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Research Paper

Evaluating the CERES-Rice model under dry season irrigated rice in Bangladesh: Calibration and validation

M Maniruzzaman • JC Biswas • MB Hossain • MM Haque • UA Naher • A Biswas • AK Choudhury • S Akhter • F Ahmed • MM Rahman • N Kalra

Irrigation and Water Management Division, Bangladesh Rice Research Institute (BRRI), Gazipur-1701, Bangladesh.

Corresponding author Email: mzamaniwm@yahoo.com.

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Abstract. Crop Environment Resource Synthesis-Rice (CERES-Rice) model was calibrated and validated for major rice varieties suitable for growing in the dry season. Yield performances for BRRI dhan28, BRRI dhan29 and BRRI dhan58 were tested at Gazipur, Rangpur, Rajshahi, Barisal, Comilla and Habiganj districts of Bangladesh under recommended agronomic management practices, respectively. Nitrogen rates (0, 40, 80, 120, 160 and 200 kg ha^{-1}) and varying sowing date experiments were conducted at Gazipur (latitude: 23° 45' N, longitude: 90° 22' E, elevation: 8.4 m amsl) during 2012/2013 and 2013/2014. Seeding interval was 15 days starting from 15 October in 2012 and was extended up to 30 January in 2013. The genetic coefficients were developed based on data from multi-locations yield trials and date of sowing and fertilizer management trials at Gazipur. The model performance was evaluated using prediction error (P_e), coefficient of determination (R^2), normalized root means squared error (NRSME) and Willmott's index of agreement (*d*). The model calibration yielded $0.81<R^2<0.99$, 0.81<NRMSE<10.74, and $0.81<d<0.97$ in simulating grain yields, biomass and growth durations, respectively. The model validation yielded $0.60<R^2<0.95$, 1.72<NRMSE<5.99, and $0.86<d<0.98$ in simulating grain yields, biomass and growth durations. During calibration, the prediction errors for average grain yield, biomass and growth duration varied from 3.46 to 4.80%, 10.20 to 15.39% and 0.92 to 2.25%, respectively indicating satisfying model performances. The changes in simulated results compared to observe values varied from -1.82 to 9.12% for grain yield, 5.38% to 18.82% for biomass production and -4.67 to 4.87% for growth duration depending on tested varieties. Thus, CERES-Rice model is ready for its use in climate change impacts and variabilities on rice production.

Keywords: CERES-Rice model, calibration, validation, model application, yield, Bangladesh.

INTRODUCTION

Rice is one of the most widely grown crops that provide food for more than 3.5 billion people worldwide (IRRI, 2012). More than 90% of the world's rice is produced and consumed in Asia (IRRI, 2012) and the demand for this crop is increasing. No more extensive rice cultivation is possible in many countries; rather arable land and fresh water availability for rice production are decreasing. The availability of both surface and subsurface fresh water for agriculture is declining in many Asian countries including Bangladesh (Postal, 1997). In Bangladesh, approximately 50% of the fresh water is used for rice production (Guerra *et al*., 1998), but its demands for drinking and hygiene and industrial uses are intensifying. Besides, unpre-dictable rainfall because of climate change impacts and no facility for storage of surface runoffs are playing a negative role for rice production in Bangladesh. As a result, water allocation has become important for policy makers, especially for dry season irrigated rice that contributes about 55% of the total rice production in Bangladesh (BBS, 2016). As a consequence, crop growth model can play an important role under such situations.

Crop growth models such as the Decision Support System for Agrotechnology Transfer (DSSAT) v4.6 is a windows-based programme that includes tools and utility programmes for managing soil, water resources, weather, genetic coefficients, crop, and pest data. It allows users to input, organize, store, retrieve and analyze crop, soil and weather data and to quantify their effects on crop growth, productivity, and sustainability of agricultural production (Nain and Kersebaum, 2007). These tools can reduce the need for expensive and time-consuming field trials and could be utilized for yield gap analyses in various crops including rice (Pathak *et al.*, 2005). The DSSAT can be used as a decision support tool for multi-location yield trials, optimizing N fertilizer management for a targeted crop yield, while minimizing nutrient losses and selecting optimum planting windows. Crop growth models have recently been used to study precision agriculture within the framework of a decision support system (DSS) that automates simulations using different crop management strategies. There is a need to understand growth and yield behavior of major rice cultivars, which mainly depends upon the genetic coefficients of a particular variety. For this purpose, there is a need to calibrate and validate DSSAT model for subsequent application in management response and climate change impact evaluation studies.

The DSSAT Crop Environment Resource Synthesis-Rice (CERES-Rice) model (Ritchie *et al*., 1986) could be used in assessing risk as well as determining management strategies because of its ability to predict crop growth and yield as reported by Tsuji *et al*. (1994), Tongyai (1994), Escano and Buendia (1994), Seino (1994), Baer *et al*. (1994) and Jin *et al*. (1995). The model has been tested over a wide range of environments by the International Benchmark Site Network for Agro-technology Transfer (IBSNAT) (Singh *et al*., 1988). It incorporates coefficients that accounts for genotypic variations in terms of phenology, physiology and genetic attributes (Hunt *et al*., 1989). These genetic coefficients are required as model inputs and they vary widely among varieties. Determining the genetic coefficients and its validation for a specific variety in a given region must be taken into account before model applications.

In Bangladesh, the main limitation for using CERES-Rice model is lack of calibrated and validated cultivar coefficients of popular rice varieties like BRRI dhan28, BRRI dhan29 and BRRI dhan58. Therefore, the study has been undertaken to evaluate the genetic coefficients for selected rice varieties in various crop growing environments and to validate the CERES-Rice model for field application.

MATERIALS AND METHODS

Description of study sites and experiments

The study was conducted in six locations of Bangladesh having diverse soil and weather conditions. The study locations were Gazipur (23° 45' N latitude, 90° 22' E longitude, 8.4 m above mean sea level [AMSL]) in central part, Rangpur (24° 41' N latitude, 89° 16' E longitude, 33.04 m AMSL), Rajshahi (24° 22' N latitude, 88° 22' E longitude, 17.24 m AMSL) in north-western part, Barisal (22° 41' N latitude, 90° 21' E longitude, 2.54 m AMSL) in south central part, Comilla (23° 28' N latitude, 91° 09' E longitude, 6.54 m AMSL) in south eastern part and Habiganj (24° 25' N latitude, 91° 25' E longitude, 22.54 m AMSL) in north-eastern part of Bangladesh.

The experiments were conducted during 2012/2013 and 2013/2014 dry season. Popular rice varieties: BRRI dhan28, BRRI dhan29 and BRRI dhan58 were used for yield, biomass production, tiller and panicle production, grain size and growth duration under varying levels of N-fertilizer management and different sowing windows. In all locations, selected varieties were sown from 15 - 30 November, 2012 in all locations and harvested during middle April to middle May, 2013. Validation field experiments were conducted in 2013/2014 following similar sowing dates. All trials utilized BRRI recommended management practices except in N-fertilizer trials. BRRI recommended fertilizer doses for BRRI dhan28 and BRRI dhan58 were 120-30-75-18-5 kg ha^{-1} (Nitrogen-Phosphorus-Potassium-Sulfur-Zinc [NPKSZn]) and for BRRI dhan29 was 140-30-75-18-5 kg ha^{-1} (NPKSZn), respectively. In N-fertilizer experiment at Gazipur 0, 40, 80, 120, 160 and 200 kg N ha^{-1} of NPKSZn were used. In sowing date experiment, seeds were sown on 15 October to 30 December at 15 days interval of 2012 and extended up to 30 January in 2013. The experiment was repeated in the similar way in next crop growing season of 2013-14.

The CERES-Rice model description

The CERES-Rice model was developed under the International Benchmark Sites for Agrotechnology Transfer (IBSNAT) project (Ritchie *et al*., 1987; Tsuji *et al*., 1994). It estimates yield of irrigated and rainfed rice, determines duration of growth stages, dry matter production and partitioning, root system dynamics, effect of soil water and N on photosynthesis and photosynthate partitioning, carbon balance, and water balance. The CERES-Rice model assumes nine stages of rice plant growth: pre-sowing, germination, emergence, juvenile, floral induction, heading, flowering, grain filling and harvesting. Completion of these growth stages is determined by accumulation of growing degree-days (GDDs). The soil water balance and N component of the model can be bypassed when user assumes a non-limiting condition. The model calculates infiltration, runoff, drainage and evapotranspiration (ET) to estimate soil water balance. The CERES-Rice estimates runoff by using USDA (1972) modified Soil Conservation Service Curve Number Technique. The difference between daily precipitation and runoff provides estimates of infiltration. If irrigation is included as an input to the crop, the model does not estimate runoff but allows all water to infiltrate. To estimate potential ET, the model offers options of using the Priestley and Taylor (1972) method and the FAO-Penman method (Doorenbos and Pruitt, 1977). The method of Ritchie (1972) has been incorporated in the model to estimate actual ET.

Nitrogen sub-model estimates N requirement of rice, its supply and uptake. The model assumes that N deficiency adversely affects leaf expansion, photosynthesis, and its concentration in grain. The final yield, as calculated by the model, depends on the grain weight which is a function of grain growth rate and length of grain filling period. In the model grain growth rate is assigned a value characteristic of the size classes of rice plant, namely, long, medium, and short. The model also assumes that yield is directly proportional to panicle weight.

Data collection

Weather data

Weather data required by DSSAT model are daily values of maximum and minimum temperatures, rainfall and solar radiation. The weather data for Gazipur location was collected from BRRI weather station and for other locations were collected from Bangladesh Meteorological Department (BMD). The solar radiation was converted from sunshine hours data by DSSAT inbuilt Weatherman.

Soil data

Soils data required by DSSAT model are the number of soil layers that differ in their characteristics, soil texture, and volumetric water content at saturation, field capacity, permanent wilting point and saturated hydraulic conductivity. Soil sample were collected in three layers upto 60 cm (0-20, 20-40 and 40-60 cm) by considering the root zone of rice before the cropping season (November to December, 2012) for Gazipur, Rangpur, Rajshahi, Barisal, Comilla and Habiganj. Collected parameters are shown in Table 1. Since measured soil hydraulic data were not available for this field soil, model inbuilt pedotransfer function was used to generate this information (Ritchie, 1998).

Plant management practices

Plant growth parameters in terms of phenological stages, temporal biomass and leaf area index and yield and its attributes were recorded. The growth stages are pre-sowing, germination, emergence, juvenile, floral induction, heading, flowering, grain filling, and harvesting (Ritchie *et al*., 1987; Tsuji *et a*l., 1994). The yield components are the number of effective tillers per unit area, number of grains per effective tiller and 1000 grain weight.

Genetic coefficients of rice

"RICER046.CUL" is a file containing genetic coefficients of rice varieties, composed of development or phasic coefficients (P coefficients) and growth coefficients (G coefficients). The P coefficients enable the model to predict the development events such as panicle initiation, flowering and maturity. The definition of P and G coefficients are presented in Table 2. The P components permit the model to predict maturation rates because the physical development of rice is driven by temperature. However, the temperature effect is modified by day length if it is photoperiod sensitive variety. Temperature is then converted into heat units or degree-days which is computed and accumulated on daily basis. The P1 and P5 coefficients are defined as the duration of the vegetative and grain filling stages, respectively. The P1 coefficient varies greatly among different types of variety. The maturity days of a particular variety depends upon the value of P1 and P5 coefficients. The P2O is a critical photoperiod or the longest day length at which the development occurs at a maximum rate. The development rate slows down when day length is greater than P2O. The panicle initiation is delayed for each hour increase in photoperiod above P2O.

The growth coefficients as defined in Table 2 represent the potential value for a particular variety. Grain size (G2) is a genetic coefficient that varies with varieties, which achieved under ideal condition and it is the most stable character of a particular variety. Grain yield is the product of grain size (G2) and grain number (G1). Grain number depends upon the number of panicle numbers in turn depends on tiller numbers (G3).

Hunt's (1989) technique was used to calibrate genetic coefficients of selected varieties by using field data. This technique estimates genetic coefficients using field experimental data sets. The processes were finally accomplished by running the model with appropriate coefficients, comparing model outputs with actual data, adjusting coefficients, and repeating process until acceptable fits were obtained. We have calculated P1, P5, G1, G2 and G3 based on field experimental data. Since all required data are not available from field experiments, we selected an existing rice cultivar from

Table 1. Physical and chemical properties of soils for selected locations.

Attributes	Gazipur			Rangpur			Rajshahi			Barisal			Comilla			Habiganj		
Soil depth (cm)	20	40	60	20	40	60	20	40	60	20	40	60	20	40	60	20	40	60
WP (vol., frac.)	0.29	0.29	0.28	0.09	0.08	0.06	0.23	0.17	0.15	0.24	0.24	0.22	0.26	0.25	0.24	0.26	0.25	0.24
FC (vol., frac.)	0.45	0.43	0.40	0.28	0.22	0.26	0.41	0.35	0.35	0.44	0.44	0.44	0.41	0.39	0.38	0.41	0.39	0.39
Porosity (vol., frac.)	0.50	0.50	0.49	0.48	0.46	0.40	0.48	0.49	0.44	0.49	0.48	0.48	0.46	0.47	0.47	0.46	0.47	0.47
Ks (cm/hr)	0.32	0.35	0.32	1.10	0.89	0.81	0.15	0.48	0.48	0.15	0.14	0.14	0.17	0.19	0.19	0.29	0.21	0.19
BD (g/cc)	1.35	1.34	1.35	1.39	1.41	1.52	1.29	1.42	1.42	1.26	1.30	1.31	1.36	1.35	1.35	1.34	1.35	1.35
OC (%)	0.72	0.60	0.38	0.45	0.37	0.20	1.18	1.10	0.90	0.90	0.70	0.40	0.54	0.31	0.29	0.74	0.31	0.21
Clay (%)	48.0	48.0	47.0	17.0	8.0	5.0	60.0	35.0	37.0	34.0	36.0	34.0	46.0	44.0	42.0	45.0	44.0	42.0
Silt (%)	47.0	46.0	47.0	51.0	37.0	15.0	27.0	30.0	30.0	59.0	58.0	56.0	42.0	41.0	40.0	43.0	41.0	40.0
Total N (%)	0.07	0.06	0.04	0.04	0.03	0.02	0.15	0.12	0.10	0.09	0.07	0.04	0.05	0.03	0.03	0.07	0.03	0.02
pH	6.4	6.3	6.2	5.5	5.9	6.1	5.6	6.0	6.2	7.5	7.0	6.8	6.7	7.0	7.3	6.6	7.0	7.2

WP- Wilting point, FC- field capacity, Ks- Saturated hydraulic conductivity, BD- Bulk density, OC- Organic carbon.

DSSAT (CERES-Rice) model having similar growth duration and yield with tested varieties and selected P2O, P2R and G4 parameters values as default values. The model was run with these coefficients with Generalized Likelihood Uncertainty Analysis (GLUE) and simultaneously Sensitivity Analysis module of DSSAT and observed the difference between simulated and observed field data. It was accomplished iteratively by running the model with all unknown genetic coefficients through sensitivity analyses, comparing model output with actual data, adjusting coefficients and repeating the process till acceptable fits were obtained. This process was repeated for each variety. The selected genetic coefficients parameters were analyzed based on standard statistical procedures. The DSSAT version 4.6 was used to predict grain yield, biomass and growth duration and analyzed based on the evaluation parameters.

Model calibration and validation

The model was calibrated by using grain yield, biomass, growth duration data from GxE experiment and multi-location trials at Gazipur, Rangpur, Rajshahi, Comilla, Barisal and Habiganj along with data from date of sowing and N-fertilizer management experiments at Gazipur during dry season 2012-2013. The simulated yield, biomass and growth duration data were compared with the field data sets and calculated the model evaluation parameters. Similarly, the validation was done based on the dry season data sets of 2013-2014 and calculated the model evaluation parameters.

Model evaluation

The CERES-Rice model simulated rice yield, above ground biomass and growth durations at harvest and the values were compared with the observed values during both calibration and validation processes. The model performance was evaluated using prediction error (P_e), coefficient of determination (R^2), normalized root means square error (NRSME), and Willmott's index of agreement (*d*) as presented below:

$$P_e = \frac{(P_i - O_i)}{O_i} \times 100 \quad (1)$$

$$R^2 = \left[\frac{\sum(Oi-\overline{O})(Pi-\overline{P})}{\sqrt{\sum(Oi-\overline{O})^2 \sum(Pi-\overline{P})^2}}\right]^2 \quad (2)$$

$$NRMSE = \frac{1}{\overline{O}}\sqrt{\frac{\sum(Pi-Oi)^2}{n}}\,100 \quad (3)$$

$$d = 1 - \frac{\sum(Pi-Oi)^2}{\sum(/\,Pi-\overline{O}\,/+/\,Oi-\overline{O}\,/)^2} \quad (4)$$

where, P_i and O_i is the predicted and observed data, $\overline{P}$ is the mean of predicted data and $\overline{O}$ is the mean

Table 2. Genetic coefficients used in CERES-Rice model.

Coefficients	Definition and unit
P1	Time period (expressed as growing degree days [GDD] in ^{o}C above a base temperature of 9°C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as basic vegetative phase of the plant.
P2O	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P2O, the developmental rate is slowed and hence there is a delayed growth of plants.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.
P5	Time period (GDD in °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9°C.
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (excluding leaf blades, sheaths and spikes) at anthesis. A typical value is 55.
G2	Single grain weight (g) under ideal growing conditions, that is, non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.
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.

Source: DSSAT model Rice cultivar file (Ritchie et al., 1986).

of observed data.

The coefficient of determination (R^2) ranges from 0 to 1 in which values close to 1 indicate a good agreement and values greater than 0.5 are considered acceptable in watershed simulations (Moriasi *et al*., 2007). In case of NRMSE, a simulation can be considered excellent if NRMSE is smaller than 10%, good between 10 and 20%, fair between 20 and 30% and poor if larger than 30% (Raes *et al*., 2012). The values of *d* ranges between 0 and 1, where 0 indicate no agreement and 1 indicate a perfect agreement between predicted and observed data (Willmott, 1984).

Model application

The model was used to estimate yield, biomass and growth duration for the selected varieties for Dinajpur at north-western part of Bangladesh. This region is comparatively low temperature for dry season irrigated rice production environment. The model was used for 30 years seasonal run from 1981 for a range of sowing dates from 15 October to 31 January at 7 days interval on the silty loam soil.

Initial conditions for each simulation were set 3 days before sowing, and simulations were carried out using 30 years (1981/1982 to 2010/2011) of historical weather data for Dinajpur soil. The soil depth and properties remained the same as for calibration and validation experiments. All simulations were carried out under N non-limiting conditions, that is, BRRI recommended fertilizer condition and also for non-limited water condition, that is, well irrigated condition.

RESULTS AND DISCUSSION

Genetic coefficients determination

Out of 20 varieties from DSSAT model through sensitivity analyses, 2 were found to be similar to our varieties. BRRI dhan28 and BRRI dhan58 comparatively matched with PR114 and BRRI dhan29 with IR 8 in terms of grain yields and growth duration for Gazipur site. The coefficients were selected for the tested varieties (Table 3).

The genetic coefficients or cultivar specific parameters were calculated based on the different experiments and locations. Then the genetic coefficient values as obtained through sensitivity analyses and GLUE runs were replaced

Table 3. Genetic coefficients of similar variety chosen from DSSAT RICER046.CUL file.

Tested variety	Chosen variety	P1	P2O	P2R	P5	G1	G2	G3	G4
BRRI dhan28	PR114	650	200	520	12.0	59	0.025	1	1
BRRI dhan29	IR 8	880	52	550	12.1	65	0.028	1	1
BRRI dhan58	PR114	650	200	520	12.0	59	0.025	1	1

Table 4. Calculated genetic coefficients parameters (P1, P5, G1 and G2) for the tested varieties.

Param	BRRI dhan28				BRRI dhan29				BRRI dhan58			
	P1	P5	G1	G2	P1	P5	G1	G2	P1	P5	G1	G2
Avg.	841.1	455.1	52	0.022	987.7	548.7	65	0.021	914.4	501.9	58	0.021
STD	59.3	21.9	4.0	0.001	33.5	29.7	5.1	0.001	40.4	20.3	3.8	0.001
SE	12.9	4.8	1.9	0.0002	7.3	6.5	2.1	0.0002	8.8	4.4	1.8	0.0002
CV (%)	7.1	4.8	5.1	4.1	3.4	5.4	5.5	5.2	4.4	4.0	4.6	4.9

Table 5. Genetic coefficients parameters for BRRI dhan28, BRRI dhan29 and BRRI dhan58.

Variety	P1	P2O	P2R	P5	G1	G2	G3	G4
BRRI dhan28	825.0	150.0	425.0	12.6	50.0	0.0220	1.0	1.0
BRRI dhan29	950.0	150.0	550.0	12.8	60.0	0.0210	1.0	1.0
BRRI dhan58	850.0	150.0	470.0	12.7	55.0	0.0210	1.0	1.0

by calculated values against tested varieties except P2O, P2R, G3 and G4 (Table 4) and saved it in RICER046.CUL file in DSSAT model. Sensitivity analyses were done several times for P2O, P2R, G3 and G4 and subsequently suitable values for the coefficients were selected. All iterations were done based on the coefficients and comparison between the observed and simulated values was done. The process was finally accomplished by running the model with genetic coefficients, model output was compared with actual data, adjusting the coefficients and process was repeated till acceptable fits were obtained based on the statistical parameters of the model simulated and actual field data sets. The final values of genetic coefficients are shown in Table 5.

Model calibration results

In calibration season (2012-13), simulated grain yield, biomass and growth duration of all the tested varieties in different locations, N management options and sowing dates were similar with measured data. However, simulated biomass yield was slightly higher than the observed data (Table 6). The test statistics for calibration results under different locations, N management options and sowing date at Gazipur were $0.92<R^2<0.98$; 1.59<NRMSE<6.70 and 0.96<d<0.97 for grain yields; $0.97<R^2<0.99$; 7.25<NRMSE<10.74 and 0.84<d<0.92 for biomass production; $0.81<R^2<0.96$; 0.81<NRMSE<3.23 and 0.81<d<0.96 for growth duration for all the tested varieties (Table 6). Therefore, the model predictions for grain yield and biomass were similar to the observed data with R^2 values approaching unit. The model overestimated average grain yield (3.46 to 4.80%), biomass yield (10.20 to 15.39%) and growth duration (0.92 to 2.25%) for all the tested varieties (Figure 1). These average overestimations of different studied parameters are rather small, and they also support the good statistical metrics presented in this study. However, the grain yield percent deviations of simulated data from observed values varied from -1.41 to 8.92% for BRRI dhan28, -1.82 to 9.12% for BRRI dhan29 and -1.59 to 8.15% for BRRI dhan58 (Figure 1). Similarly, for biomass it was from 5.38 to 15.98% for BRRI dhan28, 5.39 to 14.71% for BRRI dhan29 and 10 to 18.82% for BRRI dhan58 (Figure 1). On the other hand, growth duration values varied from -4.67 to 4.43% for BRRI dhan28, -4.15 to 4.87% for BRRI dhan29 and -2.17 to 4.66% for BRRI dhan58 (Figure 1). These results indicated that model simulated grain yields and growth durations were very close and biomass prediction was poorly matched with field measured data.

Timsina *et al*. (1998) reported that simulated yields for BR14 and BR11 were either over or underestimated (RMSE = 1.2 t ha^{-1}; d-index = 0.94), with large under predictions for 0 N in northern Bangladesh. Mahmood *et al*. (2003) also reported satisfactory performance of the model, with observed yields from 2.9 to 6.7 t ha^{-1} and simulated yield from 2.6 to 7.3 t ha^{-1}, and RMSE of 1.3 t ha^{-1}, for central and northern Bangladesh. In northwest India, RMSE for grain yield was 1.7 t ha^{-1} and d-index was

Table 6. Indicators of goodness of fit for grain yield, biomass and growth duration of different *Boro* varieties for model calibration in 2012-13.

Parameter	Simulated	Observed	Pe (%)	R^2	NRMSE	d
BRRI dhan28						
Yield, kg ha^{-1}	5877	5613	4.64	0.92	6.70	0.96
Biomass, kg ha^{-1}	15254	13881	10.20	0.97	10.36	0.92
Growth duration, days	151	147	2.25	0.81	3.23	0.81
BRRI dhan29						
Yield, kg ha^{-1}	6655	6317	4.80	0.97	6.65	0.97
Biomass, kg ha^{-1}	16607	15056	10.24	0.99	10.74	0.92
Growth duration, days	166	163	1.58	0.81	2.52	0.96
BRRI dhan58						
Yield, kg ha^{-1}	6225	6034	3.46	0.98	1.59	0.97
Biomass, kg ha^{-1}	15661	13844	15.39	0.98	7.25	0.84
Growth duration, days	156	155	0.92	0.96	0.81	0.92

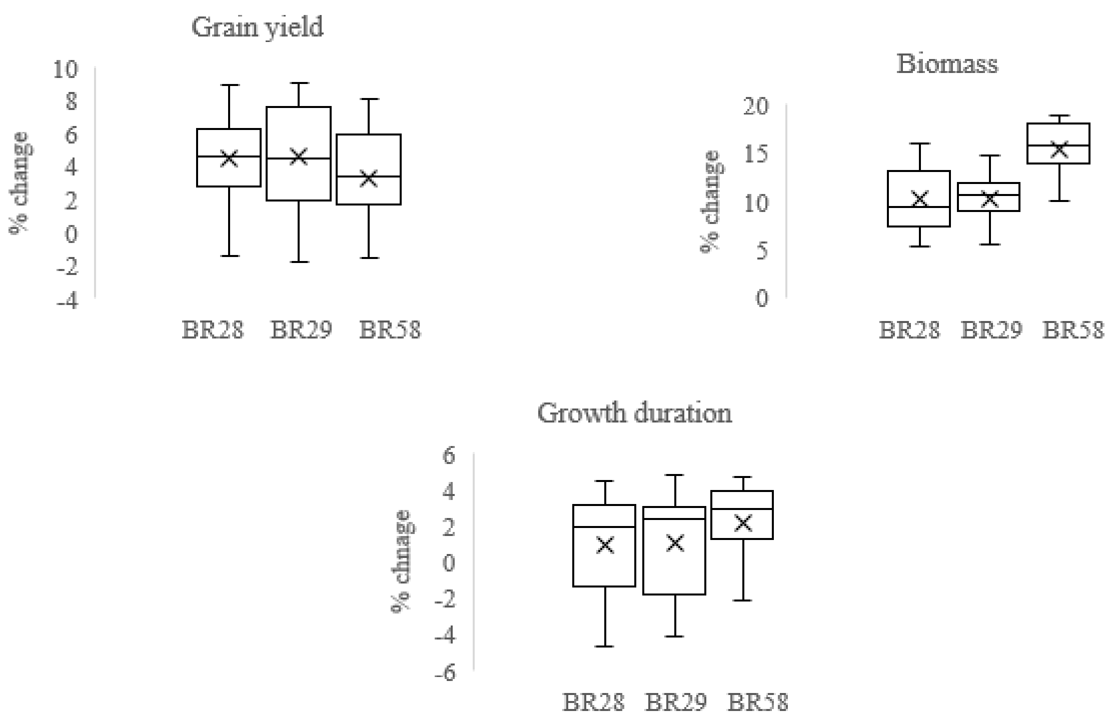

Figure 1. Percent change in simulated grain yield, biomass and growth duration compared to observed values for three different rice varieties for model calibration.

0.79, indicating large discrepancy between simulated and observed data (Timsina *et al*., 1995), largely due to inaccurate prediction of phenological stages. Pathak *et al*. (2004) evaluated CSM-CERES-Rice v4.0 using data from a range of water regimes and N management options for three rice-wheat growing environments in northwest India. Results indicated good agreement for grain yield (RMSE = 0.72 t ha^{-1}; d-index = 0.95) and reasonable agreement for dry matter yield (RMSE = 2.6 t ha^{-1}; d-index = 0.83) in well-fertilized (N) treatments, but generally poor agreement for the 0 N treatments.

Amien *et al*. (1996) reported that the CERES-Rice model v3 under-predicted grain yield by 10 to 20% for all locations in Indonesia, except at Sukamandi in west Java, due to under prediction of grain weight (R^2 = 0.83; RMSE = 0.98 t ha^{-1}). Using CERES (with CERES-Rice growth routine), Matthews *et al*. (2000) reported fairly good prediction of grain and above-ground biomass yield

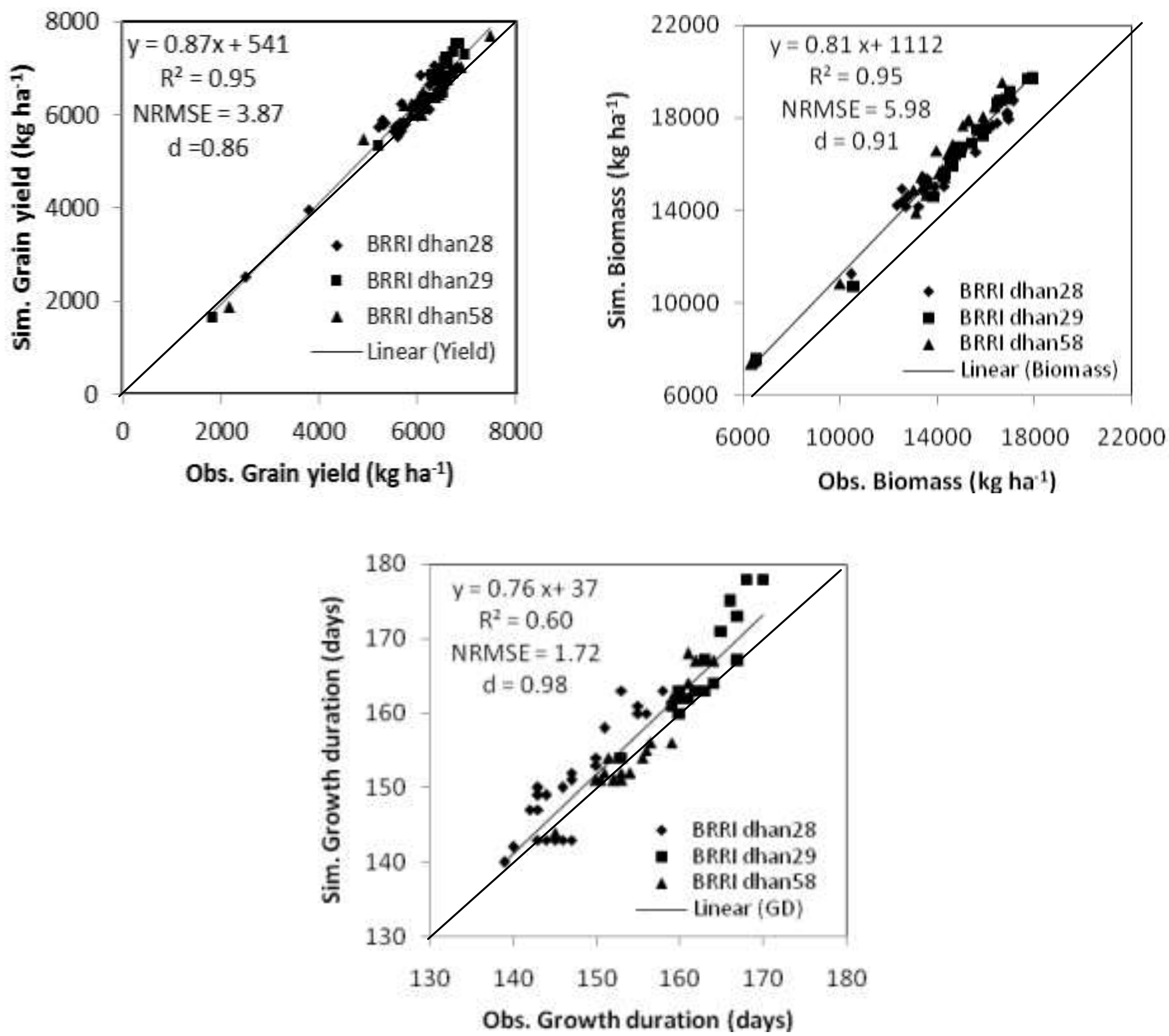

Figure 2. Validation results of grain yield, biomass and growth duration with their goodness of fit for BRRI dhan28, BRRI dhan29 and BRRI dhan58.

(RMSE = 1.1 and 3.9 t ha^{-1}, respectively) at Los Baños, Philippines and Hangzhou, China, except for three treatments with mid-season drainage in the dry season at Los Banos. In Kerala, India, Saseendran *et al*., 1998a,b predicted grain and straw yields of Jaya and IR8 within 3 and 27% of measured yields (RMSE = 0.2 and 1.9 t ha^{-1}) with d-index of 0.99 and 0.56, respectively. Rao *et al*. (2002) also reported good yield prediction in Kerala (RMSE = 0.2 t ha^{-1}, d-index = 0.99) for all transplanting dates for three cultivars in one year.

Alociljha and Ritchie (1991) reported good agreement between observed and predicted number of days to anthesis and maturity, with normalized RMSE of 4 and 3%, and d-index of 0.65 and 0.87, respectively for three upland rice cultivars (IR43, UPLRi 5, UPLRi 7) in the Philippines. In northwest India (Timsina *et al*., 1995), the absolute RMSE for both anthesis and maturity was 6 d, but d-index was 0.72 for anthesis and 0.96 for maturity, indicating less satisfactory performance of the model. In northern Bangladesh, Timsina *et al*. (1998) found a very good agreement for anthesis and maturity dates of BR11 and BR14, with normalized RMSE of 5 and 4%, and d-index of 0.98 and 0.96, respectively. Thus, the model calibration results indicated that the determined genetic coefficients were appropriate for the all of the tested varieties.

Model validation results

The calibrated model was validated using the 2013/2014 field observed data. The comparison of the observed and simulated grain yield, biomass and growth duration and their indicators of goodness of fit of the validated model are shown on Figure 2. The simulated grain yield, biomass and growth duration for all the tested varieties including the GxE conditions for different locations, N management and date of sowing effect at Gazipur and measured values are very much similar in all conditions. However, simulated biomass yield was slightly higher than observed data. The validation results under normal and GxE growing conditions for different locations, nitrogen management and date of sowing at Gazipur for grain yield was R^2 = 0.95, NRMSE = 3.87 and d = 0.86; that for biomass was R^2 = 0.95, NRMSE = 5.98 and d = 0.91; and that for growth duration was R^2 = 0.60, NRMSE = 1.72 and d = 0.98 for all of the tested varieties (Figure 2). Therefore, the model predictions for grain yield and biomass were comparable to the observed data with R^2 approaching unit. These differences are rather small, and they also support the good statistical metrics presented in Figure 2.

Jeong *et al*. (2014) used DSSAT model to assess the effect of N fertilizer rate and split N fertilizer application on rice yield in Korea, with a NRMSE and *d* values ranges from 4.1 to 11.7% and 0.94 to 0.95, respectively. Timsina and Humphreys (2006) evaluated that CERES-Rice predicted more variable data for NRMSE was 23% for both and *d* index was 0.90 and 0.76 for grain and biomass respectively in Asia, China and Australia. On the other hand, CERES-Wheat model predicted for them reasonably well (NRMSE = 13 to 16%; d-index = 0.86 to 0.97). Liu *et al*. (2011) simulated yield of corn and soybean by DSSAT model with NRMSE values ranging from 4.3 to 14.0% in Onterio, Canada. Liu *et al*. (2013) showed that DSSAT model for soybean and maize under conventional and conservation tillage practices were in good agreement between simulated and measured yields achieved in calibration (NRMSE = 9 to 15%) and good to moderate agreement for model evaluation (NRMSE = 12 to 17%).

The results of the DSSAT model can be compared with other models for rice yield prediction. Kropff *et al*. (1994) reported that ORYZA1, CERES-Rice, SIMRIW, and TRYM overestimated yields in the wet season at IRRI and, with the exception of ORYZA1, predicted LAI inaccurately in the dry and wet season at IRRI, and at Kyoto, Japan and Yanco, Australia. Mall and Aggarwal (2002) concluded that both CERES-Rice and ORYZA1N predicted grain yields satisfactorily (within ±15%), especially for yields above 4 t ha^{-1}, with RMSE of 0.7 and 0.6 t ha^{-1}, respectively. In another study with six models, all models closely predicted yields for early sowing at Moroika, Japan and Nan Chang, China, but not for late sowing at Nan Chang and for the dry season at IRRI. The largest deviations were for SIMRIW and ORYZA1, followed in order by TRYM, CERES-Rice, ORYZA-European, and RICAM. For harvest index, RICAM and ORYZA1 had the largest MSD for Nan Chang early and late seasons, while CERES-Rice had the largest MSD at Moroika. CERES-Rice also had the highest deviations for biomass yield.

Iqbal *et al*. (2014) showed that the statistical parameters for model evaluation of grain yield were RMSE = 0.58 Mg ha^{-1}, MAE = 0.38 Mg ha^{-1}, MBE = 0.01 Mg ha^{-1}, NRMSE = 11.9% and d = 0.92 and that for aboveground biomass were RMSE = 0.87 Mg ha^{-1}, MAE = 0.69 Mg ha^{-1}, MBE = 0.08 Mg ha^{-1}, NRMSE = 8.62% and d = 0.95 are comparable with those obtained by Mkhabela and Paul (2012) for winter wheat grown in Western Canada using AquaCrop model for grain yield simulation. The deviation range is considerably better for grain yield (8.22 to 11.55%) and biomass (7.95 to 11.15%) in validation season, whereas Araya *et al*. (2010a,b) reported that the deviation range in validation data was -13 to 15.1% in case of grain yield of barley and for biomass that was -4.3 to 14.6% and -0.10 to 8.70% for teff. Iqbal *et al*. (2014) reported that the AquaCrop model simulated above ground biomass more accurately than grain yield, with deviation ranging from 0.4 to 5.8% in validation. Hsiao *et al*. (2009) presented a deviation for maize biomass simulation in AquaCrop between -0.4 and 21.9%. Several authors (Iqbal *et al*., 2014; Heng *et al*., 2009; Araya *et al*., 2010a,b; Zeleke *et al*., 2011; Abedinpour *et al*., 2012) reported much greater deviations under severe water stress or rainfed conditions, as compared to well watered treatments for winter wheat, maize, teff and canola crops simulated by AquaCrop.

The results from this study therefore, suggest that DSSAT model can be used to compute genetic coefficients with considerable degree of accuracy for different N fertilizer management and date of sowing for modeling dry season irrigated rice yield and biomass production in Bangladesh. The model simulated grain yield more effectively than biomass and growth duration, which agrees with the results obtained by other models.

Effect of sowing date on grain yield in model application

Grain yield varied across years and sowing dates (Figure 3), with mean yield of 5.59 t ha^{-1} for BRRI dhan28 (short duration variety), 6.46 t ha^{-1} for BRRI dhan29 (long duration variety) and 5.88 t ha^{-1} for BRRI dhan58 (medium duration variety) at Dinajpur. In all of the tested varieties, highest yield was found on 29th October sowing date with the highest growth duration of 172, 187 and 176 days for BRRI dhan28, BRRI dhan29 and BRRI dhan58, respectively. The growth duration for the selected varieties required about 10 to 15 days more from their recommended (country average) days because Dinajpur is situated comparatively cooler regions in optimum sowing windows. The country average growth duration for BRRI dahn28 is 140 to 145 days, for BRRI dhan29 is 160 to 165 days and that for BRRI dhan58 is 150 to 155 days within 15 November to 15 December sowing windows (BRRI, 2012). All of the selected varieties produced stable yield after 15th November sowing. Fifteen October to 15 November sowing, the yield was comparatively higher with higher growth duration and

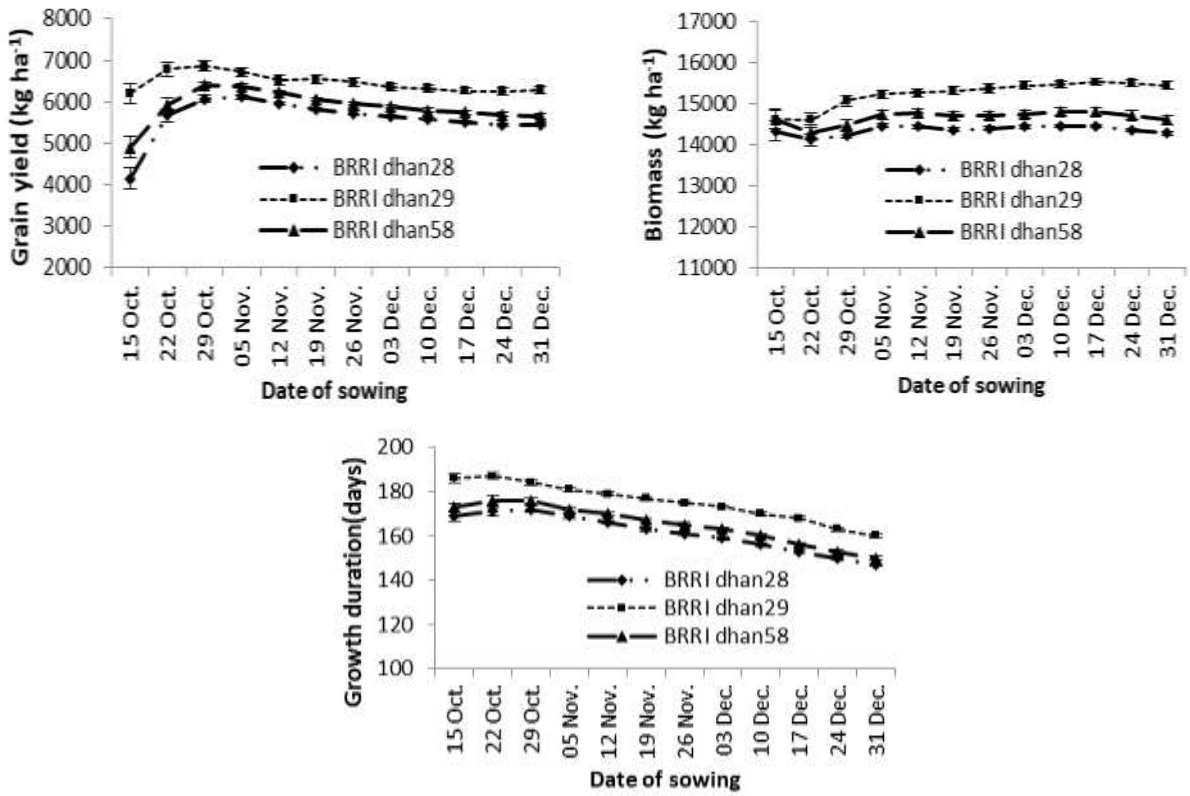

Figure 3. Date of sowing effects on grain yield, biomass and growth duration for 30 years period in Dinajur areas; Error bars indicate the standard error.

also with greater uncertainty. Therefore, for optimum yield, after 15 November to 15 December became the most suitable with reasonable growth duration with optimum biomass production, which matched with BRRI recommendation. After 15 November sowing, there was a slight declining trend of yield. But, most of the farmers of that locality start sowing at December due to avoid the cold injury of seedlings during Boro season.

There was a decline in yield by 20 kg ha^{-1} for sowing after 15 November for BRRI dhan29 and that for 36 and 37 kg ha^{-1} for BRRI dhan28 and BRRI dhan58, respectively from 1981/82 to 2010/11 for each day delay in sowing after 15 November to 31 December over the same 30 years period. BRRI (2012) reported that BRRI dhan28 decline at the rate of 30.5 kg ha^{-1} whereas BRRI dhan29 decline at the rate of 36.7 kg ha^{-1} for each day delay in sowing after 15 November. Biswas *et al*. (2001) also reported that both growth duration and grain yield of rice reduces depending on planting time. Ortiz-Monasterio *et al*. (1994) reported that for Ludhiana, the optimum sowing dates were 5 November for PBW 34 (long-season) and 15 November for PBW 154 (medium-season) and PBW 226 (short season) cultivars. After the optimum sowing dates, yields were reduced by 0.8, 0.7 and 0.7% per day, or by 37, 34 and 34 kg ha^{-1} d^{-1}, respectively, which was comparatively similar with our long and medium duration varieties. Randhawa *et al*. (1981) also reported that delaying sowing from 25 October to 15 December reduced yields of Kalyansona, WL711, HD2009, and WG357 by 1.2, 0.9, 1.2 and 1.0% per day, respectively. Our results based on model predictions are thus similar to the results obtained from the field experiments.

CONCLUSIONS

Field experiments were conducted with rice during 2012-13 and 2013-14 in various locations with BRRI dhan28, BRRI dhan29 and BRRI dhan58 under normal management practices and at Gazipur with varying levels of Nitrogen-N and various dates of sowing. The first year, 2012/2013 trial was used for calibration of CERES-Rice model, primarily genetic coefficients generation and second year, 2013/2014 was used to validate the generated coefficients, as a test for its performance evaluation. Soil and weather data were collected/determined at per dataset requirement for running of the model. The genetic coefficients were generated using GLUE and Sensitivity Analysis subroutine of DSSAT. After setting the genetic coefficients as generated through this procedure, the model was run for the first year and the simulated phenology, biomass and yield were in close agreement with the observed ones. Subsequently the model was taken for its validation by running the model with second year experimental file. The performance was evaluated in terms of phenology, final biomass and grain yield, and the results within statistical limits for the model's satisfactory performance. The application performance of that model was found satisfactory. The calibrated model, for major cultivars tested over locations, the model can now be taken for various applications viz. climate change impacts the optimal sowing evaluation, defining window for higher production.

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