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Forecasting of rice yield of South Dinajpur district of West Bengal using CERES-rice (DSSAT 4.5) model

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Abstract
The CERES-Rice (DSSAT 4.5) crop simulation model was used to forecast the yield of monsoon rice of South Dinajpur District of west Bengal for the year 2013 by simulating the growth, development and yield of two predominant rice cultivars (Swarna and Satabdi) in relation to the predominant transplanting dates (10 July, 20 July and 30 July). The CERES-Rice model is a simulation model for rice that describes phonological development and growth in response to environmental factors (soils, weather and management). Daily weather data on maximum temperature, minimum temperature, rainfall, and bright sunshine hours for 29 years (1983-2011) was analyzed to study the variability in terms of rainfall and temperature. The model was able to forecast the yield quite accurately for the South Dinajpur district. The predicted yields for 2013 at F3 stage was 2.60 t ha^{-1} with RMSE values of observed to predicted, observed to trend and trend to predict were 847.31, 93.85 and 846.93 respectively.

Keywords: CERES-Rice model, rice, predicted yield, trend yield, RMSE

Introduction
Rice is the staple food of more than 60% if the world`s population especially for most of the people of South –East Asia. The crop contributes 43% of the total food grain production and 46 % of the total cereal production in our country. Demand for rice is growing every year and it is estimated that in 2025 AD the requirement would be 140 million tonnes to sustain present food self-sufficiency and meet the future food requirements. In India, West Bengal is known as bowl of rice because it produces the major portion of rice produce for 90% of its agricultural land. During 2010-11 West Bengal contributed 13.6% of country`s production from 11.5% of the cultivated area, which signifies that the state as an important rice growing area with better productivity over the country. Crop productivity is determined by environmental variables namely weather, soil, farm inputs, technological advancement and genotype of the crop. Among these variables, weather variability is considered as one of the major factor of inter-annual variability of crop growth, development and ultimately yield in all environments. It has been reported that, 80% of the variability of agricultural production is due to the variability in weather conditions, especially for rainfed production systems (Petr, J., 1991) [8]. Based on the weather parameters there is a need for developing forecast models, that forecasts yield timely and precisely before the actual harvest of crop which is vital in policy planning, strategic planning, decision making and helps in reducing the undesirable effects on price and distress public policy (Agnihotri and Sridhara., 2014) [1]. The main objective is to predict yield, since this information can be used at farm level for decision or policy making and food security decisions (Hoogenboom, G. 2000) [3]. The timely evaluation of potential yields is important because of the huge economic impact of agricultural products on world markets and strategic planning (Doraiswamy and Paul, C. 2007) [2]. However, there are significant variations in crop yield by location due to varying environmental conditions. In various studies, yield forecasting models used a series of weather predictors (Hoogenboom, G. 2000) [3], more specifically, temperature (Peng *et al*., 2014) and rainfall (Mkhabela *et al*., 2005) [6], which affect crop yield the most. The use of crop simulation models for predicting crop yield as function of weather and climate has been studied extensively (Hoogenboom, G. 2000) [3]. Many such crop models are available in Decision Support System for Agrotechnology Transfer (DSSAT) (Jones *et al*., 2003) [5] which was developed by the International Benchmark Sites Net-work for

Agrotechnology Transfer (Uehara *et al*., 1993) [10] at the University of Hawaii. Crop Environment Resources Synthesis (CERES -Rice) model is a process based management oriented model that can simulate the growth and development of rice crop (Ritchie *et al*., 1998) [9]. CERES-Rice model was used to forecast the rice yield of South Dinajpur district of West Bengal.

Materials and Methods

Crop growth Simulation Model

The CERES-Rice model developed by (Hoogenboom *et al*., 1999) [11] is a growth and development simulations model for the rice crop in upland and lowland conditions. It is a daily step model that simulates grain yield and growth components of different varieties in a given agro climatic conditions. The model simulates phonological development, growth and biomass partitioning of leaves, stem, panicle and grains. This model was widely validated and calibrated at different locations in India (Rathore *et al*., 2001) [12].

Model Input data

Weather: Model requires daily weather data such as maximum and minimum temperature and rainfall. These agro meteorological variables were collected from the India Meteorological Department, Pune for the period from 1983-2013 for South Dinajpur district. Solar radiation was generated from DSSAT model.

***Soil*:** Soil input data, which included profile wise soil texture, slope, soil classification, bulk density, organic carbon, pH and CEC (Cation Exchange Capacity) of the soil profile, presented in Table 1.

Table 1: Physical property of different soil layers.

Soil depth (cm)	Particle size			Bulk density ($g.cm^{-3}$)	Saturated hydraulic conductivity ($cm.d^{-1}$)	Field capacity (% vol)	Wilting point (% vol)
	Clay	Silt	Sand				
0-5	24.3	64.1	11.6	1.49	0.97	0.187	0.058
5-15	24.3	64.1	11.6	1.49	0.87	0.187	0.058
15-30	28.3	59.4	12.3	1.54	0.76	0.169	0.058
30-45	28.3	59.4	12.3	1.59	0.94	0.157	0.057
45-60	28.3	59.4	12.3	1.46	0.93	0.165	0.058

Cultivar: Crop genetic coefficient of the predominant variety Swarna and Satabdi was selected for the experiment. The coefficients at developmental and growth stages are presented in Table 2.

Table 2: Genetic coefficient of Swarna and Satabdi of West Bengal used in CERES-Rice model.

Rice Genotype file								
Cultivar	P1	P2R	P5	P2O	G1	G2	G3	G4
Swarna	700	120	300	12.2	48.0	0.022	1	
Satabdi	650	80	400	12.5	56.0	0.020	0.70	1

Yield Data: Historical yield data of rice crop for districts was obtained from SMC, Kolkata, India.

Management: Agronomic practices for rice, such as date of nursery, transplanting, harvesting, irrigation depth, and irrigation are appropriated to the existing situation. The amount of fertilizer 80:40:40 (N: P: K) kg ha^{-1} was applied to the crop. The *kharif* rice was transplanting on 10th of July, 20th of July and 30th of July respectively.

Observed yield analysis and simulated yield

Rice yield data (Y_{obs}) has been provided by Regional Meteorological Center, Kolkata, India for the years 1983 to 2011. Yield simulation was done using daily weather observations, soil, cultivar and other necessary input requirements of the district for the period 1983-2011. The, simulated rice yields (Y_{sim}) were analysed against observed district average yield for the period 1983-2008 for developing regression coefficient for yield prediction.

Computation of trend yield, observed yield deviation

Observed yields (Yobs) for the period 1983-2011 were analysed with time to obtain contribution of technological improvement in observed yield. A single linear trend approach was used for calculating trend yields of South Dinajpur district.

i. Single linear trend

$$\hat{Y}_{obs1} = a_0 + b_0 * \text{time}. \quad (1)$$

ii. *Estimation of simulated yield deviation*: Deviation in simulated yield (Yd_{sim}) from its average (Y_{mean}) show the likely effect of environment variables on average rice yield as identified by CERES-Rice model and was computed as:

$$Yd_{sim} = ((Y_{sim} – Y_{mean}) / Y_{mean}) \quad (2)$$

iii. *Prediction of yield deviation:* Yield deviation ($\hat{Y}d$) for 28 years was predicted by regressing the simulated yield deviations (Yd_{sim}). The resulting regression coefficients a1 and b1 were used for prediction of yield deviation as:

$$\hat{Y}d = a_1 + b_1 * \text{time} \quad (3)$$

With this regression eq. [3], correction factor for two years (2008-11) were calculated and further used for validation of these two years.

$$CF = a_1 * \text{time} + b_1 \quad (4)$$

iv. *Yield forecast*: Likely increase in crop yield due to technological advancement was obtained using step 1 and likely impact of current year weather on crop performance have been judged using step 4. The yield predictions for the period 1983-2011 were generated by the method as:

$$\hat{Y}_p = \hat{Y}_{sim} – CF \quad (5)$$

Results and Discussions

Trend analysis of rice yield

The historical rice yield for South Dinajpur district has been presented in Table 3, for the period of 1983-2011. From the Table values it can be seen that the rice yield was low during 1983 to 2001 and was slightly higher in the year 1996, 1997, 2000 and 2001, respectively. From the table it can be said that the yield drastically increased from the year 2002-2011. The linear trend of historical observed yield of rice for the 1983-

2011 period (Figure 1) shows an increase in rice yield by 57.39 kg/ha/year (R^2=0.89), due to the advancement and adaptation of new technology in farming system. The RMSE (Root Mean Square Error) of observed to predicted, observed to trend and trend to predict were 847.31, 93.85 and 846.93 respectively. The trend yield of the observed yield for the period of 1983-2011 was:

$$Y = 57.399*x + 982.26 \quad (6)$$

A mean of simulated yield was taken into account to derive the simulated yield deviation for all the years. The approach used for simulated yield deviation from simulated yield is as given in equation 2. The regression analysis of simulated yield deviation with deviation of the observed yield (Figure 2) shows that the simulated deviation has a positive correlation with the linear trend deviation with R^2 value of 0.026. A linear regression equation of Y= 0.4003*x - 15.148 was obtained as shown in figure 2. These results reveal that during the 29 years period the adaptation of high yielding potential cultivars along with input management practice were very low. This result is supported by the studies conducted by Rathore *et al*., (2008).

Table 3: Final result of observed, trend and predicted yield of DSSAT CERES-Rice model.

Year	Observed yield kg/ha	Trend yield kg/ha	Predicted yield (kg/ha)
1983	1124	1040	3206.90
1984	1143	1097	3105.29
1985	1246	1154	3052.79
1986	1345	1212	3266.27
1987	872	1269	3239.79
1988	1312	1327	3032.28
1989	1526	1384	3383.42
1990	1480	1441	3249.89
1991	1406	1499	3260.03
1992	1488	1556	3348.81
1993	1631	1613	3042.55
1994	1599	1671	2475.40
1995	1458	1728	2670.77
1996	1977	1786	3169.48
1997	2042	1843	2942.67
1998	1916	1900	3028.21
1999	1790	1958	2913.59
2000	2036	2015	1287.74
2001	1880	2073	3176.55
2002	2167	2130	3213.04
2003	2372	2187	3078.04
2004	2482	2245	2995.06
2005	2424	2302	3167.48
2006	2224	2360	3208.74
2007	2399	2417	2607.70
2008	2254	2474	2586.39
2009	2405	2532	2521.36
2010	2954	2589	3269.43
2011	2502	2647	3208.24
Predicted yield			
2013			2606

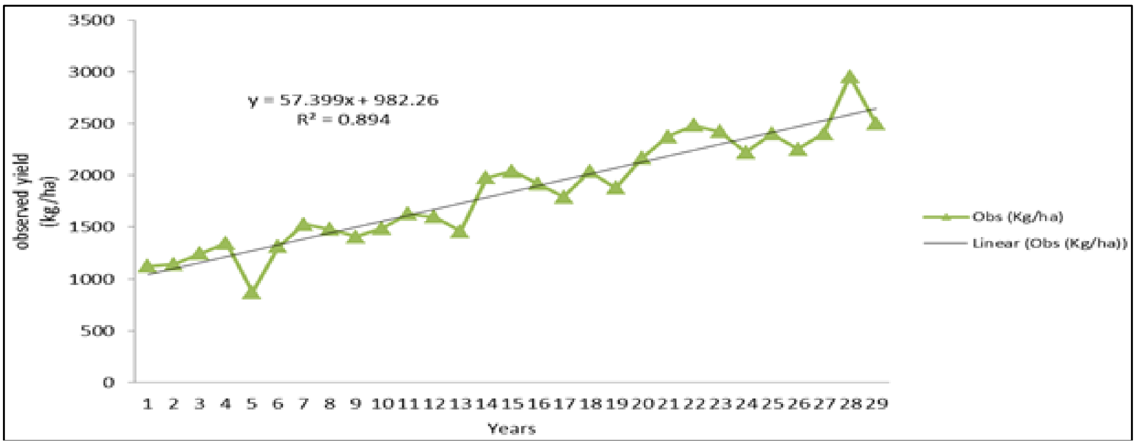

Fig 1: Linear Regression between observed yield and year.

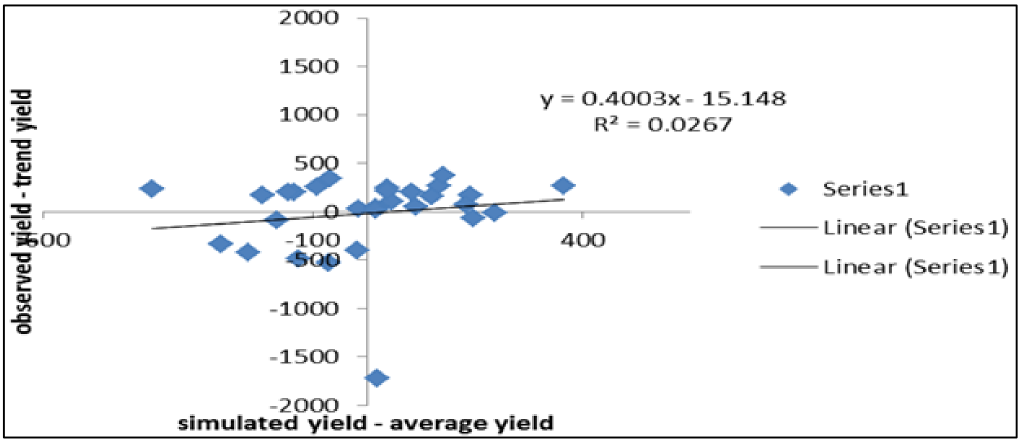

Fig 2: Regression between simulated and trend yield deviation.

Prediction of Rice yield

The forecasted rice yield for the year 2013 were generated using three step approaches, comprising (a) prediction of trend yield ($\hat{Y}_{obs}$) from equation [1]; (b)simulation of rice yields (Ysim) and estimation of simulated rice yield deviations (Yd_{sim}) from equation [2] and predicted yield deviations ($\hat{Y}$) using equation [4] and (c) forecast of final yield using equation [5]. The regression analysis of the observed and predicted yield (Figure 3) shows that the daily weather parameters determines the final yield while cultural practice and technology inputs were kept constant for the period of 2011-2012. The results of the above mention study reveals that the crop simulation model and perform well in Indian conditions and can forecast summer rice yield accurately (Rathore *et al*., 2008).

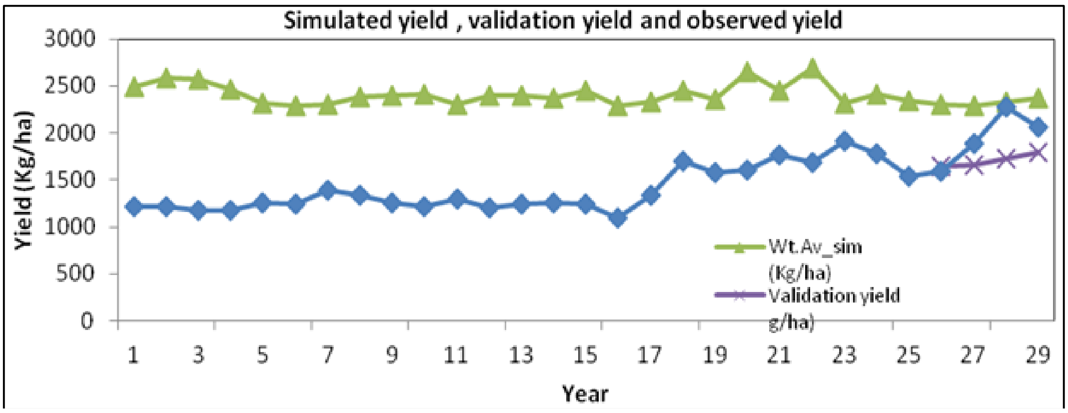

Fig 3: The magnitude of observed, validated and trend yield

Conclusion

The CERES-Rice model was able to quite accurately simulate phenology and yield of the rice variety Swarna and Satbadi in the rainfed condition in South Dinajpur district of West Bengal, India. The linear trend of historical observed yield of rice for the 1983-2011 period showed an increase in rice yield by 57.39 kg/ha/year (R^2=0.89), due to the advancement and adaptation of new technology in farming system. The regression analysis of simulated yield deviation with deviation of the observed yield showed that the simulated deviation has a positive correlation with the linear trend deviation with R^2 value of 0.026.

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