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Rice phenology and growth simulation using CERES-Rice model under the agro-climate of upper Brahmaputra valley of Assam

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सार – फसल वृद्धि अनुकरण मॉडल, जो प्रायोगिक आँकड़ों के मामलों में वेध हैं। कृषि के क्षेत्र में नीतिगत निर्णय लेने में सक्षम हैं। इस प्रकार के वेध मॉडल स्थान विशिष्ट प्रयोगों और अन्य स्थानों पर किए गए प्रयोगों तथा विभिन्न समय अवधियों के लिए प्राप्त सूचना का भी उपयोग कर सकते हैं। फसल अनुकरण मॉड़लों के सही कैलीब्रेशन और आकलन के लिए सभी शस्य विज्ञान प्रयोगों में मृदा, मौसम और फसल प्रबंधन के विस्तृत न्यूनतम आँकड़ों के सेट के संग्रहण की आवश्यकता है। इसके मद्देनजर, वर्षा की स्थितियों में उगाई गई लम्बी अवधी की धान की फसल रंजीत के लिए 1998 से 2005 के दौरान जोरदार (26° 47′ उ., 94° 12′ पू., 87 m amsl) के किए सात फील्ड प्रयोगों के आँकड़े एकत्रित किए गए। CERES – Rice v4.5 मॉडल के लिए अपेक्षित अनुवांशिकी गुणांक प्राप्त किए गए और ऊपरी ब्रह्मपुत्र घाटी की जलवायु में मॉडल के निष्पादन का आकलन किया गया। इन परिणामों से पता चलता है कि CERES – Rice v4.5 मॉडल ऊपरी बह्मपुत्र घाटी की जलवायविक स्थितियों को रंजीत धान की ऊपज और वृद्धि के चरणों का समुचित सटीकता के साथ आकलन करने के लिए सक्षम है। अत: राज्य में कृषि योजना संबंधी विभिन्न नीतिगत और कुशल निर्णय लेने के लिए इस मॉडल को साधन के रूप में उपयोग किया जा सकता है।

ABSTRACT. Crop growth simulation models, properly validated against experimental data have the potential for facilitating strategic decision making in agriculture. Such validated models can also make use of the information generated for site specific experiments and trials to other sites and for different time durations. For proper calibration and evaluation of crop simulation models, there is a need for collection of a comprehensive minimum set of data on soil, weather and crop management in all agronomic experiments. Keeping this in view, data from seven field experiments conducted at Jorhat (26° 47' N, 94°12' E; 87 m amsl) during 1998-2005 for long duration rice cultivar Ranjit grown under rainfed conditions were collected. Genetic coefficients required for running the CERES-Rice v4.5 model were derived and the performance of the model under the climate of upper Brahmaputra valley was evaluated. These results indicate that the CERES Rice v4.5 model is capable of estimating growth stages and grain yield of rice cultivar Ranjit in the climatic conditions of upper Brahmaputra valley with reasonable accuracy. Hence, the model have the potential for its use as a tool in making various strategic and tactical decisions related to agricultural planning in the state.

Key words – CERES-Rice, Phenology, Genetic coefficients, Brahmaputra valley.

1. Introduction

Over the last two decades, crop models have evolved considerably which have reasonably good approximations of reality and are used for applications after careful calibration and validation in the target environment (Ritcher and Sondgerdth, 1990). The crop growth model developed can be useful in crop management, if phenological stages are accurately simulated in necessary detail needed for practical applications (Miller *et al.*, 1993). Some of the crop management decisions which can be linked to phenology are: (1) irrigation application which should be made at strategic phenophases to achieve maximum water use efficiency, (2) fertilizer application at early, mid & maximum tillering and at panicle initiation, (3) herbicide application, which can be based on the leaf stage of the crop as well as the target weeds, (4) invertebrate pest control, which must take place prior to a given leaf stage and (5) harvest. The works of Wickham (1973) and Ahuja (1974) clearly showed that the yield variation in rice crop due to weather, management and biotic factors can be addressed through a modeling approach. Later many attempts have been made with different extents of success at developing an ideal weather-dependent model for rice crop (Angus and Zandstra, 1979; Whisler, 1983; Penning de Vries *et al*., 1989; Miller *et al*., 1993; Kropff *et al*., 1994). The CERES-Rice model, as available in DSSATv4.5 (Hoogenboom *et al*., 2010), is a growth and development simulations model of the rice crop under rainfed and lowland conditions. Predictions of different phenological stages of the crop are crucial because at different critical stages of growth of the plant, for instance at anthesis, it is essential to ensure that the crops do not suffer from moisture and fertiliser stresses. Also, good prediction on the date of maturity can help the farmer to plan for harvesting and marketing his crop. A reasonably validated model for its phenological predictions can be utilised for advising the farmer to plan and optimize his farm operations for better outputs. Keeping in view the potential of crop simulation models in agricultural research and applications, an attempt has been made to evaluate the CERES-Rice model in simulating crop growth, development and yield of rice at Jorhat situated in the upper Bramhaputra valley of Assam.

2. Materials and method

2.1. *CERES-Rice crop model*

The CERES-Rice crop model (Singh *et al*., 1993) was used, which is embedded in the DSSAT v4.5 software (Hoogenboom *et al*., 2010). The DSSAT software consists of Minimum Data Set (MDS), suite of Crop models and Analysis package. The CERES-Rice is a physiologically based, management oriented model that utilizes carbon, nitrogen, water and energy balance principles to simulate the processes that occur during the growth and development of rice plants within an agricultural system. The model simulates the following processes on a daily basis, *viz*., (1) phenological development of rice as the genetic characters of the crop variety studied and weather; (2) growth of leaves, stems and roots; (3) biomass accumulation and partitioning among leaves, stem, panicle, grains and roots; (4) soil water balance and water use by the crop; and (5) soil nitrogen balance and uptake by the crop (Alocilja and Ritchie, 1990). Also, the phenological stages, *viz*., sowing, germination of seeds, emergence, transplantation, juvenile phase, panicle initiation, heading, beginning and end of grain filling and physiological maturity are simulated by the model. Phenological phases are simulated in the CERES-Rice model using the concept of thermal time or degree-days and photoperiod as defined by the genetic characteristics of the crop. Crop growth is simulated employing a carbon balance approach in a source-sink system. The analytical relationships of the soil water balance and nitrogen transformation and uptake leading to the quantification of these stress factors are presented by Jones and Kiniry (1986). Detailed description of the model structure and initial validation was given by Alocilja and Ritchie (1988) and Alocilja (1987).

2.2. *Input requirements*

The model requires a set of minimum data pertaining to weather, soil, genotype characteristics and crop management details to run. These data are provided to the model through data files. In addition to these, the experiment performance data is also used as input, if the simulated results are to be compared with data recorded in a particular experiment. To run the model, a file containing information about all the available experiments is provided to the model.

Weather data : Daily weather data on maximum temperature, minimum temperature, total solar radiation and rainfall for the crop period are required for simulation.

Soil data : Soil properties, including single value of drainage, runoff, evaporation and radiation reflection coefficients; values of several depth increments of rooting preference factors; soil water contents at the drained upper limit, lower limit, and saturation; N and organic matter details; initial conditions of soil water content; texture, bulk density, pH, NO_3 and NH_4 at several depth increments (Jones *et al*., 2003) are the essential parameters needed for running the model.

Cultivar data file : Eight cultivar specific genetic coefficients are required for describing the various aspects of performance of a particular genotype in the model (Table 1).

Experiment details file : This contains the details of all inputs (observed field data) to the models for each simulation (Table 2).

Experiment performance file : This contains observed values of experimental performance of the crop, which can be used for comparison with the simulated outputs of the model runs. The information provided includes anthesis date, physical maturity, yield, grain weight, grain number, panicle number, maximum LAI and dry matter.

Different statistical indices were used for evaluation of simulation performance, including root mean square error (RMSE) (Wallach and Goffinet, 1987) and index of agreement (*d*-value) (Willmott, 1982). The computed values of RMSE, normalized RMSE and *d*-value determine the degree of agreement between the predicted

TABLE 1

Genetic coefficients of rice

S. No.	Parameter definition
1.	Time period (expressed as growing degree days GDD in °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 referred to as the basic vegetative phase of the plant (P1)
2.	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 (P2O)
3.	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O (P2R)
4.	Time period (in GDD °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9 °C (P5)
5.	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis. A typical value is 55 (G1)
6.	Single grain weight (g) under ideal growing conditions, *i.e.*, non limiting light, water, nutrients, and absence of pests and diseases (G2)
7.	Tillering coefficient (scaler value) relative to IR-64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0 (G3)
8.	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 (G4)

values with their respective observed values and a low RMSE value and d-value that approaches one are desirable. The RMSE was calculated according to Eqn. 1.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \quad (1)$$

where, P_i and O_i refer to predicted and observed values for the studied variables, respectively. Normalized RMSE ($RMSE_n$) gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent with a normalized RMSE less than 10%, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30% and poor if the normalized RMSE is greater than 30% (Jamieson *et al*., 1991). The $RMSE_n$ (Loague and Green, 1991) was calculated following Eqn. 2.

$$\mathrm{RMSE_n} = \left[\frac{\mathrm{RMSE} \times 100}{\mathrm{M}}\right] \quad (2)$$

TABLE 2

Experimental details required for running the model

Type of information	Details of information
Field characteristics	Weather station name, soil and field description details
Soil analysis data	Soil properties used for the simulation of nutrient dynamics, based on filed nutrient sampling, if any
Initial soil water and inorganic nitrogen conditions	Starting conditions for water and nitrogen in the profile and also used for root residue carry over from the previous crop, and N symbiosis initial conditions when needed
Seedbed preparation and planting geometries	Planting date, population, seeding depth and row spacing data
Irrigation and water management	Irrigation dates, amounts, thresholds and rice flood water depths
Fertiliser management	Fertiliser date, amount and type information
Organic residue application	Additions of straw, green manure, animal manure
Chemical applications	Herbicide and pesticide application data
Tillage operations	Dates and types of tillage operations
Environmental modifications	Adjustment factors for weather parameters as used in climate change and constant environment studies
Harvest management	Harvest dates and plant components harvested
Specification of simulation options	Starting dates
On/off options for model components	water and nitrogen balances

where, M is the mean of the observed variable.

The index of agreement (*d*) proposed by Willmott *et al.* (1985) was estimated by

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(\left|P_i^{/}\right| - \left|O_i^{/}\right|)^2}\right], 0 \le d \le 1 \quad (3)$$

where, n is the number of observations, P_i the predicted observation, O_i is a measured observation, $P_i^{/} = P_i – M$ and $O_i^{/} = O_i – M$ (M is the mean of the observed variable). According to the *d*-statistic, closer the index value is to one, better the agreement between the two variables that are being compared and *vice versa*.

2.3. *Background of the study area*

During the rice cropping season (June/July to Nov/Dec), the average seasonal maximum and minimum

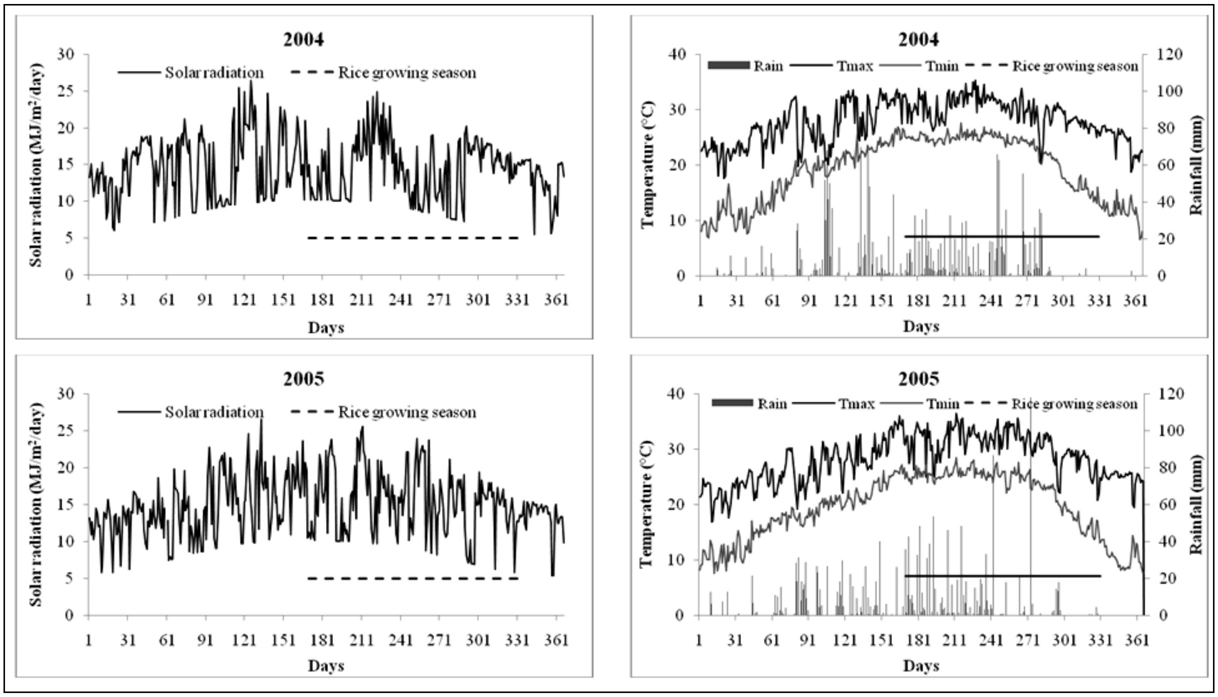

Fig. 1. Weather conditions during the rice growing seasons of 2004 and 2005

temperature are 29.5 °C and 21.4 °C respectively. Overall, 70% of the total annual rainfall (range 1226 to 2278 mm) occurs during the rice growing season. The monthly average solar radiation during the rice season ranges from 12.0 to 16.2 MJ/m^2/day.

The soil of the experimental area is characterized as fine, mixed, hyperthermic family of *Humic Endoaquepts*. It is alluvium-derived, poorly drained, nearly level to very gently sloping flood plains of the Brahmaputra valley. The soil is very deep. The texture is silt loam at the surface horizon and silty clay loam or clay loam or clay at the lower horizons. The bulk density of the soil ranges from 1.5 to 1.8 gm/cm^3. The saturation percentage varies from 20 to 49%. The organic matter content of the surface horizon is 1.2% and its value decreases with depth. The pH of the soil is 5.0.

Rice is the main staple food in Assam. It is grown in an area of 24.25 lakh ha with a production of 39.31 lakh tones during triennium ending (TE) 2009-10. Winter rice (*kharif*) occupies 17.1 lakh ha of the total rice area and contributes 71% of total production in the state. The average productivity of winter rice in Assam during 2009-10 was 1824 kg/ha (DES, 2010). In the upper Brahmaputra valley zone, rice is grown in 4.10 lakh ha area out of which winter rice occupies an area of 3.89 lakh ha with a production of 7.37 lakh tones (TE: 2009-10).

2.4. *Experimental details*

2.4.1. *Selection of variety*

A long duration (150-155 days), photoperiod insensitive winter rice variety "Ranjit" (TTB 101-17) was selected for all the seasons of the experiment. Ranjit is recommended for shallow submergence (0-30 cm water depth) areas during *sali* (*kharif*) season in Assam. It is a semi-tall (105-110 cm) variety with moderate tillering ability (10-12 tillers). The panicle length is 28 cm with 194 grains/panicle. The potential yield of the variety is 6.0 t/ha and at about 4.9 t/ha at frontline demonstration (FLD) in farmers fields (Siddiq, 2000).

2.4.2. *Crop management data*

The rice variety Ranjit was transplanted in three different dates during *kharif* seasons of 1998, 1999, 2003, 2004 and 2005. Transplanting dates during 1998, 1999, 2003, 2004 and 2005 respectively were 22nd June, 7th July and 22nd July; 20th June, 5th July and 20th July; 24th June, 8th July and 26th July; 24th June, 7th July and 24th July and 21st June, 6th July and 22nd July. There were 20 rows per plot and 25 hills per row. Thirty-day old seedlings were transplanted at a depth of 3-4 cm at a spacing of 20 cm by 20 cm of hill and row spaces. The number of seedlings per hill was two.

TABLE 3

Soil profile data of the experimental site at Jorhat

Depth (cm)	Clay (%)	Silt (%)	Stones (%)	Bulk density (gm/cm^3)	Organic carbon (%)	pH (1:2.5 H_2O)	Soil nitrogen (%)	CEC (meq/100g)
0-5	17.1	15.8	0	1.5	0.85	5.5	0.08	5.8
0-15	17.1	15.8	0	1.5	0.83	5.5	0.05	5.8
15-30	20.8	13.5	0	1.4	0.68	5.7	0.04	4.4
30-45	32.7	20.4	0	1.5	0.46	6.0	0.02	6.2

TABLE 4

Calibrated genetic coefficients for the rice variety *Ranjit* under the agroclimatic condition of Jorhat

S. No.	Genetic coefficients	Unit	IR-36	Ranjit
1.	Juvenile phase coefficient (P1)	GDD (°C)	470.0	1100.0
2.	Critical photoperiod (P2O)	h	11.7	12.4
3.	Photoperiodism coefficient (P2R)	GDD (°C)	149.0	250.0
4.	Grain filling duration coefficient (P5)	GDD (°C)	400.0	320.0
5.	Spikelet number coefficient (G1)	-	68.0	44.0
6.	Single grain weight (G2)	mg	0.023	0.023
7.	Tillering coefficient (G3)	-	1.00	0.90
8.	Temperature tolerance coefficient (G4)	-	1.00	1.00

TABLE 5

Simulated and observed phenological events and grain yield from model calibration during 2004 and 2005 for rice variety *Ranjit* under different transplanting dates

Year	Date of transplanting	Anthesis date (DAT)		Physiological maturity date (DAT)		Grain yield (kg/ha)	
		Observed	Simulated	Observed	Observed	Observed	Simulated
2004	24 June	116	113	143	142	4690	4632
	8 July	108	109	137	142	4500	4699
	24 July	104	106	132	139	4380	4483
2005	22 June	103	106	138	132	4500	4553
	6 July	100	104	133	133	4275	4344
	25 July	97	101	129	131	3750	3821
RMSE			3.0		4.4		105
Normalized RMSE			2.9		3.2		2.4
d-value			0.91		0.72		0.97

DAT days after transplanting

The N fertilizer (40 kg N/ha in the form of urea) was applied in three applications. The first half of urea was applied during final land preparation; the remaining half was applied in two equal splits after 30 and 60 days of transplanting. In addition, P_2O_5 and K_2O - 20 kg/ha each in the form of Single Super Phosphate (SSP) and Muriate of Potash (MOP) were also applied during final puddling. All other agronomic practices such as weeding and plant protection measures were standard and uniform for all the planting dates. The crop was raised as rainfed. The required data were collected in standard format in each season for calibration and validation of CERES-Rice model.

2.4.3. *Weather data*

The weather file of DSSAT software includes information on location of the weather station (latitude

TABLE 6

Simulated and observed phonological events and grain yield from model validation during 1998, 1999 and 2003 for rice variety Ranjit under different transplanting dates

Year	Date of transplanting	Anthesis date (DAT)		Physiological maturity date (DAT)		Grain yield (kg/ha)	
		Observed	Simulated	Observed	Observed	Observed	Simulated
1998	22 June	112	107	138	131	4795	4720
	7 July	110	102	136	128	4380	4813
	22 July	108	100	132	126	3960	4585
1999	20 June	106	108	140	134	4204	4624
	5 July	100	103	134	130	4387	4630
	20 July	97	101	127	130	4150	4717
2003	24 June	113	108	140	134	4550	4220
	22 June	108	103	137	133	4230	4413
	7 July	103	102	133	136	3980	4385
RMSE			5.1		5.5		401
Normalized RMSE			4.8		4.1		9.3
d-value			0.54		0.40		0.12

and longitude) daily values of incoming solar radiation (MJ/m^2/day), maximum and minimum air temperature (°C) and rainfall (mm) as minimum data set. Required data (maximum temperature, minimum temperature, rainfall and bright sunshine hours) during experimental period were collected from Assam Agricultural University, Jorhat where the observatory is located near the experimental site. As the model requires daily total solar radiation, it is derived from bright sunshine hours using Angstrom equation by the model (Saseendran *et al.*, 2000). Weather conditions during the rice growing seasons of 2004 and 2005 are depicted in Fig. 1.

2.4.4. *Soil data*

The required soil data of the model include soil classification, surface slope, soil color, permeability and drainage class. Soil profile data by soil horizons include: upper and lower horizon depths (cm), saturation water content, upper and lower limit (field capacity and wilting point), percentage sand, silt and clay content, bulk density, organic carbon, pH in water, aluminum saturation and potential root distribution and depth. Soil data of the experimental site was collected from the Department of Soil Science, Assam Agricultural University, Jorhat (Table 3). The soil is very deep; thickness of the A horizon is 16 to 20 cm while B horizon is 70 to 80 cm thick. The texture is silt loam at the surface horizon and silty clay loam or clay loam or clay at the lower horizons. The bulk density of the soil ranges from 1.5 to 1.8 gm/cm^3. Saturation percentage varies from 20% to 49%. The pH of the soil is 5.5.

3. Results and discussion

3.1. *Calibration of CERES-Rice model*

Model calibration or parameterization is the adjustment of parameters to the local conditions so that simulated values compare well with the observed ones (Timsina and Humphreys, 2006). Calculating the genetic coefficient of cultivars is the first step in the conventional use of the CERES models. Data from six (6) field experiments conducted in *kharif* seasons of 2004 and 2005 for rice cv. *Ranjit* in conjunction with requisite soil and weather parameters were used to derive its genetic coefficients. To begin with, the genetic coefficients of rice cv. IR-36 available in the list provided with DSSAT package were used and further these coefficients were modified following an iterative procedure (Hunt *et al.*, 1993) to match the simulated values with the observed values mainly flowering duration, maturity duration, grain yield, grain weight and harvest index. The order of priority in which the coefficients were modified, was phenolgical coefficients (P1, P2O, P2R and P5) followed by growth coefficients (G1, G2, G3 and G4) following Hunt and Boote (1998). Genetic coefficients, along with their definition, derived for cv. Ranjit are given in Table 4. The juvenile phase coefficient, photoperiodism coefficient and grain filling duration coefficient of Ranjit were 1100, 250 and 350 degree days (°C), respectively. Because of its longer duration, Ranjit had the highest juvenile phase coefficient. The critical photoperiod (P2O) was 12.4 hours.

Calibration results shown in Table 5 indicates that simulation of main physiological events, *viz*., anthesis and physiological maturity dates compared with observed ones ranges from ±4 days and ±6 days respectively. The variation of simulated and observed grain yield ranges from 58 kg/ha to -199 kg/ha which lie within ±4.4% over observed yields. The lower value of RMSE and higher d-value close to one revealed that the model predicted phonological events, grain yield, and unit-grain weight quite well.

3.2. *Validation of CERES-Rice model*

The data from field experiments conducted in each of the year 1998, 1999 and 2003 were used to validate the calibrated CERES-Rice model. The results indicated that simulation of main physiological events, *viz*., anthesis and physiological maturity dates were in close agreement with observed ones and RMSE ranged from 5.1 to 5.5 days respectively (Table 6). The variation in simulated yields over the observed yields was within ±16% for all the transplanting dates with a RMSE value of 401 kg/ha. The *d*-value was found to be low (0.12) due to lower yields observed in third transplanted crop during 1998 and 2003. The normalized RMSE value was below 10%. These results indicated that the CERES-Rice v4.5 model is capable enough in estimating growth and yield of rice with reasonable accuracy under the prevailing agro-climatic conditions of upper Brahmaputra valley and hence can be considered as a reasonably reliable model for use in climate risk assessment studies in the study area. Work by Saseendran *et al.* (1998) evaluated the performance of the CERES Rice v4.0 for the climatic conditions of the state of Kerala and found that in four experiments using different transplanting dates during the Virippu (June-September) season under rainfed conditions, the flowering date and crop maturity was predicted within an error of 4 and 2 days respectively. Also the grain yield prediction was within an error of 3% for all transplanting dates. Accurate prediction of different stages may help farmers to take decisions on crop management operations linked to crop phenology.

4. Conclusions

Genetic coefficients required for the CERES-Rice v4.5 model for simulation of the growth and development of rice crop have been derived for rice cultivar Ranjit under the agro-climatic conditions of upper Brahmaputra valley of Assam, India. The model was validated using the field data of 1998, 1999 and 2003. The model was found to be able to predict the phenological occurrence of the crop well enough to help the farmers to make broad scale decisions on the crop management operations which can be directly linked to crop phenology. The model predicted the grain yields from 85% to 107% of the observed grain yield. The better ability of the model in simulating total grain yield of the crop would enable the policy makers and planners on taking agriculture based economic decisions in the upper Brahmaputra valley. It is envisaged that the validated model would provide insights for rice crop physiologists and agronomists about the response mechanisms to various weather/climate conditions. Also, it can be concluded that the modelling of rice crop yield using CERES-Rice v4.5 is accurate enough to be considered a reasonably reliable tool for use in climate risk assessment studies in agriculture. Reasonably validated models can replace much of the trial and error type methods in agricultural research. Once a model has been developed, calibrated and tested to the stage that it accounts for the major yield factors in a region, the model can be made part of the whole system of regional agricultural research by adopting a system frame-work for the crop and agrometeorology data collection. To apply a model this way there is a need for a regional experimental programme to collect a balanced set of data about the crop, environmental and weather with which the model can be used.

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