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Performance Evaluation of Aqua Crop Model for *Broccoli* 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. 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 field experiment was conducted at the experimental farm of College of Technology, GBPUA and 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 simulation of yield and biomass for all treatments with the prediction statistics $0.98 < E < 0.99$, $0.80 < RMSE < 1.20$ and $0.25 < MAE < 0.30$ t ha^{-1}. 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 obserevd that the Aqua crop model was more accurate in predicting the *broccoli* yield under full and 80% of FI through drip irrigation as compared to and 60% through drip and flood irrigation method. The Aqua crop model predicted yield and biomass of *broccoli* with good accuracy under different irrigation regimes.

Keywords Aqua crop model; Coefficient of determination, Mean absolute error, Root mean square error.

INTRODUCTION

The cultivation of sprouting *broccoli* has becoming increasing popular among Indian growers for the last couple of years primarily due to its high nutritive values and export potentials. The crop is rich in vitamins and minerals and is a good source of sulphoraphane, a compound associated in reducing the risk of cancer

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(Kalia 1995). *Broccoli* (*Brassica oleraces* var Italica) is one of the excellent source of natural antioxidants and dietary fiber (Alsalver *et al.* 2005, Zhang and Hummauzu 2005).

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. Hence, search for sustainable methods to increase crop water productivity 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 behavior 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). 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 (Azam *et al*. 1994). Accordingly, three main crop growth modules 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 water productivity (WP) parameter (Tanner and Sinclair 1983, Steduto and Albrizio 2005). 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 Crop Syst 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 Aqua Crop model (Raes *et al.* 2009, Steduto *et al*. 2009, Kumar *et al.* 2018) 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. Keeping the above things in mind a study was carried out to evaluate the performance of Aquacrop model for *Broccoli* crop under *Tarai* condition of Uttarakhand.

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. The field experiment was conducted at the experimental farm of department of Irrigation and Drainage Engineering, College of Technology, GBPUA and 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 Center, 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.

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 was found to be 23.8% and permanent wilting point 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 m × 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 cm × 50 cm.

Table 1. Experimental details of drip and surface method of irrigation for *Broccoli* crop.

Irrigation treatments	Details of irrigation and mulching treatments
	Drip irrigation
T_1	100 % level of estimated crop water requiremen
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

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:

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

Where,

V = Estimated crop water requirement of okra plant at 100% water use level, liter/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, were used based on the FAO-56 curve methods. The crop coefficient K_c values are varying with the type of crop, its growing stage, growing season and prevailing weather conditions. The shape of the curve represents the changes in vegetation and ground cover during plant development and maturation that affect the ratio of ET_c or ET_0. The crop coefficient value for initial stage $K_c$init was taken as 0.7, for mid stage K_c mid was taken as 1.05 and for end stage it was taken as K_c end as 0.95.

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.

Input data requirement of aqua crop model

Aqua Crop 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 Aqua crop 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

Aqua crop 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 ($K_cT_{r,x}$); (iii) minimum and maximum root depths Zr (m) and roots expansion shape factor; (iv) the initial and maximum crop canopy cover (CC_o,CC_x), canopy growth coefficient (CGC) and the canopy decline coefficient (CDC); (v) adjustment biomass (water) productivity (BWP*); (vi) reference harvest index (HI_o), (vii) water stress coefficients relative to canopy expansion, stomatal closure, early canopy senescence and aeration stress due to water logging.

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

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

Soil parameters

Data pertaining to the soil of experiment site required as input parameters for Aqua crop are viz., number of soil horizons, soil texture, field capacity (FC), permanent wilting point (PWP), saturated hydraulic conductivity (Ksat) 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 Aqua crop model. In full irrigation treatment (i.e. 100%), water was applied up to field capacity level when soil moisture in the root zone approached 50% of total available water (TAW). 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 this study the Aqua Crop model was evaluated through calibration and validation to estimate yield and biomass under different irrigation levels.

Testing of aqua crop model

The FAO- Aqua crop model was tested for *broccoli* 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 Aqua crop model was accomplished by using the observed values from the field experiment during 18th November, 2013 to 10th February, 2014 for broccoli 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 Aqua Crop parameters which was calibrated, measured and adopted are as follows :

Cut-off temperature

Adapted Canopy cover per seedling at 90% emergence (CC_0)
Canopy growth coefficient (CGC)
Calibrated maximum canopy cover (CC_x)
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

Aqua crop simulation results of *broccoli* 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 (Pe), 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 Pe, 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 (Pe) model efficiency (E) (Nash and Sutcliffe1970), given by:

$$Pe \frac{(S_i - O_i)}{O_i} \times 100 \tag{3}$$

$$E = 1 - \frac{\sum^{N}_{i=1} (O_i - S_i)^2}{\sum^{N}_{i=1} (O_i - S_i)^2} \tag{4}$$

Where S_i and Oi are predicted and actual (observed) data, O_i ismean value of O_i and N is the number of observations.

$$RMSE = \sqrt{\frac{1}{(N) \sum_{I=1}^{N} (O_i - S_i)}} \tag{5}$$

$$MAE = \sqrt{\sum^{N}_{i=} \frac{(Si - Oi)}{n}} \tag{6}$$

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

Table 2. Input data of adapted crop parameters (*Broccoli*) used in Aqua crop model to simulate okra productivity.

Sl. No.	Crop parameters	Value	unit
1.	Base temperature	5	^{0}C
2.	Cut off temperature	30	^{0}C
3.	Canopy cover per seedling at 90 % emergence (CC_0)	15	cm^2
4.	Canopy growth coefficient (CGC)	24.3	% day^{-1}
5.	Canopy decline coefficient at senescence (CDC)	3.0	% day^{-1}
6.	Water productivity (WP)	35	gramm^{-2}
7.	Reference harvesting index (HI_0)	65	%
8.	Building 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	6.0	-
12.	Upper threshold for stomatal closure	0.7	-
13.	Stomata stress coefficient curve shape	4.0	-
14.	Time from transplanting to recovered transplant	2	Days
15.	Time from transplanting to maximum rooting depth	40	Days
16.	Time from transplanting to start senescence	72	Days
17.	Time from transplanting to maturity	86	Days
18.	Maximum effective rooting depth	0.35	m

RESULTS AND DISCUSSION

Aqua crop model calibration and validation for okra crop

Aqua Crop model was calibrated using the experimental data of 2013-14 to predict green fruit yield and biomass under different level of irrigation in the experiment. The calibrated values of canopy growth coefficient and canopy decline coefficient were 24.3 % day^{-1} and 3.0 % day^{-1} for *broccoli.* The days to recover from transplanting, transplanting to maximum rooting depth, senescence and maturity were 2, 40, 72 and 86 days respectively. The maximum rooting depth was taken as 0.35 m. The base temperature and cut off temperature were set at 5 ^{0}C to 30 ^{0}C respectively. The calibrated value of water productivity (WP) was obtained as 35 g m^{-2}, which was in the range suggested for Aqua crop for C_4 crop (i.e. crops that produces 4-carbon compound oxalocethanoic (oxaloacetic) acid as the first stage of photosynthesis). The harvestable yield produced by the crop was the product of biomass and harvesting index (HI). The harvesting index was obtained as 65%. Under the crop water stress category factors pertaining to expansion stress factor to be 0.3, 0.8 and 6.0 respectively. The stomatal closure upper threshold and shape factor were 0.7 and 4.0 respectively, while the lower threshold was set at the permanent wilting point.

The model performance pertaining to crop yield is shown in Fig. 1, which reveals good correlation between observed and simulated yield. It was observed from the table that the highest crop yield and biomass was 19.8 and 30.0 t ha^{-1} for treatment (T_1) with drip irrigation based on 100% evaporation re-

Table 3. Calibration results of crop yield and biomass of *broccoli* under different irrigation water regimes.

Treatments	Yield (t ha^{-1})		Pe (± %)	Biomass (t ha^{-1})		Pe (± %)
	Observed	Simulated		Observed	Simulated	
T_1	19.8	19.00	4.04	30.00	28.9	3.67
T_2	19.35	18.50	4.39	29.10	28.4	2.41
T_3	13.5	14.60	8.15	21.30	23.6	10.80
T_4	17.3	17.60	1.74	26.51	26.4	0.41

Table 4. Prediction error statistics of calibrated Aquq crop model for broccoli.

Model output parameters	Mean		RMSE	MAE	E	R^2
	Measured	Simulated				
Fruit yield (t ha^{-1})	17.50	17.42	0.80	0.25	0.99	0.99
Biomass (t ha^{-1})	26.72	26.83	1.25	0.31	0.98	0.99

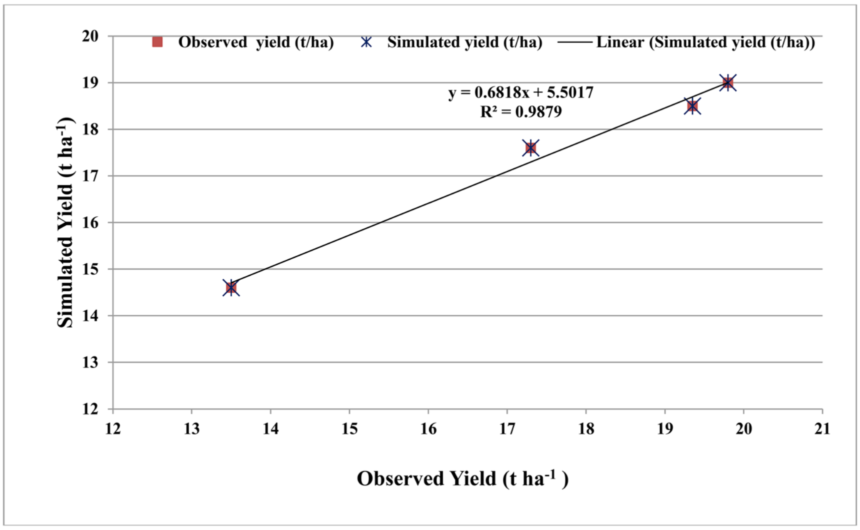

Fig. 1. Model calibration results for crop yield of *broccoli* under all irrigation levels.

Table 5. Validation results of crop yield and biomass of broccoli under different irrigation water regimes.

Treatments	Yield (t ha^{-1}) Observed	Simulated	Pe (± %)	Biomass (t ha^{-1}) Observed	Simulated	Pe (± %)
T_1	18.10	17.20	4.97	27.8	26.7	3.96
T_2	17.50	16.75	4.29	26.9	25.9	3.72
T_3	13.80	15.00	8.69	21.4	23.5	9.81
T_4	17.00	16.71	1.71	26.15	26.03	0.46

plenishment and minimum was 13.5 and 21.3 t ha^{-1} for treatment (T_3) with drip irrigation based on 60% evaporation replenishment. The simulated results of the model after calibration shows that the highest

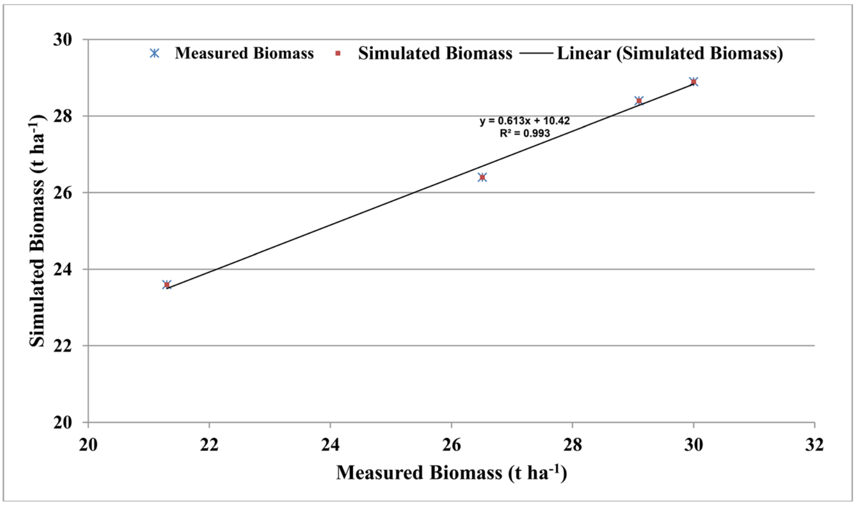

Fig. 2. Model calibration results for biomass of *broccoli* under all irrigation levels.

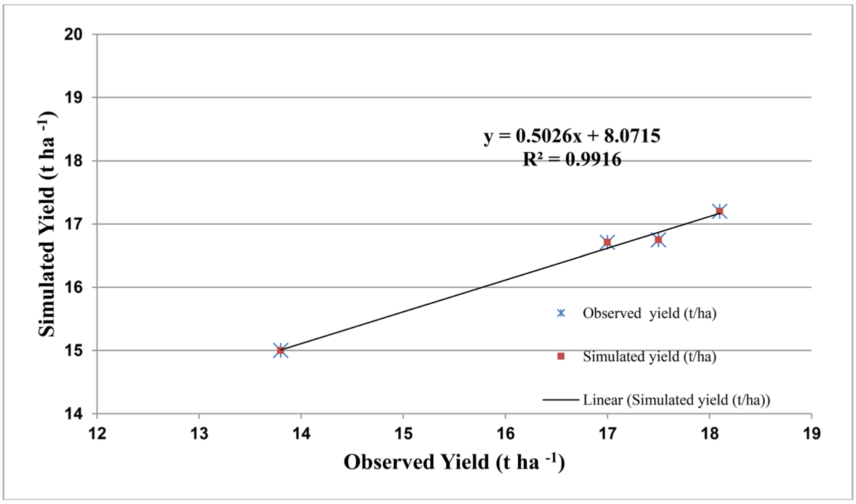

Fig. 3. Model validation results for crop yield of *broccoli* under all irrigation levels.

crop yield and biomass was observed to be 19.0 and 28.9 t ha^{-1} for treatment (T_1) with drip irrigation based on 100% evaporation replenishment and minimum was 14.6 and 23.6 tha^{-1} with drip irrigation based on 60% evaporation replenishment (T_3). The model was calibrated for yield with E and R^2 of 0.99 and 0.99, respectively. It was observed that, the maximum and minimum errors in yield prediction were 8.15 % and 1.74 %, respectively for treatments T_3 and T_4 (Table 2). The model performance for biomass is shown in Fig. 2. The model was calibrated with a model efficiency of 0.98 and R^2 value of 0.99. The biomass prediction error for treatments T_3 and T_4 were 10.8 % and 0.41 % respectively. The prediction error statistics of the calibrated model is presented in Table 2. It was observed from the Table 3 that the model was calibrated for simulation of yield and biomass for all treatments with the prediction statistics $0.98 < E < 0.99$, $0.80 < RMSE < 1.20$ and $0.25 < MAE < 0.30$ t ha^{-1}. Aqua Crop model predictions for yield and biomass of *broccoli* were in line with the observed data corroborated with E and R^2 values approaching one.

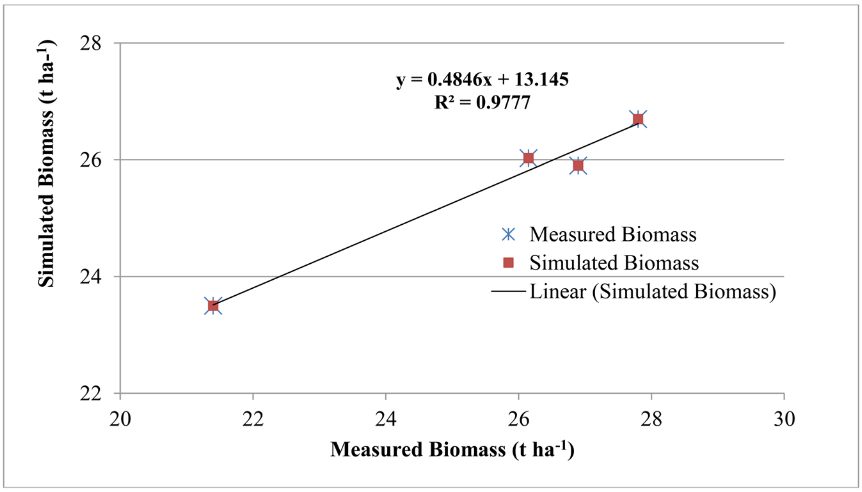

Fig. 4. Model validation results for biomass of *broccoli* under all irrigation levels.

Table 6. Prediction error statistics of validated Aquq crop model for broccoli.

Model output parameters	Mean Measured	 Simulated	RMSE	MAE	E	R^2
Fruit Yield (t ha^{-1})	16.6	16.41	0.84	0.41	0.99	0.99
Biomass (tha^{-1})	25.57	25.53	1.23	0.18	0.98	0.98

The validation results for yield shows that the maximum and minimum prediction errors were 8.69 % and 1.71 % respectively for treatments T_3 and T_4 respectively (Table 4). Moreover, the maximum and minimum error for biomass was observed to be in 9.81 % and 0.46 % in T_3 and T_4 treatments respectively (Table 4). The prediction error statistics of model validation is shown in Table 4. The Tables 5 and 6 shows that the model was validated for crop yield and biomass with all treatment combinations with prediction error statistics values, $0.98 < E < 0.99$, $0.84 < RMSE < 1.23$, $0.98 < R^2 < 0.99$ and $0.18 < MAE < 0.41$ t ha^{-1}. Model validation results and observed values of yield and biomass of *broccoli* for all treatment combinations were plotted in Fig. 3 to 4 respectively. It was observed from the E and R2 values that the crop yield and biomass prediction by Aqua crop model under different irrigation regimes were in line with the observed data. The Table 5 clearly shows that the FAO-Aqua crop model was more accurate in predicting the *broccoli* yield under treatment T_1 (drip irrigation based upon 100 % evaporation replenishment) and T_4 (conventional furrow irrigation). Compared to T_3 (drip irrigation based upon 60 % evaporation replenishment.

CONCLUSIONS

It was observed that the model was calibrated for simulation of yield and biomass for all treatments with the prediction statistics $0.98 < E < 0.99$, $0.80 < RMSE < 1.20$ and $0.25 < MAE < 0.30$ t ha^{-1}. 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 obserevd that the Aqua crop model was more accurate in predicting the *broccoli* 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 Aqua crop model could be used to predict the broccoli yield with acceptable accuracy under variable irrigation and field management situations in the *Tarai* regions of northern India.

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