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Performance of CERES-Rice Model for Estimating Yield During Drought Years in Madhya Pradesh

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Abstract Different sowing dates for four stations in Madhya Pradesh for each year were used to assess the performance of the Decision Support System for Agrometeorology Transfer (DSSAT) v4.6 model for rice crop yield from 1990–2011 during drought years. Drought years were identified using observed rainfall datasets from India Meteorological Department (IMD) from June to September (JJAS) for the selected stations viz., Balaghat, Jabalpur, Narsinghpur and Seoni. Two popular varieties of rice (IR 36 and Swarna) were taken in this study. It is found that the DSSAT CERES-rice model predicted yield was higher than the observed yield requiring a bias correction and detrend analysis. The detrend yield anomalies indicated that the model follows observed pattern during most of the drought or deficit phases. Modeling experiments were performed to examine the sensitivity of the mosel in respect to variations in daily rainfall.

Keywords DSSAT, CERES-Rice, Drought, Rainfall, Genetic coefficients.

Introduction

The prediction of crop yield plays a vital role in developing and applying policies in extreme conditions. Crop simulation models are mathematical equations describing crop growth, yields, climate and management practice [1]. Many researchers used simulated model approach in various crops (rice, wheat, maize) with satisfactory results [2, 3]. The performance of crop prediction models during drought and non-drought years has been assessed over many places around the world. The DSSAT v4.6 model is computer based system that has combination of different crop growth models i.e. CERES-Barley, CERES-Maize, CERES-Rice, CERES-Sorghum, CERES-Sunflower, CERES-Wheat, Cropgro-Drybean, Crogro-Soyabean. It simulate crop growth, development, and yield

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Table 1. Excess and deficit rainfall years for the four districts of Madhya Pradesh.

District	Excess	Deficit
Balaghat	1994, 1995, 1999, 2001, 2003	1991, 1996, 2000, 2006, 2007, 2009
Jabalpur	1994, 1999, 2003, 2005	1996, 1998, 2006, 2007, 2009
Narsinghpur	1994, 1999, 2005	1996, 2000, 2003, 2004, 2007, 2008, 2009,
Seoni	1993, 1994, 2003, 2010	1991, 2004, 2007, 2008, 2009

through the effects of weather, management, genetics, and soil water, carbon and nitrogen [4] however not perfect to predict precise output due to the incidences of pest, disease, extreme weather conditions as these parameters are not available in the model. The yield gap between observed and simulated data were noticed by many researchers in the past using simulation model in wheat and rice crops and found the inaccuracies of DSSAT soil water balance module and suggested modifications to improve model forecast [5]. It is anticipated that the cropping system is very complex and the crop production varies spatially as well as temporally [1]. Nyang'au et al. [2] carried out sensitivity analysis of CERES-Rice and suggested that maximum, mean, minimum temperature or rainfall directly correlates with observed crop yield. They have documented the impact of increased temperature over crop yield.

The Indian agriculture mainly depends on summer monsoon rainfall because summer monsoon it brings around 75 to 90% of India's annual rainfall [6]. Rice is one of the important food crops in Asian subcontinent basically in India. In Madhya Pradesh, majority of rice area comes under rainfed conditions (78.4%) of which 20.7% area is sown in Jabalpur, Seoni, Balaghat, and Narsinghpur districts [7]. It suggests that the meteorological parameters have large inter-annual variability on rice yield in these areas. No studies have been found so far on the use of DSSAT model for forecasting rice yield during drought conditions for these districts. The aim of this study is to

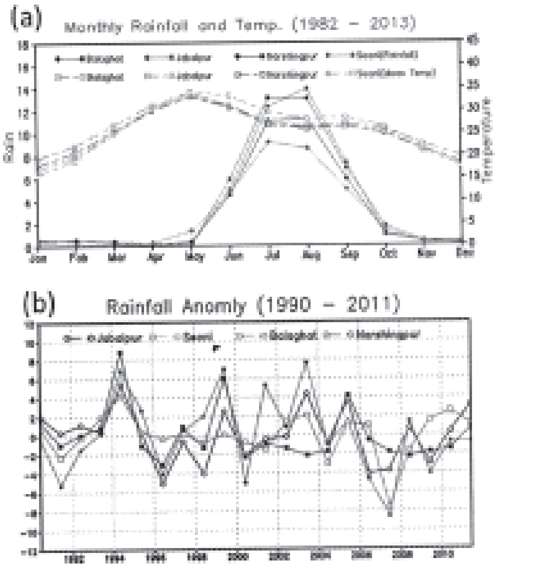

Fig. 1. (a) Climatology of rainfall and mean temperature during January to December, (b) Seasonal mean (JJAS) rainfall anomaly for Balaghat, Jabalpur, Narshingpur and Seoni.

document the model performance on the estimates of rice yield under rainfed conditions.

Materials and Methods

Study area

The location for study is located in eastern Madhya Pradesh, India. The four stations selected for the experiments are Balaghat (21.86 N, 80.36 E), Jabalpur (23.18 N, 79.98 E), Narsinghpur (22.91 N, 79.10E) and Seoni (22.08 N, 79.54 E). The soil textures are silty clay loam, sandy clay loam, and black cotton soil is mostly found in Madhya Pradesh region [8]. The numerical experiments were conducted from 1990 to 2013 growing season of *kharif* rice crop.

Data used

The daily weather data (rainfall, maximum and minimum temperature, solar radiation) for all the four sta-

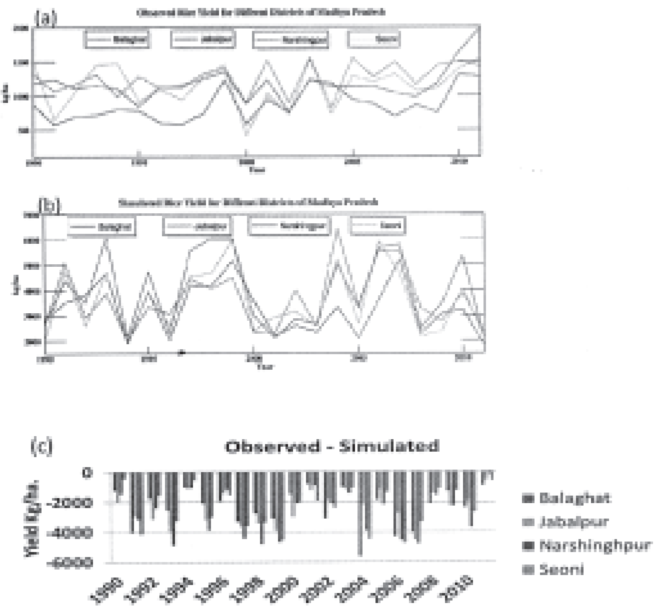

Fig. 2. (a) Observed yield and (b) Simulated yield and (c) Difference between the observed and simulated yield from 1990 to 2011 for Balaghat, Jabalpur, Narshingpur and Seoni.

tions in MP are collected from India Meteorological Department (IMD), New Delhi. The IMD gridded rainfall (0.25 × 0.25 degree) and mean temperature (1.0 × 1.0 degree) have been used (Table 1). The soil is classified as a rice soil according to the Jawaharlal Nehru Agricultural University (JNKVV) Jabalpur, MP, India under forecasting agricultural output using Space, Agrometeorology and Land based observations (FASAL) scheme. The crop yield is collected from the farmer welfare and agriculture development department of Madhya Pradesh (Available at www.mpkrishi.mp.gov.in) from 1990 to 2011 years. The DSSAT input such as soil profile, fertilizer, and other management practices were collected from India meteorological department IMD and JNKVV under FASAL scheme. Similarly, genetic coefficient of different rice varieties (IR 36 and Swarna) is presented in the Table 2 is used in this study.

The CERES-Rice model was run with different management practices with different dates of sowing for each station. The sowing window in Balaghat, Jabalpur, Narsinghpur and Seoni were June 5–July 10. Therefore, the first week on south-west monsoon with 50 to 110 mm has been chosen for direct seed sowing of rice under rainfed conditions. Plot management is followed the local standard practices (weed control, and fertilizer application) for rice production in all the districts. Sensitivity experiments were carried out to examine the impact of daily rainfall variation. The daily rainfall values were reduced and increased by 20% and 50% in the experiments for all stations.

Results and Discussion

Observed rainfall and temperature variability

Figure 1 shows the observed rainfall and mean temperature for Balaghat, Jabalpur, Narsinghpur and Seoni stations. The rainfall amount over all the stations var-

Table 2. Genetic coefficients for IR 36 and Swarna rice varieties.

Experiment No.	Source	P1	P20	P2R	P5	G1	G2	G3
				IR 36				
1	Singh et al. [12]	450	11.7	149	350	45	0.023	1.0
2	Hoogenboom et al. [10]	450	11.7	149	350	68	0.023	1.0
3	Rao [9]	550	11.7	149	550	70	0.023	1.0
4	Satapathy et al. [13]	470	11.5	50	350	65	0.02	1.0
5	Swain et al. [11]	475	11.7	90	385	68	0.023	1.0
6	DSSAT Default	500.0	11.5	149.0	450.0	30.0	0.0230	1.0
			Swarna					
1	Jain and Sastri [14]	800.0	11.1	052.0	550.0	45.0	0.0280	1.0

ies from 0 to 14 mm/day from January to December. The peak months of rainfall are June, July, August and September (JJAS) where the rainfall reaches up to 14 mm/day or more. The maximum amount of rainfall comes in Madhya Pradesh from July and August. June and September are major months which contribute to the total rainfall over these districts. Figure 1b shows time series of seasonal rainfall anomaly for JJAS from 1990 to 2011 at each station. The JJAS domain average anomaly of rainfall for Balaghat, Jabalpur, Narsinghpur and Seoni has been plotted. The deficit and excess year of rainfall for all stations have been identified. Rainfall more than 2 mm/day is considered as an excess year and less than 2 mm/day as a deficit year. Table 1 shows the excess and deficit years for all the four stations of Madhya Pradesh. As per the climatology of temperature over these districts, April, May and June are the hottest months in every year. The maximum mean temperature reaches upto 30 degree during the hottest month of May and minimum mean temperature reaches upto 14 degree in January. As per Figure 1a November to March are coldest months in Madhya Pradesh. During peak months of monsoon (July and August), temperature decreases but after August, it increases by more than 3 to 4 degrees.

Variability in crop yield

Figure 2a shows the year-to-year variations in the observed rice yield for Balaghat, Jabalpur, Narsinghpur and Seoni stations from 1990 to 2011. The observed yield varies from 826 to 1,547 kg/ha in Balaghat district, 578 to 1302 kg/ha in Jabalpur, 749 to 1971 kg/ha in Narsinghpur and 416 to 1,532 in Seoni district. Among these four stations, Jabalpur has the lowest yield, especially during 1991 to 1998. In 2000, Seoni and Jabalpur had minimum rice yield while in 2003 and 2005, Balghat had maximum yield during the study period. An increasing trend in noticed in the observed rice yield for all the stations (not shown in Figure).

Simulation of crop yield

Figure 2b shows that the model simulated yield over Balaghat, Jabalpur, Narsinghpur and Seoni from 1990 to 2011 using the DSSAT provided genetic parameters for IR 36 rice variety. Large variations in the simulated field is noticed which is not seen in the observed yield. The inter-annual standard deviation (SD) of observed yield is 224.78 kg/ha and simulated yield is 1217.19 for Balaghat district, for Jabalpur SD observed and simulated yield are 237.64 kg/ha and 1037.48 kg/ha respectively. For Narsinghpur, the SD of observed yield is 253.06 kg/ha and simulated yield is 1499.90 kg/ha and for Seoni, SD of observed yield is 315.46 kg/ha and simulated yield is 1323.38 kg/ha. In addition to this, a large yield gap between observation and simulation results is also noticed for all

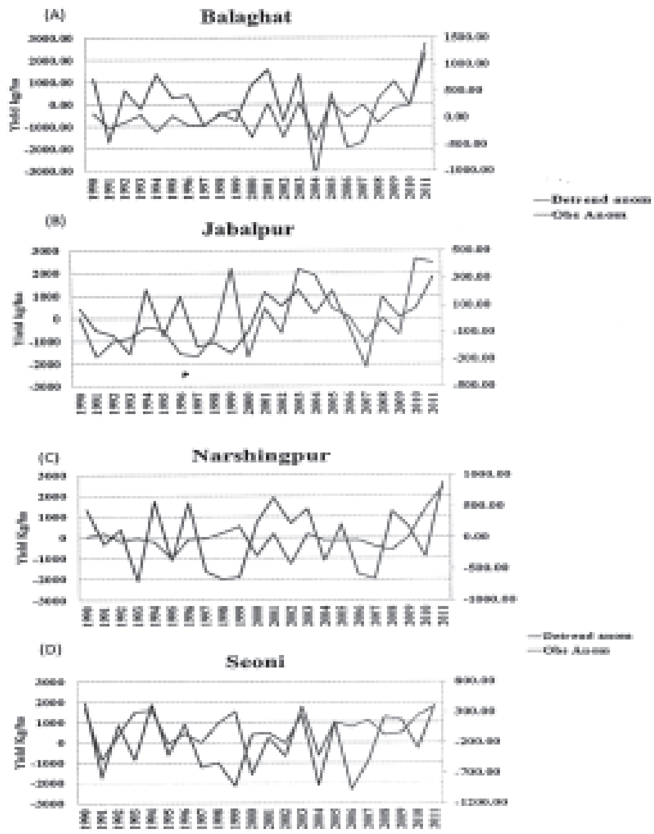

Fig. 3. Observed anomaly and de-trend anomaly of rice yield (A) Balaghat, (B) Jabalpur, (C) Narshingpur and (D) Seoni.

the districts.Figure 2c shows the difference in observed and simulated yield for all the four station. The average bias in the model simulations for Balaghat is -2389.45 kg/ha, for Jabalpur, it is -2475.92 kg/ha. For Narsinghpur and Seoni, the bias values are -2789.13 kg/ha and -2397.59 kg/ha respectively. As a result of this large bias between model and observed yield, the root mean square errors (RMS) are also very large for all the four stations. The RMSE errors are 2690.21, 2624.74, 3158.96, and 2752.71 kg/ha for Balaghat Jabalpur Narsinghpur and Seoni stations respectively.

In this study, genetic parameters have not been estimated for the rice crop for the region. Instead, the genetic parameters as shown in Table 2 for IR 36 variety from [9—13] and for Swarma [14] along with default parameters for IR 36 variety of rice from DSSAT model have been used. The model was run with all the genetic coefficients for different districts of Madhya Pradesh from 1990 to 2011. The comparison has been made for examining the model performance with all genetic coefficients of rice crop. The experiments have shown a huge differences between observed and simulated yield for IR 36. The variations in the yield for Balaghat is from 1225.01 to 1966.59 kg/ha. For Jabalpur variation is from 1427.89 to 2392.13 kg/ha. For Narsinghpur variation is from 1394.25 to

2533.74 kg/ha. For Seoni variation in the yield is from 1324.75 to 2089.24 kg/ha. The RMS errors obtained from these experiments have been summarized. The RMS Error for Balaghat is from 2577.92 to 4423.93 kg/ha. RMS Error for Jabalpur is from 3061.71 to 5270.59 kg/ha. RMS Error for Narshingpur is from 3150.65 to 4947.30 kg/ha. RMS Error for Seoni is from 2770.35 to 4568.72 kg/ha. Though, the amount of simulated yield is changed but the pattern of simulated yield is not changed in the experiments.

Sensitivity analysis

Sensitivity of CERES-Rice model was studied using the changes in weather data. Experiments were carried out by reducing the rainfall by 20% and 50% and increasing the rainfall by 20% and 50%. These experiments show how the model responds to changes in rainfall in the selected districts of Madhya Pradesh while all other parameters being the same. The change was made in weather data (WTH) file of the DSSAT model for each station. The impact of rainfall over simulated yield was clearly seen that during normal and excess years, when the raifall amount is further increased, the yield amount reduces. However, during drought years, when the rainfall amount is increased, an increase in rice yield is noticed. Similarly, rice yield is increased when rainfall amount is reduced in flood years. This feature is seen for all the stations for which experiments were carried out. These experiments show that the model is sensitive to input rainfall parameters and right amount of rainfall values are required for simulation of correct trend in rice yield by the model. In the sensitivity analysis, it is found that the model is sensitive to both rainfall and genetic coefficients. If a change is made in the genetic coefficient, the model will respond in terms of increasing or decreasing the yield. It is also found that in the model, the simulated yield is not totally rainfall dependent. However, in all the cases, the model simulated yield is larger than the observed yield when very less rainfall (-50%) is used.

De-trend analysis of the simulated yield

Due to the large yield gap that has been noticed between the observed and model simulated yield, direct use of the model simulated yield values may lead to improper policy decisions. In order to know the model performance and the ability of the model to capture the trend, de-trend technique has been used. The simulated yield has been de-trended by removing the tendency in simulated yield as a function of time. Figure 3 shows the de-trended anomalies of model simulated yield along with observed yield anomalies. After de-trend, it is sen that the model is able to capture the trend as well as fall in yield during specific years. For Balaghat, the observed anomaly varies from -1000 to 1500 kg/ha and the simulated de-trend anomaly is varying from -3000 to 2000 kg/ha. The model has very well captured the observed anomaly pattern from 1997 to 2011 and model is able to capture the pattern of observed yield especially in drought years. For Jabalpur, the observed anomaly varies between -400 to 500 kg/ha and the simulated de-treand anomaly ranges from -2000 to 2000 kg/ha. From 1990 to 1996, the pattern does not match well with the observation. In the drought years, the simulated de-trend yield pattern is very similar to observed yield anomaly. In non-drought years, the similated yield matches well with observed anomaly. For Narshinghpur, the range of observed yield anomaly is between -500 to 1000 kg/ha and simulated de-trend anomaly varies from -2000 to 2000 kg/ha. Simulated de-trend model yield is again able to capture the observed anomaly pattern especially in drought years. For Seoni, the observed anomaly varies between -700 to 300 kg/ha and the simulated de-trend anomaly from -3000 to 2000 kg/ha. The simulated de-trend anomaly very well captures the observed anomaly pattern.

Conclusion

The model over estimates yield in every year for all the stations however simulated yield follows the observed pattern especially in the drought years. The results are good with simulated yield pattern. Lack of experimental data on locally adopted rice varieties makes a difference in observed and simulated yield. Beside this, many forces work on crop growth and development in the field and it is not possible to give all information in a model because of lack of observation. The sensitivity of the model shows large variations with genrtic coefficient parameters particularly G1 coefficients. Yield gap between observed and simulated yield was reduced by choosing a proper G1 coefficient. Overall study shows that with proper tuning, the DSSAT (model can be used for crop yield of rice) for MP region during drought years.

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