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Performance evaluation of AquaCrop model for rice (*Oryza sativa*) crop in Trans-Gangetic plains

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ABSTRACT

A study was undertaken to evaluate the performance of FAO AquaCrop model in simulating the grain yield of rice under two different rice cultivation methods. Field experiment was conducted during *kharif* 2012 and 2013 at research farm of Indian Agricultural Research Institute, New Delhi and data pertaining to soil, crop, water and weather parameters were collected. First year data was used for calibration and second year data was used for validation of the model. Experiment was conducted under Conventional Puddled Rice cultivation (CPR) and System of Rice Intensification (SRI) methods and standard agronomic practices for these methods were followed. The performance of the model was evaluated using different statistical parameters like coefficient of determination (R^2), prediction error (PE), model efficiency (E) and mean absolute error (MAE). Model calibration showed good results in simulating grain yield of both the methods with PE varying from -5.26% to 1.71% and -3.81% to -10.93% for CPR and SRI methods, respectively. Prediction error statistics during validation showed very good results with R^2 value 0.92 and 0.98 for CRP and SRI methods, respectively, whereas, MAE was 0.44 and 0.64 for CRP and SRI methods, respectively. Performance of AquaCrop model was found good in simulating rice yield under both CPR and SRI methods of cultivation.

Keywords: Crop modelling, Deficit irrigation, System of rice intensification, Water productivity

The irrigated area of rice (*Oryza sativa* L.) in India is 58.9% (Handral *et al.* 2017). Decrease in irrigation water availability demands enhancement in water productivity of irrigated rice for its sustainable production. Adoption of new water saving technologies is a plausible solution but long-term field experiments need to be carried out for deciding appropriate region-specific technologies. Crop simulation models are useful tools as they simulate long term effects of various practices from data collected through short-term field experiments. These models take into consideration physiological processes and morphological traits to assess crop performance under environments varying in physical, biological and agronomic factors. Furthermore, they can be used to evaluate key interactions quickly and identify traits with the greatest impact on yield potential (Aggarwal *et al*. 1997). Calibrated model is also useful to identify better varieties and management practices for different rice growing environments (Kumar *et al*. 2011). Different crop models like ORYZA 2000, CERES-RICE module of DSSAT, RICAM, AquaCrop, APSIM, and Infocrop are available for simulating yield of rice. These models follow different principles depending upon whether they are water driven, carbon driven or radiation driven (Steduto 2003).

AquaCrop is a water driven model which simulates the attainable crop biomass, harvestable yield and corresponding water productivity in response to the quantity of available water (Steduto *et al.* 2009). The model has been used by different researchers across the world for simulation of crop yield and growth of various major crops like rice, wheat and maize. It was found very useful in irrigation studies and irrigation engineers used it to simulate the water productivity under varying irrigation conditions (Iqbal *et al*. 2014, Ran *et al*. 2018). Water availability has been a serious concern in Trans-Gangetic plains of India and water productivity needs to be improved for sustaining production of rice-wheat cropping system in the region. In present study, performance of AquaCrop model was evaluated for simulation of rice grain yield in Trans-Gangetic plains of India. The validated model can be helpful in maximising the water productivity of rice in the region by adopting appropriate method of rice cultivation.

MATERIALS AND METHODS

Site description: Field experiment was conducted during *kharif* 2012 and 2013 at Research Farm of ICAR-Indian

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Agricultural Research Institute, New Delhi, India. The farm is located at 28°36' N latitude and 77°12' E longitude at an elevation of 228 m above mean sea level. Climate of the area is semi-arid with an average annual temperature of 25°C and average annual rainfall of 650 mm. The daily meteorological data of the study area for the observation period was obtained from the Agromet observatory of Division of Agricultural Physics, ICAR-IARI. Data regarding rainfall, temperature, humidity, bright sunshine hours and wind speed was acquired. Groundwater in the area remained more than 18 m deep during the entire study period. The soil type of the study area was silty clay loam with an upper 15 cm layer of silt, and subsequent layers of clay loam soil. The weather parameters during the crop growth period were analysed and subsequently used for estimation of reference evapotranspiration.

Experimental design: Split-split plot design was adopted in the study with main plot containing different methods of cultivation. The sub-plots had two different rice varieties under adequate and deficit irrigation regimes. Two rice varieties, viz. PRH-10 (V_1) and Pusa 1460 (V_2) were cultivated under two methods of cultivation, viz. System of Rice Intensification (SRI) and Conventional Puddled Rice (CPR) with adequate and deficit irrigation regimes. Standard agronomic practices were adopted for these cultivation methods and periodic data of soil, plant and irrigation water depths was recorded to generate primary experimental data for calibration and validation of AquaCrop model.

Field management practices: PRH-10 and Pusa 1460 were planted in the year 2012 and 2013. Pusa 1460, a semi dwarf type plant is suitable for irrigated-transplanted production conditions. It is a Basmati type product developed using molecular marker assisted selection. PRH-10, an aromatic rice hybrid was developed for commercial cultivation in the irrigated ecosystems of Haryana, Delhi and Uttaranchal. It is an early maturing hybrid (115 days) as against 135 days taken by the best check variety, Pusa Basmati-1. Its yield was 6–10 t/ha in farmers' fields (Viraktamath *et al*. 2009).

Irrigation was given to different experimental plots though the network of HDPE pipelines and flow regulating valves were provided at appropriate places to supply required quantity of water to each plot. Volume of water to be supplied was calculated before every irrigation and the exact volume was supplied through the pipeline network by using a digital water meter. In adequate irrigation treatment of CPR method, 50 mm irrigation was given when the ponded water disappeared, whereas alternate wetting and drying method was followed in deficit irrigation treatment. For adequate irrigation treatment of SRI method, soil was irrigated up to the field capacity after development of hairline crack whereas 25% less water than the adequate treatment was applied in deficit irrigation treatment.

Water productivity: In the crop production system, water productivity is used to define the relationship between the grain yield and the amount of water used in crop production. It is expressed as grain yield per unit volume of water (Ali and Talukder 2008). In this study, water productivity based on total water applied during the growing season has been calculated. The mathematical expression is given here.

$$\text{Water Productivity} = \frac{\text{Grain yield}}{\text{Total water applied}}$$

Input parameters of AquaCrop model: AquaCrop model requires various parameters related to weather, soil, crop, and management practices. Weather data include rainfall, temperature, reference evapotranspiration and annual CO_2 concentration values. Soil data pertaining to number of soil layers, soil water content at saturation, field capacity, permanent wilting point and saturated hydraulic conductivity is required. Moreover, plant density, crop development parameters, crop coefficient, stress factors, rooting depth, water extraction pattern, crop water productivity and harvest index data is necessary for crop parameters. In case of management practices, fertilizer application and irrigation data is required.

Estimation of reference evapotranspiration (ET_0): CropWat 8.0 tool developed by FAO was used for estimation of reference evapotranspiration. CropWat assesses monthly, 10-day basis and daily input of climatic data for calculation of reference evapotranspiration (ET_0) by using FAO Penman-Monteith equation. In the present study, daily reference evapotranspiration was estimated.

Crop parameter values for calibration of AquaCrop model: The crop parameters were adjusted separately for both Pusa 1460 and PRH-10 variety of rice. The parameters like base temperature, upper temperature, soil surface covered by individual seedling, plants per hectare, minimum effective rooting depth, maximum effective rooting depth and crop coefficient were same for both the varieties and their values were 8°C, 30° C, 6 cm^2/ plant, 3,00,000 plants, 0.3 m, 0.4 m and 1.10, respectively. The parameters like time from transplanting to recovery, canopy growth coefficient, canopy decline coefficient at senescence, maximum canopy cover, time from transplanting to start senescence, time from transplanting to maturity, time from sowing to flowering, decline of crop coefficient as a result of ageing were different for both the varieties and their values were 80 and 83 GDD, 0.007 and 0.006 fraction per GDD, 0.005 and 0.004 fraction per GDD, 95% and 99%, 1411 and 1445 GDD, 1752 and 1768 GDD, 1280 and 1288 GDD, 0.15% and 0.14 % per day for PRH-10 and Pusa 1460 variety, respectively.

Model evaluation criterion: Grain yield simulation results given by AquaCrop model were compared with the observed values 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 (PE), coefficient of determination (R^2), mean absolute error (MAE) and model efficiency (E) 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 and MAE indicated the error in model prediction. Mathematical expressions of these different parameters are given here.

$$\text{Prediction Error, PE} = 1 - \frac{(P_i - O_i)}{O_i}100$$

$$\text{Nash-Sutcliffe model efficiency, E} = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

$$\text{Mean Absolute Error, MAE} = \frac{\sum_{i=1}^{n}|P_i - O_i|}{n}$$

Coefficient of determination,

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2 \sum_{i=1}^{n}(P_i - \bar{P})^2}}\right]^2$$

Where, P_i is Predicted data, O_i is Observed data and $\bar{O}$ is the Mean value of O_i.

E and R^2 approaching one and PE close to zero are indicators of better model performance.

RESULTS AND DISCUSSION

Yield and water productivity: Two years data of grain yield, water productivity and water consumption under different treatments of Conventional Puddled Rice (CPR) and System of Rice Intensification (SRI) methods is given in Table 1. SRI method gave superior grain yield compared to CPR method for both the years as well as both the varieties. In 2012, highest yield (5.93 t/ha) was observed for PRH-10 (V_1) variety under SRI method with adequate irrigation (A) whereas, for equivalent treatment in CPR method it was 4.67 t/ha. This 27% increase in the grain yield for SRI method may be attributed to synergetic effect of several agronomic practices. Similar results were observed by Ravichandran *et al*. (2015) who obtained 20% higher grain yield. Moreover, if we compare varietal performance during 2012, PRH-10 variety gave superior grain yield than the respective treatment of Pusa 1460 variety. This increase in grain yield is because of the hybrid nature of PRH-10 variety. Rout *et al*. (2020) also reported that 15-20% increase in grain yield was possible with hybrid rice varieties. Superior performance of SRI method and PRH-10 variety was also observed in 2013.

Water productivity was higher in the SRI method compared to CRP method for all treatments because of higher yield and lower water consumption. Moreover, all deficit irrigation (D) treatments gave higher water productivity than their respective adequate irrigation treatments as yields were reduced marginally despite reduction of about 25% in water consumption. In 2012, highest water productivity (4.82 kg/ha.mm) was observed for PRH-10 variety under SRI method with deficit irrigation whereas it was lowest (2.25 kg/ha.mm) for Pusa 1460 variety under CPR method with adequate irrigation. Similar results were observed in 2013 with highest and lowest values of water productivity as 3.97 kg/ha.mm 2.26 kg/ha.mm, respectively.

Calibration and validation of AquaCrop model: Calibration of AquaCrop model was carried out using experimental data of year 2012. The model has given good results in calibration of grain yield of rice crop under both CPR and SRI methods with R^2 of 0.99 for both the methods. Moreover, model also performed well in terms of other model performance evaluation criterion with PE -5.26% to 1.71% and -10.93% to -3.81% (Table 2), E 0.96 and 0.93, and MAE 0.11 and 0.28 for CPR and SRI methods, respectively. Similar results were reported by Maniruzzaman *et al*. (2015) who observed an average PE of 6.94% during calibration of AquaCrop model for rice crop.

AquaCrop model has given good results in validation of grain yield of rice crop under both CPR and SRI methods with R^2 of 0.92 and 0.98, respectively. Moreover, model has also performed well in terms of other model performance evaluation criterion with PE -21.88% to 2.62% and -25.38% to 3.49% (Table 2), E -6.94 and -1.85, and MAE 0.44 and 0.64 for CPR and SRI methods, respectively. The AquaCrop model validated by Ndiiri *et al.* (2019) for the Mwea irrigation scheme of Kenya also showed good results with

Table 1 Water consumption, grain yield and water productivity for 2012 and 2013

Treatment	2012			2013		
	Total water used (mm)	Grain yield (t/ha)	Water productivity (kg/ha.mm)	Total water used (mm)	Grain yield (t/ha)	Water productivity (kg/ha.mm)
SRI_A_V_1	1287	5.93	4.61	1507	5.72	3.80
SRI_D_V_1	1093	5.27	4.82	1356	5.38	3.97
SRI_A_V_2	1333	3.67	2.75	1548	4.82	3.11
SRI_D_V_2	1127	3.35	2.97	1386	4.49	3.24
CPR_A_V_1	1549	4.67	3.01	1902	4.68	2.46
CPR_D_V_1	1301	4.27	3.28	1628	4.45	2.73
CPR_A_V_2	1612	3.63	2.25	1949	4.40	2.26
CPR_D_V_2	1346	3.13	2.33	1664	4.12	2.48

SRI, System of Rice Intensification; CPR, Conventional Puddled Rice; A, Adequate Irrigation; D, Deficit Irrigation; V_1, PRH-10 variety; V_2, Pusa 1460 variety.

Table 2 Performance of AquaCrop model

Treatment	Calibration			Validation		
	Observed grain yield (t/ha)	Simulated grain yield (t/ha)	PE (%)	Observed grain yield (t/ha)	Simulated grain yield (t/ha)	PE (%)
SRI_V_1_A	5.93	5.61	-5.36	5.72	5.92	3.49
SRI_V_1_D	5.27	5.07	-3.81	5.38	5.29	-1.73
SRI_V_2_A	3.67	3.27	-10.93	4.82	3.69	-23.55
SRI_V_2_D	3.35	3.14	-6.42	4.49	3.35	-25.38
CPR _V_1_A	4.67	4.75	1.71	4.68	4.81	2.62
CPR _V_1_D	4.27	4.34	1.69	4.45	4.36	-1.93
CPR _V_2_A	3.63	3.44	-5.26	4.40	3.75	-14.77
CPR _V_2_D	3.13	3.04	-2.94	4.12	3.22	-21.88

deviation error of 4.2% and 8.7% in case of conventional continuous flooding and SRI methods, respectively.

Overall, calibration and validation results showed that AquaCrop model is very useful in simulating rice grain yield for distinct rice cultivation methods.

Selecting appropriate water saving technology is very important for increasing water productivity of irrigated rice ecosystems and crop simulation models can play a vital role by simulating the region-specific effect of these technologies. AquaCrop model was calibrated and validated in this study for simulating grain yield of CPR and SRI methods in Trans-Gangetic plains of India and its performance was observed good in both the methods of cultivation with R^2 value more than 0.9. The study showed that the SRI method gave superior yield as well as water productivity and can be adopted in Trans-Gangetic plains of India. Furthermore, the validated model can be used for comparing the effect of different management practices of CPR and SRI methods at different locations in the region.

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