and 80% of FI through drip irrigation as compared to flood irrigation methods. The AquaCrop model predicted yield and biomass of *Okra* with good accuracy under different irrigation regimes. The tested results of this study on AquaCrop can be used as a planning tool to assist management decisions under changing climatic situations.

1. INTRODUCTION

Okra (*Abelmoschus esculentus* L. *Moench*) belongs to the family Malvaceae and is an important vegetable crop cultivated all over the tropical and subtropical regions of the world. *Okra* is one of the important vegetable crops grown throughout the tropics and warmer part of the world, where water availability is the major constraint to crop production (Tiwari *et al*., 1998). The crop is commonly grown with irrigation in dry season. India is the topmost country, producing 6.35 Mt of *Okra* annually which is around 73 % of global *Okra* production (NHB, 2014). *Okra* has a vast potential as one of the foreign exchange earner crops and accounts for about 60% of the export of fresh vegetables excluding potato, onion and garlic.

In many water scarce countries, and even otherwise, irrigation is the dominant user of water. Water withdrawal for agricultural purposes accounts for about 75% of all usages in developing countries and the FAO has predicted a 10 % net increase in use of water to meet the food demands by the year 2030 as compared to year 2000 (FAO, 2011). At the same time, irrigation is widely criticized as a wasteful user of water, especially in the water-scarce regions. Under different water availability situations, judicious management is essential to enhance water productivity (WP). Hence, search for sustainable methods to increase crop WP is gaining importance especially in arid and semiarid regions (Debaeke and Aboudrare, 2004). Traditionally, agricultural research has focused on maximizing total production. But, in recent years the focus has shifted to the limiting factors in production systems, notably the availability of either land or water.

Simulation models are designed to imitate the behaviour of a system. 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. Often a 1-day time stem is considered adequate for simulation models because the climatological database comprising rainfall, temperature, wind speed and many others are for a minimum time interval of 1 day. The short simulation time-step demands that a large amount of input data (*viz.,* climate parameters, soil characteristics and crop parameters) be available for the model to run. These models usually offer the possibility of specifying management options and they can be used to investigate a wide range of management strategies at low costs (Kumar and Ahlawat, 2004; Sekar *et al.,* 2012; Ramteke *et al.,* 2013; Mangal *et al.,* 2019; Sajeena and Kuriean, 2019). Crop growth models in general contain a set of equations that estimates the production rate of biomass from the captured resources such as carbon dioxide, solar radiation, and water. Accordingly, three main crop growth models can be distinguished: (i) carbon-driven, (ii) radiation-driven and (iii) water-driven (Steduto, 2003).

The water-driven crop growth models considers a linear relation between biomass growth rate and transpiration through a WP parameter (Tanner and Sinclair, 1983, Steduto and Albrizio, 2005, Kumar *et al.,* 2007). This approach avoids the subdivision into different hierarchical levels, which results in a less complex structure and reduces the number of input parameters (Steduto *et al.*, 2009). The water driven growth concept is used in CropSyst and Aqua Crop model (Steduto *et al*., 2009; Raes *et al.*, 2009). Most of these models, however, are quite sophisticated; require advanced modelling skills for their calibration and subsequent operation, and require large number of model input parameters. Some models are cultivar-specific and are not easily amenable for general use. In this context, the recently developed FAO AquaCrop model (Raes *et al.*, 2009; Steduto *et al.*, 2009) is a user-friendly and practitioner oriented type of model, because it maintains an optimal balance between accuracy, robustness, and simplicity, and requires a relatively small number of model input parameters. In the recent times many researchers are using FAO-AquaCrop model to assess the effect of environmental and management factors on crop production (Abedinpour *et al*., 2014; Pawar *et al.,* 2016; Jadhav *et al.,* 2018; Revathy and Balamurali, 2019; Jorge *et al.*, 2020). Evaluation of AquaCrop model for vegetable crops in *Tarai* condition of Uttarakhand can provide insight to the planners and vegetable growerers for optimum use of irrigation water. Keeping the above things in mind a study was carried out to evaluate the performance of AquaCrop model for *Okra* crop under *Tarai* Condition of Uttarakhand.

2. MATERIALS AND METHODS

Study Area

The study area comes under climatic zone of western Himalayan region and is located in the Shivalik foothills of the Himalayas and represents the *Tarai* region of Uttarakhand state (Fig. 1). The field experiment was conducted at the experimental farm of department of Irrigation and Drainage Engineering, College of Technology, GBPUA&T, Pantnagar, Uttarakhand, located at 29˚N latitude, 79˚30´E longitude and at an altitude of 243.83 m above mean sea level. The meteorological data such as temperature, relative humidity, wind speed, sunshine hours, rainfall and pan evaporation during the crop period was obtained from the meteorological observatory located at Crop Research Centre, Pantnagar about 0.4 km away from the experimental site.

Climate

Geographically, Pantnagar comes under the humid subtropical zone with average annual rainfall of 1400 mm with the monsoon season of four months. The 80% of annual rainfall is received during monsoon season. The monsoon generally starts in the second week of June and continues up to September with its peak in July. The summer is too dry and hot, and the winter is very chilly. The dry season starts from November and ends in May and Monsoon season starts after mid June to mid October. The mean monthly temperature ranges from 5˚C to 25˚C while the mean maximum temperature varies from 20˚C to 40˚C.

Fig. 1. Location map of study area

Soil Characteristics

The experimental site consists of sandy clay loam. The average bulk density was found to be 1.50 g cm^{-3}. The field capacity (FC) was found to be 23.8% and permanent wilting point (PWP) was estimated as 9% by weight basis.

Agronomic and Field Management Practice

A field plot of 20 m long × 20 m wide was divided into twelve equal plots of 6 × 4 m. The experiment was laid out in randomized block design having four treatments. The treatment details of the experiment are presented in Table 1. One meter gap was provided between each plot to avoid the effect of irrigation treatments. The variety of the crop was US 7109 F_1 hybrid. The plant to plant and row to row spacing was maintained at 50 × 50 cm.

Irrigation Scheduling

The daily crop water requirement/volume of water to be applied was estimated using the following relationship as given in INCID, 1994. The water requirement of plant is calculated as:

$$V = \sum(E_p \times K_c \times K_p \times S_p \times S_r \times WP - ER \times S_p \times S_r) \quad \ldots(1)$$

Where, V = Estimated crop water requirement of *Okra* plant at 100% water use level, litre/day/plant; E_p = Pan evaporation, mm/day; k_p = Pan coefficient; k_c = Crop coefficient; S_p = Plant to plant spacing, m; S_r = Row to row spacing, m; W_p = Percentage wetted area; ER = Effective rainfall, cm.

The crop coefficients, K_c for different growth stages of *Okra* were considered based on the unpublished report and local studies carried out in India. The crop coefficient K_c values are varying with the type of crop, its growing stage, growing season and prevailing weather conditions. The crop coefficient value for initial stage $K_{c\ init}$ was taken as 0.75, for mid stage K_{cmid} was taken as 1.15 and for end stage it was taken as K_{cend} as 0.87 (Tiwari *et al.,* 1998).

Drip irrigation system was laid with 16 mm dripline (Turboslim). Lateral was provided with drippers of 1.3 LPH discharge capacity with minimum pressure of 1 kg cm^{-2} spaced at 30 cm. The drip lines were laid parallel to the crop rows and each dripline served two rows of crop. The duration of delivery of water to each treatment was controlled with the help of valves provided at inlet of each laterals. In case of surface irrigation, scheduling was done on the basis of soil moisture reaching 50% of depletion of available water. The plants under furrow method were irrigated by impounding water in furrows. The discharge of the individual pipe coming to the each furrow was measured by volumetric method.

Table: 1
Experimental details of drip and surface method of irrigation for *Okra* crop

Irrigation treatments	Details of irrigation and mulching treatments
	Drip irrigation
T_1	100% level of estimated crop water requirement
T_2	80% level of estimated crop water requirement
T_3	60% level of estimated crop water requirement
	Control-furrow irrigation
T_4	50% level of available water depletion

Input Data Requirement of AquaCrop Model

AquaCrop uses a relative small number of explicit parameters and largely intuitive input variables, either widely used or requiring simple methods for their determination. Input consists of weather data, crop and soil characteristics, and management practices that define the environment in which the crop will develop. The inputs are stored in climate, crop, soil and management files and can be easily adjusted through the user interface.

Climatic Data

The weather data required by AquaCrop model are daily values of minimum and maximum air temperature, reference crop evapotranspiration (ET_o), rainfall and mean annual carbon dioxide concentration (CO_2). ET_o was estimated using ET_o calculator using the daily maximum and minimum temperature, wind speed at 2 m above ground surface, solar radiation and mean relative humidity (RH).

Crop Data

AquaCrop uses a relatively small number of crop parameters describing the crop characteristics. FAO has calibrated crop parameters for major agricultural crops and provides them as default values in the model. When selecting a crop its crop parameters are downloaded.

The model input data includes crop data referring to: (i) the dates of emergence, when maximum canopy cover is reached, when maximum root depth is attained, when canopy senescence starts, when maturity is reached, when flowering starts and ends; (ii) maximum value of the transpiration crop coefficient ($K_{cTr,x}$); (iii) minimum and maximum root depths Zr (m) and roots expansion shape factor; (iv) the initial and maximum crop canopy cover (CCo, CCx), canopy growth coefficient (CGC) and the canopy decline coefficient (CDC); (v) adjustment biomass (water) productivity (BWP*); (vi) reference harvest index (HIo), (vii) water stress coefficients relative to canopy expansion, stomatal closure, early canopy senescence and aeration stress due to waterlogging.

As per the input requirement of the model the data were collected for *Okra* crop. Canopy development was measured in terms of growth stages, leaf area and root length on monthly basis by removing two plants per plot. Date of emergence, maximum canopy cover (CC), duration of flowering, start of senescence and maturity were recorded. LAI was converted to crop canopy cover (CC). Relationship between LAI and CC used for both the vegetable crop is presented in equation:

$$CC = 1.005\,[1 - \exp(-0.6 \times LAI)]^{1.2} \qquad ...(2)$$

Soil Parameters

Data pertaining to the soil of experiment site required as input parameters for AquaCrop are *viz.,* number of soil horizons, soil texture, field capacity (FC), permanent wilting point (PWP), saturated hydraulic conductivity (K_{sat}) and volumetric water content at saturation (sat). The experiment site did not contain any impervious or restrictive soil layer to obstruct the expansion of root growth. The curve number (CN) of the site was used to estimate surface runoff from rainfall that occurred during the experiment.

Irrigation and Field Management Parameters

Irrigation and field management during the experiment are two important components considered in the AquaCrop model. In full irrigation treatment (*i.e.* 100%) of drip irrigation water was applied according to the full crop requirement of *Okra* crop. In the deficit irrigation treatments (*i.e.* 60 and 80% of full irrigation), water was applied on the same day as the fully irrigated plot, but the irrigation depths were reduced to 60 and 80% of the full irrigation. In furrow irrigation treatment irrigation water was applied up to FC level when soil moisture in the root zone approached 50% of total available water (TAW) (Table 1). The field management components were the fertility levels, mulching to reduce evaporation from soil and furrow end bunds to eliminate surface runoff. In this study the AquaCrop model was evaluated through calibration and validation to estimate yield and biomass under different irrigation levels.

Testing of AquaCrop Model

The FAO - AquaCrop model was tested for *Okra* under different level of irrigation. In a first step, parameters were fitted using the whole dataset (*i.e.* calibration). Next, different sub-sets of the data were used for cross-validation. Finally, simulation results using the complete dataset and the cross-validation subsets are compared for evaluation. The most extreme form of cross validation, known as leave one out cross validation (LOOCV) has been widely studied because of its mathematical simplicity. (Cawlwy and Talbot, 2003). As the name suggests, LOOCV involves using a single observation from the original sample as the validation data and remaining observation as the training data. The set of parameters are calibrated and the best results applied on the validation data.

Calibration or fine tuning of the AquaCrop model was accomplished by using the observed values from the field experiment during 21st March, 2014 to 10th July 2014 for *Okra* as model input and then simulating the model to predict the output *viz.,* the yield and biomass. 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 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 model simulated and observed value of the experiment for each treatment combination. The standard crop parameters after calibration was used for validation. The AquaCrop parameters which was calibrated, measured and adopted are as follows:

- Cut-off temperature
- Adapted canopy cover per seedling at 90% emergence (CC_o)
- Canopy growth coefficient (CGC)
- Calibrated maximum canopy cover (CCx)
- Canopy decline coefficient (CDC)
- Water productivity (WP*)
- Dry above-ground biomass per m^2
- Reference harvest index (HIo)
- Upper threshold for canopy expansion
- Lower threshold for canopy expansion
- Leaf expansion stress coefficient curve shape
- Upper threshold for stomatal closure
- Stomata stress coefficient curve shape
- Time from transplanting to recovered transplant
- Time from transplanting to maximum rooting depth
- Time from transplanting to start senescence
- Time from transplanting to maturity
- Maximum effective rooting depth

Model Evaluation Criterion

AquaCrop simulation results of *Okra* yield and biomass were compared with the observed values from the experiment during 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), mean absolute error (MAE), root mean square error (RMSE) and model efficiency were used as the error statistics to evaluate both the calibration and validation results of the model. The R^2 and E were used to access the predictive power of the model while the P_e, MAE 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. Model performance was evaluated using the following statistical parameters such as prediction error (P_e) model efficiency (E) (Nash and Sutcliffe, 1970), given by:

$$Pe = \frac{(Si - Oi)}{Oi} \times 100 \qquad ...(3)$$

$$E = 1 - \frac{\sum_{i=1}^{N}(Oi - Si)^2}{\sum_{i=1}^{N}\left(Oi - \overline{Oi}\right)^2} \qquad ...(4)$$

Where S_i and O_i are predicted and actual (observed) data, O_i is mean value of O_i and N is the number of observations:

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

$$MAE = \sqrt{\sum_{i=1}^{N}\frac{(Si - Oi)}{n}} \qquad ...(6)$$

Model efficiency (E) and R^2 approaching one and P_e, MAE and RMSE close to zero were indicators for better model performance.

3. RESULTS AND DISCUSSIONS

AquaCrop Model Calibration and Validation for *Okra* Crop

AquaCrop model was calibrated using the experimental data of 2014 to predict fruit yield and biomass under different level of irrigation in the experiment. The calibrated and adapted crop parameters used in AquaCrop model to simulate *Okra* productivity are presented in Table 2. The calibrated values of CGC and CDC were 17.4% day^{-1} and 7.5% day^{-1}. The days to emergence, sowing to flowering, senescence and maturity were 7, 44, 90 and 110 days. The maximum effective rooting depth was adapted as 0.45 m. The base temperature and cut off temperature were set at 10°C to 32°C, respectively. The calibrated values of WP were obtained as 19 g m^{-2} which was in the range suggested for AquaCrop for C_3 crop (*i.e.* crop that produces 3-carbon compound as the first stage of photosynthesis). The harvestable yield produced by the crop was product of biomass and the harvest index (HI). The HI was obtained as 71%. Subsequently under the crop water stress category, factors pertaining to expansion stress were calibrated to have the upper threshold, lower threshold and shape factor to be 0.3, 0.8, and 3.0, respectively. Also the stomatal closure stress, the upper threshold and shape factor were 0.5 and 3.0, respectively, while the lower threshold was set at the PWP.

The model performance pertaining to fruit yield is shown in Fig. 2, which shows a good correlation between

Table: 2
Input data of adapted crop parameters (*Okra*) used in Aqua Crop model to simulate *Okra* productivity

S.No.	Crop parameters	Value	Unit
1.	Base temperature	10	^{0}C
2.	Cutoff temperature	32	^{0}C
3.	Canopy cover per seedling at 90% emergence (CC0)	5	cm^2
4.	Canopy growth coefficient (CGC)	17.4	% day^{-1}
5.	Canopy decline coefficient at senescence (CDC)	7.5	% day^{-1}
6.	Water productivity (WP)	19	gramm^{-2}
7.	Reference Harvesting Index (HI0)	71	%
8.	Bulilding up of Harvesting index	50	%
9.	Upper threshold for canopy expansion	0.3	-
10.	Lower threshold for canopy expansion	0.8	-
11.	Leaf expansion stress coefficient curve shape	3.0	-
12.	Upper threshold for stomatal closure	0.5	-
13.	Stomata stress coefficient curve shape	3.0	-
14.	Time from sowing to emergence	7	Days
15.	Time from sowing to start flowering	44	Days
16.	Time from sowing to start senescence	90	Days
17.	Time from sowing to maturity	110	Days
18.	Duration of flowering	45	Days
19.	Maximum effective rooting depth	0.45	M

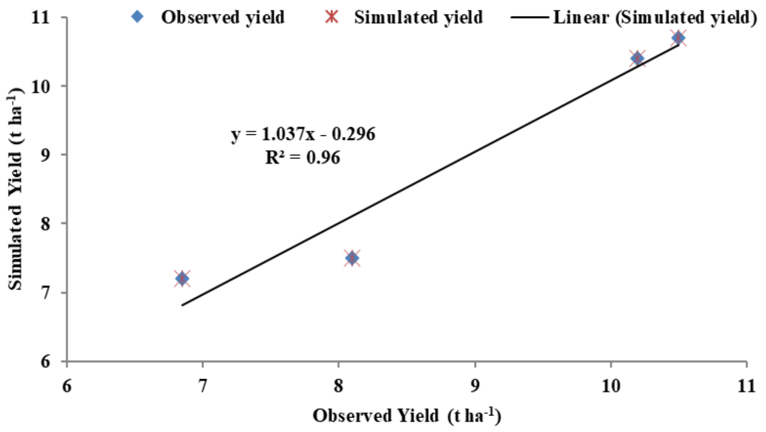

Fig. 2. Model calibration results for fruit yield of *Okra* under all irrigation levels

observed and simulated yield. It was observed from the table that the highest yield and biomass was 10.5 and 14.5 t ha^{-1}, respectively for treatment with drip irrigation based on 100% evaporation replenishment. The minimum value of yield and biomass was 6.85 and 9.60 t ha^{-1} for treatment under conventional furrow irrigation. The model simulated results after calibration shows that the highest grain yield and biomass was observed to be 10.7 and 14.7 t ha^{-1} for treatment with drip irrigation based on 100% evaporation replenishment and minimum was 7.2 and 10.2 t ha^{-1} for treatment with conventional furrow irrigation. The model was calibrated for fruit yield with model efficiency (E) and R^2 of 0.97 and 0.96, respectively. It was observed that, the maximum and minimum error in fruit yield prediction was in T$_3$ and T$_1$ treatments amounting to 7.42 and 1.90%, respectively (Table 3). The model performance for biomass is shown in Fig. 3. The model was calibrated with a model efficiency of 0.96 and R^2 value of 0.95. The prediction error for biomass for treatment T$_3$ and T$_1$ treatments were 7.34 and 1.38%, respectively. The prediction error statistics of the calibrated model is presented in Table 3. It was observed from the table that the model was calibrated for simulation of yield and biomass for all treatment with the prediction statistics 0.96 < E < 0.97, 0.34 < RMSE < 0.50 and 0.19 < MAE < 0.30 t ha^{-1}. AquaCrop model predictions for fruit yield and biomass of *Okra* were in line with the observed data corroborated with E and R^2 values approaching one. The similar results has been reported by Kumar *et al.,* 2018 for *rabi* Maize in North Bihar condition.

The validation results for fruit yield shows that the maximum and minimum prediction error were found in treatment T$_3$ and T$_2$ amounting to 5.06 and 0.34%, respectively (Table 4). Moreover the maximum and minimum error for biomass was observed to be in T$_4$ and T$_1$ treatments with 7.0 and 0.37%, respectively (Table 4). The prediction error statistics of model validation is shown in Table 5. The Table 6 shows that the model was validated for fruit yield and biomass with all treatment combinations with prediction error statistics values 0.90 < E < 0.91, 0.30 < RMSE < 0.42, 0.89 < R^2 < 0.91 and 0.11 < MAE < 0.25 t ha^{-1}. Model validation results and observed values of fruit yield and biomass of *Okra* for all treatment combinations were plotted

Table: 3
Calibration results of crop yield and biomass of *Okra* under different irrigation water regimes

Treatments	Yield (t ha^{-1})		P$_e$ (± %)	Biomass (t ha^{-1})		P$_e$ (± %)
	Observed	Simulated		Observed	Simulated	
T$_1$	10.50	10.70	1.90	14.50	14.70	1.38
T$_2$	10.20	10.40	1.96	14.00	14.40	2.85
T$_3$	8.10	7.50	7.41	10.90	10.10	7.34
T$_4$	6.85	7.20	5.11	9.60	10.20	6.25

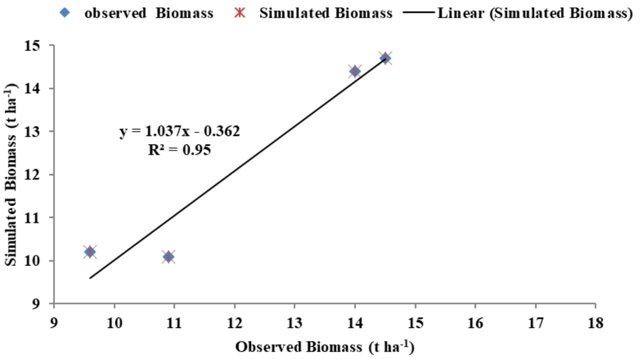

Fig. 3. Model calibration results for biomass of *Okra* under all irrigation levels

Table: 4
Calibration results of crop yield and biomass of *Okra* under different irrigation water regimes

Model output parameters	Mean		RMSE	MAE	E	R^2
	Measured	Simulated				
Fruit yield (t ha^{-1})	8.91	8.95	0.34	0.19	0.97	0.96
Biomass (t ha^{-1})	11.25	11.36	0.50	0.30	0.96	0.95

Table: 5
Validation results of crop yield and biomass of *Okra* under different irrigation water regimes

Treatments	Yield (t ha^{-1})		P$_e$ (± %)	Biomass (t ha^{-1})		P$_e$ (± %)
	Observed	Simulated		Observed	Simulated	
T$_1$	9.60	10.00	4.16	13.40	13.45	0.37
T$_2$	8.90	8.87	0.34	12.00	11.80	1.67
T$_3$	7.90	7.50	5.06	10.80	10.30	4.63
T$_4$	7.50	7.80	4.00	10.00	10.70	7.00

Table: 6
Prediction error statistics of validated AquaCrop model for *Okra*

Model output parameters	Mean		RMSE	MAE	E	R^2
	Measured	Simulated				
Fruit yield (t ha^{-1})	8.47	8.55	0.30	0.25	0.90	0.91
Biomass (t ha^{-1})	11.50	11.58	0.42	0.11	0.91	0.89

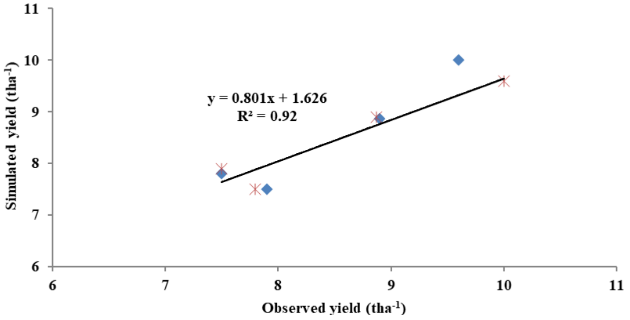

Fig. 4. Model validation for simulating fruit yield of *Okra*

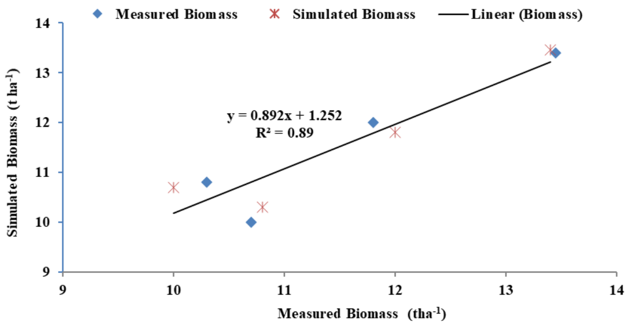

Fig. 5. Model validation for simulating biomass of *Okra*

in Fig's 4 to 5, respectively. The AquaCrop model predicted yield and biomass of *Okra* with good accuracy under different irrigation regimes. Therefore, FAO Aqua Crop model can be used to predict the *Okra* yield and biomass for different irrigation and field management situations.

4. CONCLUSIONS

It was observed that the model was calibrated for yield and biomass with the prediction statistics $0.96 < E < 0.97$, $0.34 < RMSE < 0.50$ and $0.19 < MAE < 0.30$ t ha^{-1} for different irrigation levels. The model was validated for fruit yield and biomass with all treatment combinations with prediction error statistics values $0.90 < E < 0.91$, $0.30 < RMSE < 0.42$, $0.89 < R^2 < 0.91$ and $0.11 < MAE < 0.25$ t ha^{-1}. It was observed that the AquaCrop model was more accurate in predicting the *Okra* yield under full and 80% of FI through drip irrigation as compared to and 60% through drip and flood irrigation method. 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 *Okra* yield with acceptable accuracy under variable irrigation and field management situations in the *Tarai* regions of northern India.

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