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Simulation of maturity duration and productivity of two rice varieties under system of rice intensification using DSSAT v 4.5/CERES-Rice model

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ABSTRACT

Crop growth models have been considered as potential tools for simulating growth and yield of crops. Hence, Decision Support System for Agro-technology Transfer/Crop Estimation through Resource and Environment Synthesis (DSSAT v 4.5/CERES-Rice) model was applied to the data recorded in two years (2008 and 2009). The field experiment included two rice varieties ('Pant Dhan 4' and 'Hybrid 6444') cultivated with system of rice intensification (SRI) method, under three irrigation schedules (irrigation at 1, 3 and 5 day after disappearance of ponded water) and two planting spacings (20 cm x 20 cm and 25 cm x 25 cm). The model was calibrated using data of 2009 and validated with the data of 2008. For 'Pant Dhan 4' maturity was slightly under predicted (gap 2-6 days) by the model with an overall gap between observed and predicted values being 2%, during 2009. However, model predictions were closer (gap 1-2 days) during 2008. The predicted maturity of 'Hybrid 6444' was close to the observed one (gap 1 day) but it was over predicted for the year 2008. The model predicted the yield of both the varieties with fair accuracy. The overall gap between predicted and observed yield was 5% for 'Pant Dhan 4' and 11.4 % for 'Hybrid 6444'. Hence the model can be used for predicting maturity and yield of these rice varieties grown with SRI method.

Key words: CERES-Rice, 'Pant Dhan-4', 'Hybrid 6444', irrigation, spacing, yield simulation

Rice constitutes staple food for more than half of the global population. Thus, food security in the world as well as in India is largely determined by the rice production. Year to year fluctuations in its production has direct bearing on the food security. In India rice yields are low and have become static. Of various research efforts made for improving productivity and quality of rice, SRI is the recent one. Main components of SRI as reported by Latif *et al*. (2009) include: (1) use of young seedlings (8-15 days old with 1 seedling per hill), (2) wider plant spacing from 25 cm x 25 cm to 50 cm x 50 cm, (3) minimum of three hand- weedings at 10-12, 22-25, and 40-42 days after transplanting, (4) addition of organic matter (organic manure and/or compost) to supply adequate nutrients, (5) intermittent drainage and soil drying for soil aeration during the vegetative stage, and (6) transplanting completed within 15-30 minutes of uprooting. However, the individual as well as interaction effects of the key production components like genotype, irrigation regime and crop geometry on productivity of rice under SRI need to be investigated for making any policy on the cultivation of rice with SRI method, especially in the water scarce areas.

Recently, crop modeling and systems analysis have also been viewed as a potential tool to quantify the effects of climate, seasonal weather conditions, soil environment, management and genotype as well as their interactions on crop growth, yield, resource-use efficiency and environmental impacts (Boote *et al*., 1996). These tools can be used to compute the gaps between potential and actual yields, to evaluate management options and to determine likely environmental impacts. They can also be used to forecast yields prior to harvest. Kar *el al*. (2009) used CERES-Rice and ORYZA 1 models on five rice varieties under tropical monsoon climate in eastern India and found that the correlation between above–ground dry biomass yield at flowering stage and grain yield of rice can be predicted in advance (atleast 30 days before harvesting the crop).

The calibration and validation of DSSAT/CERES-Rice is limited, particularly with respect to irrigation management in general and SRI technique in particular. Hence the present investigation was carried out to calibrate and validate DSSAT v 4.5/CERES-Rice model for predicting maturity duration and yield of two varieties of rice cultivated with SRI method.

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MATERIALS AND METHODS

Minimum data requirement

To generate the required experimental and crop management data, a field experiment was conducted at N. E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar (29^0 N latitude, 79.29^0 E longitude and 243.8 m above the mean sea level), Uttarakhand, India, during rainy season of 2008 and 2009. The study site is located in tarai (young alluvial soils with shallow to medium water table and no or low cracking tendency) belt of India and is characterized by a sub-humid and sub-tropical climate. Daily data on weather parameters, like sunshine hours, rainfall, minimum temperature and maximum temperature, required for the model were recorded at weather station located in the vicinity of the experimental field. The soil profile data needed for the model was retrieved from the publication of earlier research work on characterization of Pantnagar soils (Patharchatta series). The initial soil characteristics were determined by collecting samples from the profile extending up to 90 cm depth and analyzing in the laboratory. All records of inputs applied were maintained.

Treatments of the field experiment included two genotypes ('Pant Dhan 4' and 'Hybrid 6444') each planted under 6 combinations of 3 irrigation schedules (Irrigation at 1, 3 and 5 days after disappearance of ponded water) and two spacings (20 cm x 20 cm and 25 cm x 25 cm). The model was applied to two years experimental data, one year's data for calibration and other year data for validation of the model. The main aim was to find out as to how accurately the model simulates genotype x climatic conditions x irrigation interactions and predicts maturity and yield of rice cultivated with SRI method. The model was run separately for each variety.

Model calibration and validation

The current study involved the treatments of irrigation schedules and during crop season of 2009, a relatively better control over water application could be achieved due to less rainfall. Thus, the model was calibrated using field measured data for 'Pant Dhan 4' and 'Hybrid 6444' individually for 2009 and validated using the data of 2008. The calibration of model is based on certain Genetic coefficients. Genetic coefficients of 'Pant Dhan 4' already available in the model were used after careful adjustment. However, the Genetic coefficients for 'Hybrid 6444' were created using the genetic data base system of the model (Table 1).

RESULTS AND DISCUSSION

Predicted maturity and yield of 'Pant Dhan 4' were reasonably close to the observed values. Maturity was slightly under predicted by the model during 2009, the overall variation between observed and predicted values being near 2%. However, the absolute gap (under prediction) ranged from 2-6 days depending upon the treatments (Table 2). However, during 2008 (validation year), model predictions were closer (1-2 days gap). The value tcal was 0.95 and 2.56, which were smaller than t tabulated value at 1% level of significance (4.03), indicating that the difference between observed and predicted values was non-significant.

The relatively higher variation in observed and predicted maturity during 2009 is attributed to climatic and moisture stress, at initial vegetative stages, especially in treatments receiving irrigation at 5 DADPW, which actually caused delay in attaining different phonological stages by rice. It seems the model could not predict very accurately the actual unusual behaviour of the crop caused by climatic and moisture stress and treatment effects during 2009. The predicted maturity of 'Hybrid 6444' was close to the observed one (gap 1 day) during 2009 as the model was calibrated using the input data of 2009. The gap between the predicted and observed values was non-significant as indicted by t-test (tcal 1.27). But the maturity was much over predicted for the year 2008 (Table 2). This happened due to larger differences in climatic conditions of two study years the effects of which, it seems, could not be accurately simulated by the models.

The data pertaining observed and predicted yield of 'Pant Dhan 4' and 'Hybrid 6444' grown with SRI method are shown in Table 3. During calibration year (2009), CERES–Rice over predicted 'Pant Dhan 4' yield for four out of six treatments. However, barring one treatment, the variations between predicted and observed yield were well within the acceptable limit. The overall variation, irrespective of treatments was only 5%. When the calibrated model was run using 2008 input data, yield predictions were still closer to observed ones. For all the treatments the difference between observed and predicted yield was below 10%, the overall gap being below 5%. The smaller values of tcal than t tab for both years also indicated non significant differences between observed and predicted yield.

In 'Hybrid 6444', the predicted yield was reasonably close to the observed one for most of the treatments for the

Table 1 : Genotype coefficients for 'Pant Dhan 4' and 'Hybrid 6444' varieties computed through CERES-Rice model

Symbol	Description	Genetic Coefficients of varieties	
		PANT-4	HYB-6444
P1	P1 Time period (expressed as growing degree days (GDD) in 0C above a base temperature of (90C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.	850	900
P2O	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O developmental rate is slowed, hence there is delay due to longer day lengths.	120	110
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in ^{0}C) for each hour increase in photoperiod above P2O.	200	200
P5	Time period (in GDD ^{0}C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9^{0}C.	12	115
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less leaf blades and sheaths plus spikes) at anthesis. A typical value is 55.	45	50
G2	Single grain weight (g) under ideal growing conditions, i.e.non-limiting light, water, nutrients, and absence of pests and diseases.	0.025	0.023
G3	Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient > 1.0.	0.8	1
G4	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0.	1.5	1

year 2009 as the model had been calibrated using the input data/observed data for the years 2009. Yield predicted by model run for validation using 2008 data, were above 15% for three and below 10% for rest of the treatments. Overall gap was 11.4% (Table 3). Here too, t-test indicated overall non-significant difference between predicted and measured yields. Saseendran *et al*. (1998) reported that CERES-RICE vs. 3.0, predicted maturity and yield of Jaya variety of rice with a fair accuracy in Kerala and concluded that the model could be used for making various strategic and tactical decisions related to agricultural planning in the Kerala state. Kar *et al*. (2009), Yadav (2004) and Sharma and Tripathi (2002) also reported that maturity and yield of rice crop can be predicted with DSSAT-CERES Rice in advance with acceptable variation between predicted and actual yields.

In our study, although, the yields of both the varieties were predicted with acceptable variation from observed yield, the model failed to simulate the spatial variations in treatments. This fact is clearly noticeable from the observed and predicted yield data presented in Table 3. The observed yields were higher under wider than closer spacing, but the predicted yield showed an opposite trend. Such results demonstrate that the benefit of large size panicles with heavier grains found with wider spacing under SRI remained largely unaccounted for by the model in estimating or predicting the yield. Rather, the model was more sensitive to tiller density/m^2. Overall, the yield predictions were quite closer to the observed yield, thus model can be used for predicting yield of rice grown with SRI method. However, further studies are needed in these directions to generate the required data base for improving the efficiency of the model in predicting rice growth and yield.

Table 2 : Days to maturity of rice varieties under SRI as predicted by DSSAT/CERES-Rice model and observed from the field experiment

Treatments	'Pant Dhan 4'						'Hybrid 644'					
	2008			2009			2008			2009		
	Observed	Predicted	Variation (%)	Observed	Predicted	Variation (%)	Observed	Predicted	Variation (%)	Observed	Predicted	Variation (%)
1D x 20x20 cm	107	105	-1.9	111	109	-1.9	110	122	10.9	115	116	0.9
3D x 20x20 cm	104	106	1.9	113	109	1.9	110	122	10.9	117	116	-0.9
5D x 20x20 cm	108	106	-1.9	115	109	-1.9	111	122	9.9	119	115	-3.4
1D x 25 x25 cm	105	105	0.0	111	110	0.0	110	122	10.9	115	116	0.9
3D x 25 x25 cm	105	106	1.0	114	110	1.0	108	122	13.0	117	118	0.9
5D x 25x25 cm	106	106	0.0	114	111	0.0	111	122	9.9	118	118	0.0
Average	106	106	-0.1	113	110	-0.1	110	122	10.9	117	117	-0.3
t_{cal}	0.95		2.56		(-) 147		1.27					

Note: D: Days after disappearance of ponded water

Table 3 : Grain yield (kg/ha) of rice varieties under SRI as predicted by DSSAT/CERES-Rice model and observed from the field experiment

Treatments	'Pant Dhan 4'						'Hybrid 644'					
	2008			2009			2008			2009		
	Observed	Predicted	Variation (%)	Observed	Predicted	Variation (%)	Observed	Predicted	Variation (%)	Observed	Predicted	Variation (%)
1D x 20x20 cm	5894	6445	9.35	6407	6727	5.0	5509	6445	17.0	6438	6371	-1.0
3D x 20x20 cm	6133	6559	6.95	6043	6660	10.2	5555	6559	18.1	6405	6264	-2.2
5D x 20x20 cm	5953	6461	8.53	5431	6404	17.9	5975	6461	8.1	5859	6282	7.2
1D x 25 x25 cm	6759	6356	-5.96	6707	6244	-6.9	6018	6356	5.6	6800	5942	-12.6
3D x 25 x25 cm	6210	6357	2.37	6180	6122	-0.9	6139	6357	3.6	6613	6089	-7.9
5D x 25x25 cm	5917	6203	4.83	5640	5990	6.2	5337	6203	16.2	6422	5988	-6.8
Average	6144	6397	4.34	6068	6358	5.2	5756	6397	11.4	6423	6156	-3.9

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