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Climate Change Impact Assessment and Evaluation of Agro-Adaptation Measures for Rice Production in Eastern India

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ABSTRACT. Climate change is expected to affect the global food production adversely. Rice, being a major food for more than half of the world population, its production management needs attention to mitigate the adverse effect of climate change and to ensure global food security. Crop simulation model CERES-Rice was used to simulate rice grain yield of two popular cultivars namely 'Lalat' (medium duration type,120d) and 'Swarna' (long duration type, 145d) for climate change scenarios and to evaluate agro-adaptations at three locations (Kharagpur, Dumdum and Purulia) in eastern India. Using historical weather data of the locations, the CERES-rice model simulated higher average grain yield of the cultivar 'Swarna' as compared to 'Lalat' under rainfed agro-ecosystem. Use of future climate change scenarios of the General Circulation Models (GCMs); Geophysical Fluid Dynamics Laboratory, Goddard Institute for Space Studies, and United Kingdom Meteorological Office predicted variable yield of these cultivars at all the locations. For all the GCMs, the crop model simulated lower yield reduction of long duration cultivar 'Swarna' as compared to the medium duration cultivar Lalat with current farming practice. The yield reduction was to the extent of 27% and 14% at Kharagpur and 17% and 7% at Purulia for the cultivars Lalat and Swarna, respectively. An advanced planting time of 10 to 30 days from current farmers' planting time (15 July) is expected to mitigate the adverse effect of climate change on the rice yield. Cultivar selection and plating time adjustment could be suitably managed for better adaptation to minimize the risk of yield loss due to climate change.

Keywords: adaptation, CERES- rice model, climate change, rice yield, planting time

1. Introduction

Crop production is very sensitive to climate change (McCarthy et al., 2001), with varying effects according to region. The climate change associated with increasing levels of CO_2 may bring benefits to agricultural production in some parts of the world, especially northern latitudes above about 55°, while the places particularly tropical and sub-tropical countries (developing world) will be adversely affected (Parry et al., 2004; Stern, 2006; Hadley-Centre, 2006). In tropical regions of the developing world, farming is risky, because of high variability of climate, which is responsible for as much as 80% variability in agricultural production. If the climate change effects dominate, world crop yields are likely to be decreased significantly (Parry et al., 2004).

Elevated CO_2 concentration is generally expected to enhance photosynthesis of crop species of C3 photosynthetic pathway (Drake et al., 1997), leading to increases in growth and yield of crops (Horie et al., 2000; Kimball et al., 2002). Rice being a C3 crop, its biomass increases up to 40%, under elevated CO_2 (Baker et al., 1996; Ziska et al., 1997) with a range in responses varying depending on N level (Nakagawa et al., 1994; Ziska et al., 1996), air temperature (Baker et al., 1996; Ziska et al., 1997; Nakagawa and Horie, 2000) and cultivar (Moya et al., 1998). However, the stimulative effect of elevated of CO_2 on the photosynthesis of rice crop is likely to be reduced with increasing duration of CO_2 exposure (Nakano et al., 1997).

Climate model projections summarized by the IPCC indicate that average global surface temperature will likely rise a further 1.1 to 5.4 °C during the twenty-first century (IPCC, 2007). The rise in temperature will have potential impact on crop yield. Gradual temperature changes from 1982 to 1998 have caused a measurable impact on yield of corn and soybean in the United States (Lobell ans Asner, 2003). Rice grain yield in Philippines was found to be declined by 10% for each 1 °C increase in growing-season minimum temperature in the dry season (January to April) from 1992 to 2003 (Peng et al., 2004). Under climate change scenarios, the rising temperature nullifies the positive effect of increased CO_2 concentraetion on rice yield as has been reported by several reserachers (Peng et al., 2004; Sheehy et al., 2006; Krishnan et al., 2007; Masutomi et al., 2009; Mohammed and Tarpley, 2009).

Rice is the second most important food crop after wheat in world, which is grown on about 145 million hectares with an annual production of 518 million tones of rice (FAO, 2002).

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In India, rice is grown in 44 million ha, which is 28% of world rice area and contributes 22% of global rice grain production (FAI, 2008). Rice is mainly grown in India during wet season (June-November) with monsoon rain under abundant supply of water. Many parts of eastern India receives 1700 mm of annual rainfall of which 80% is received during the wet season favors the rice cultivation as a predominant crop of the region. Climate change due to global warming is a challenge to rice production of the country. After 1990's there is a decline in rice production and productivity, as compared to rate of population growth in India. A review of climate change impact studies on Indian agriculture (Mall et al., 2006), mainly from the perspective of physical impact predicts significant drop in yields of important cereal crops like rice and wheat under climate change conditions.

The potential impacts of climate change on rice production of India are of concern and have been assessed by simulation analysis (Matthews et al., 1997; Mall et al., 2006; Krishnan et al., 2007; Masutomi et al., 2009), but few studies have evaluated the agro-adaptation measures to combat the climate change effects. In this study, we have simulated the effect of climate change on phenology, growth and yield of two rice cultivars of varying maturity duration at three locations of eastern India. The objective was to simulate the effect of climate change on rice yield of eastern India and to evaluate the agro-adaptation measures such as cultivar change and planting time adjustment for the climate change risk mitigation.

2. Materials and Methods

2.1. Study Area

Three locations in eastern India which differed in their agro-climatic properties were selected for the study. The locations were Midnapur/Kharagpur (22.30° N latitude and 87.20° E longitude), Dumdum (22.32° N latitude and 88.38° E longitude) and Purulia (23.62° N latitude and 88.28° E longitude). The soil of Kharagpur region is of lateritic type with sandy loam texture, which is taxonomically grouped under the group 'Haplustalf' and the site receives an average rainfall of 1500 (±130) mm with an occurrence of 70 to 75% of the total rainfall in the wet season (June to November). The minimum and maximum temperature of the region varies between 13.4 °C in January to 25.8 °C in June and 25.3 °C in January to 36.8 °C in April, respectively. The soil of Dumdum region is clay in texture and fertile. The average annual rainfall of Dumdum is 1697 (±114) mm and about 80% of the total rainfall is received during the wet season. The minimum and maximum temperature of the region varies between 12.8 °C in January to 26.2 °C in June and 25.7 °C in January to 35.5 °C in May, respectively. The average annual rainfall of Purulia is 1677 (±123) mm and soil fertility status is low. The minimum and maximum temperature of the region varies between 10.9 °C in January to 25.5 °C in June and 24.2 °C in January to 38.0 °C in May, respectively.

2.2. Crop Model

CERES (Crop Environment Resource Synthesis)-Rice model of DSSAT (Decision Support System for Agrotechnology Transfer) version 4.0 was used for this study. The model is based on understanding of plants, soil, weather and management interaction to predict growth and yield. Yield limiting factors like water and nutrient stresses are considered by the model. The model simulates total biomass of the crop as the product of the average growth rate and the growth duration. The simulation of yields at the process level involves the prediction of these two important processes. The principal environmental factor affecting the growth rate is solar radiation and the development is temperature. The crop growth is simulated by employing a carbon balance approach in a source-sink system (Ritchie et al., 1998). Daily crop growth rate is calculated as:

$$PCARB = \frac{RUE * PAR}{PLTPOP}\left(1 - e^{(-k * LAI)}\right) * CO_2 \tag{1}$$

where:

PCARB = Potential growth rate, g/plant

RUE = Radiation use efficiency (g dry matter/ MJ PAR)

PAR = Photosynthetically active radiation (MJ m^{-2})

PLTPOP = Plant population, plant m^{-2}

K = Light extinction factor

LAI = Green leaf area index

CO_2 = CO_2 modification factor

The growth duration of a particular stage (developmental phase) is directly related to temperature, which could be predicated using the sum of mean daily air temperature (Wang, 1960), known as thermal time (T_d):

$$T_d = \sum_{i=1}^{n} (T_a - T_b) \tag{2}$$

where:

T_d = The thermal time, °C day

T_a = The daily mean temperature, °C

T_b = The base temperature, °C of the crop at which development stops

The calculation of T_d is applicable for the conditions such as (i) the temperature response of the development rate is linear, (ii) T_a is not lower than T_b (iii) T_a does not exceed upper thresh hold temperature for the crop, and (iv) the growing region of plant has the same mean temperature as T_a (Ritchie and Smith, 1991)

2.3. Model Evaluation

The CERES-Rice model calibrated and evaluated in the location (Swain and Yadav, 2009) for medium- and long-duration cultivars, was used for the rice growth and yield simulation. To understand the model uncertainty, the genotype parameters of the model for the cultivars 'Lalat' of medium duration group (110 to 120 d) and Swarna of long duration group (140 to 150 d) were evaluated through in-season yield forecasting based on yield data from the on-going field experiments during wet season (June to November) of 2008 at the research farm of the Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, India. Both the cultivars were transplanted on 19 July 2008 and the grain yield was forecasted starting from July at every one month interval (July, August, September, October, November) up to harvest of the crop. For each forecasting period, observed weather data was used up to the forecasting month and averaged weather data of the location for the rest of the months.

2.4. Model Application to Climate Change Scenarios

Rice growth and yield of the medium duration cultivar 'Lalat' and long duration cultivar 'Swarna' was simulated using historical weather data and climate change scenarios of General Circulation Models (GCM) for all the three locations.

2.4.1. Historical Weather Data

The simulation was performed using the historical weather data of the locations, with the normal farmers' planting time (15 July) and varying planting time for both the cultivars. Historical weather collected from Indian Meteorological Department for years 1974 to 2008 at Kharagpur/Medinpur, 1974 to 2003 at Dumdum and 1986 to 2000 at Purulia were used for analysis of weather uncertainty on grain yield of rice through cumulative probability distribution plots.

2.4.2. General Circulation Models

The outputs from climate models of GCM scenarios were used in the crop model. The coarse grid from each GCM was interpolated using a four point inverse distance-squared algorithm to a 0.58 latitude × 0.58 longitude grid using a raster-based Geographical Information Systems software package. Scenarios were produced by applying ratios of precipitation or differences in temperature predicted for the 2 × CO_2 and 1 × CO_2 simulation to the baseline present climate data set for different sites (Mathews and Wassmann 2003). The important features of three GCMs; Geophysical Fluid Dynamics Laboratory (GFDL) Model, Goddard Institute of Space Studies (GISS) model and the United Kingdom Meteorological Office (UKMO) model used in the present study are rise in average air temperature of 4, 4.2, and 5.2 ^{o}C; and increase in precipitation of 8, 11, and 15%, respectively. The GCM scenarios were produced by applying the ratios of precipitation or differences in temperature predicted for the 1 × CO_2 (380 ppm) and 2 × CO_2 (760 ppm) simulations to the baseline daily weather data set.

2.5. Evaluation of Agro-adaptation Measures

The crop yield was simulated with changing management options for evaluation of agro-adaptation measures. As an adaptation measure, the effect of seven planting dates starting on 15 June at 10 days interval up to 15 August were simulated for both the cultivars (Lalat and Swarna) for the climate change risk management. The change in the average yield was compared with the normal yield for each scenario, and based on the percentage change in yield, the adaptive measures were evaluated:

$$\text{Change in yield (\%)} = \frac{y_c - y_n}{y_n} \times 100 \qquad (3)$$

where:
Y_c = Average yield for the climate changed scenario
Y_n = Average yield for the normal scenario

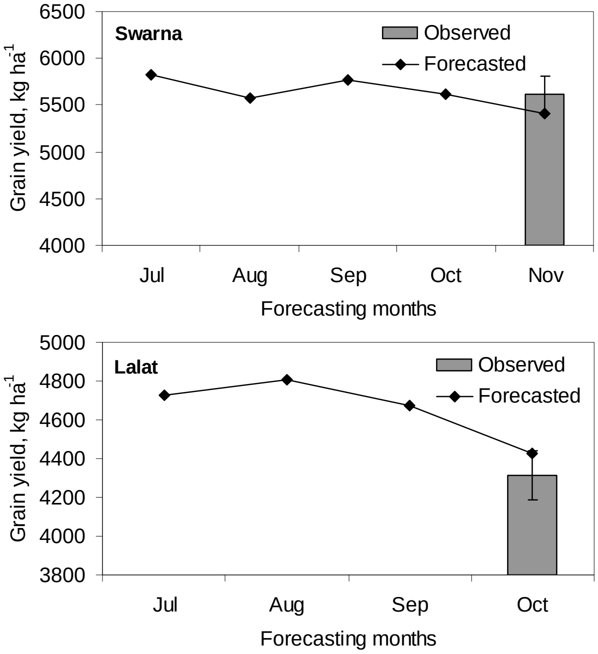

Figure 1. Forecasted rice grain yield at one month interval from transplanting to maturity of cultivars Lalat and Swarna using CERES-Rice model and observed grain yield during wet season 2008 at Kharagpur, India.

3. Results and Discussion

3.1. Model Evaluation

The model was evaluated through in-season yield forecasting for both the cultivars 'Lalat' and 'Swarna' at Kharagpur (Figure 1). The yield was forecasted at one month interval starting from July (transplanted) up to maturity of the crop. The change in simulated grain yield over the observed values of the cultivar 'Lalat' for the forecasting periods July, August, September and October (maturity) were 10, 11, 8, and 2%, respectively. A gradual decrease in the variation between the observed and simulated yield was found with later forecasting periods, which approaches towards maturity of the crop. The yield simulated using the actual weather data up to maturity of the year 2008 was almost similar to the observed value. For the cultivar 'Swarna', the change in the simulated grain yield over the observed value were 4, -1, 3, 0.1 and -4% for the forecasting periods July, August, September, October and No-

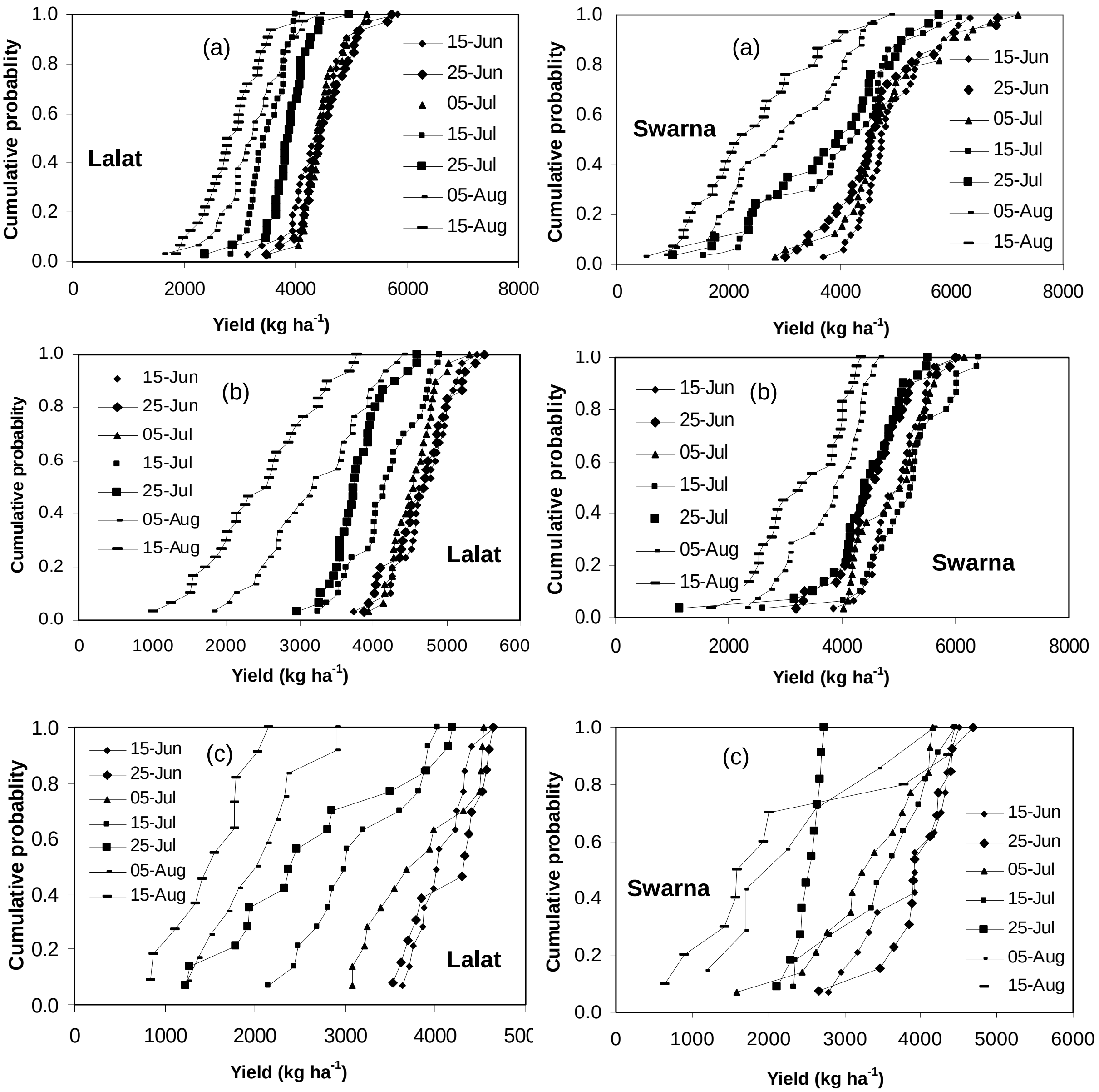

Figure 2. Simulated cumulative probability curves showing rice grain yield of the cultivars Lalat and Swarna for different planting dates using past weather data at Kharagpur (a), Dumdum (b) and Purulia (c) of eastern India.

vember (maturity) respectively. The yield simulated using the actual weather data of the year 2008 up to maturity of the crop was close to the observed yield. Using actual weather data, an accurate yield could be simulated at maturity of both the cultivars of rice. Similar results have been reported in other crops like maize (Soler et al., 2007) millet (Thornton et al., 1997) and peanut (Garcia et al., 2003), in which accurate yield forecasts during the growing season were shown. As in our study, the variation between simulated and observed grain yield, when forecasted at maturity of both the cultivars was very low (< 5%), so the CERES-Rice model could be used in different scenarios for evaluation of production uncertainties associated with management technologies.

3.2. Climate Change Impacts

The model was used to simulate the grain yield and growth parameters of rice using historical weather data and climate outputs of GCM scenarios for the three locations in eastern India.

3.2.1. Historical Weather

For analysis of weather uncertainty, historical weather data of locations Kharagpur/Medinpur, Dumdum and Purulia were used for rice grain yield simulation at these locations of eastern India under rainfed agro-ecosystem. Simulated cumulative probability curves showing rice grain yield of the cultivars "Lalat" and "Swarna" at these locations is shown in Figure 2. The average simulated grain yield with normal farmers planting time (July 15) were 3542 (±385), 4182 (±470), 3131 (±617) kg/ha for the cultivar Lalat and 4028 (±1006), 5135 (±781), and 3485 (±758) kg/ha for the cultivar Swarna at the locations Kharagpur, Dumdum and Purulia, respectively. For the cultivar Lalat, the highest grain yield at 0.50 cumulative probabilities was on 25 June, 15 June and 25 June planting at Kharagpur, Dumdum, and Purulia, respectively. Similarly for the cultivar Swarna, the highest grain yield at 0.50 cumulative probabilities was simulated on 15 June planting at Kharagpur, 15 July at Dumdum, and 25 June planting at Purulia. In view of the weather uncertainty, advanced planting projects higher rice grain yield production as compared to farmers' planting time (15 July) as well as delayed planting in all the locations for the cultivar Lalat/Swarna.

Table 1. Mean Simulated Growth and Phenological Events of Cultivars Lalat and Swarna for the GCM Scenarios (GFDL, GISS and UKMO) at Different Locations in Eastern India

Locations	Scenarios	Total Biomass (kg/ha)	Days After Transplantation	
			Flowering	Maturity
LALAT:				
Kharagpur	Normal	6502	63	88
	GFDL	6232	56	78
	GISS	6191	58	78
	UKMO	5989	58	77
Dumdum	Normal	7326	62	87
	GFDL	7145	55	77
	GISS	6078	55	77
	UKMO	6668	55	77
Purulia	Normal	5956	67	93
	GFDL	5776	57	81
	GISS	5755	57	80
	UKMO	5613	57	80
SWARNA:				
Kharagpur	Normal	7576	92	119
	GFDL	7153	83	106
	GISS	7120	83	106
	UKMO	6924	83	106
Dumdum	Normal	9561	93	120
	GFDL	9057	84	107
	GISS	9009	84	107
	UKMO	8689	84	107
Purulia	Normal	6563	97	129
	GFDL	6473	82	106
	GISS	6460	82	106
	UKMO	6399	82	106

3.2.2. GCM Scenario

The model simulated total biomass and appearance of phenological events i.e. flowering and maturity of both the cultivars for different scenarios at all the locations (Table 1). A higher biomass was simulated for the location Dumdum followed by Kharagpur and Purulia. The UKMO scenario predicted higher reduction in biomass, followed by GISS and GFDL scenarios. Appearance of flowering was earlier by 5 to 7, 7, and 10 days in Lalat and 9, 9, and 15 days in Swarna for the GCM scenarios at Kharagpur, Dumdum, and Purulia, respectively. Similarly, the maturity duration was reduced by 10 to 13 days in Lalat and 13 to 23 days in Swarna for the GCM scenarios over the locations. The productivity estimate of the CERES- Rice model is highly sensitive to rise in temperature (Mahmood, 1998). The calculation of genetic coefficients of the model is based on threshold temperature. The genetic coefficients include thermal time required to complete the juvenile stage, rate of photoinduction, optimum photoperiod, thermal time for grain filling, conversion efficiency from sunlight to assimilate, tillering rate and grain size (Ritchie et al., 1987). Increases in air temperature can accelerate crop growth and consequently shorten the growth period. In cereal crops for example, such changes can lead to poor vernalization (e.g., hastened flowering) and reduced yield. Mathews et al. (1997) reported a 7% decrease in simulated rice yield per every 1 °C rise in air temperature in major rice growing regions of Asia. Under optimal irrigation management, at the International Rice Research Institute (IRRI) farm, about 77% of yield variation could be explained by minimum temperature (Peng et al., 2004). Due to temperature increase as the crop matures earlier, the biomass and ultimately the yield gets reduced.

The predicted changes in yields of rice for the three locations under different climate change scenarios for rainfed condition is given in Table 2. In general, the model simulated a decrease in yield for the three scenarios GFDL, GISS, UKMO for both the cultivars Lalat and Swarna at all the three locations. For the cultivar Lalat, GFDL GISS and UKMO scenarios predicted changes in grain yield of -10.55, -12.61 and -26.82% at Kharagpur; -11.86, -13.7 and -28.91% at Dumdum; and -5.78, -6.02 and -13.95% at Purulia, respectively. The yield reduction of the cultivar Swarna was significantly lower at Kharagpur and Purulia, varying from 1.03% at Purulia to 17.13% at Kharagpur against the respective variation of 5.78 to 26.82% of Lalat for the GCMs. However, at Dumdum, the change in yield of Swarna was comparable to that of Lalat for all the GCM scenarios. The highest yield re- duction under UKMO scenarios was possibly due to highest rise in temperature output of 5.2 °C. Similar results were repor- ted by Krishnan et al. (2007), who used INFOCROP and ORYZA model for grain yield simulation of a single medium duration rice variety (IR 36) under the GCM scenarios in eas- tern India. They predicted yield changes of -7.63, -9.38 and -15.86% with ORYZA1 and -9.02, -11.30 and -21.35% with INFOCROP model for the GDFL, GISS and UKMO scenarios, respectively. They stated that these decrease in yield predictions were mainly attributed to the sterility of rice spikelets at higher temperatures. Similarly Masutomi et al. (2009) assessed the impact of climate change on rice production in Asia in comprehensive consideration of the process/parameter uncertainty in general circulation models and found that in the 2020s, production probability decrease values were high for all Special Report on Emissions Scenarios because the negative impacts of climate change were larger than the positive effects of CO_2 fertilization in almost all climate scenarios in the near future.

Table 2. Mean Simulated Rice Grain Yield and the Percentage Change in Yield for the Cultivars Lalat and Swarna under the GCM Scenarios (GFDL, GISS and UKMO) at Different Locations of Eastern India

Locations	GFDL		GISS		UKMO	
	Yield (kg/ha)	Change in yield (%)	Yield (kg/ha)	Change in yield (%)	Yield (kg/ha)	Change in yield (%)
LALAT:						
Kharagpur	3168 (±282)	-10.55	3095 (±357)	-12.61	2592 (±431)	-26.82
Dumdum	3686 (±413)	-11.86	3609 (±468)	-13.70	2968 (±401)	-28.91
Purulia	2950 (±293)	-5.78	2941 (±258)	-6.02	2694 (±476)	-13.95
SWARNA:						
Kharagpur	3803 (±422)	-5.58	3747 (±439)	-6.97	3338 (±509)	-17.13
Dumdum	4593 (±539)	-10.55	4447 (±541)	-13.39	3852 (±594)	-24.98
Purulia	3465 (±509)	-1.03	3449 (±544)	-1.10	3228 (±586)	-7.37

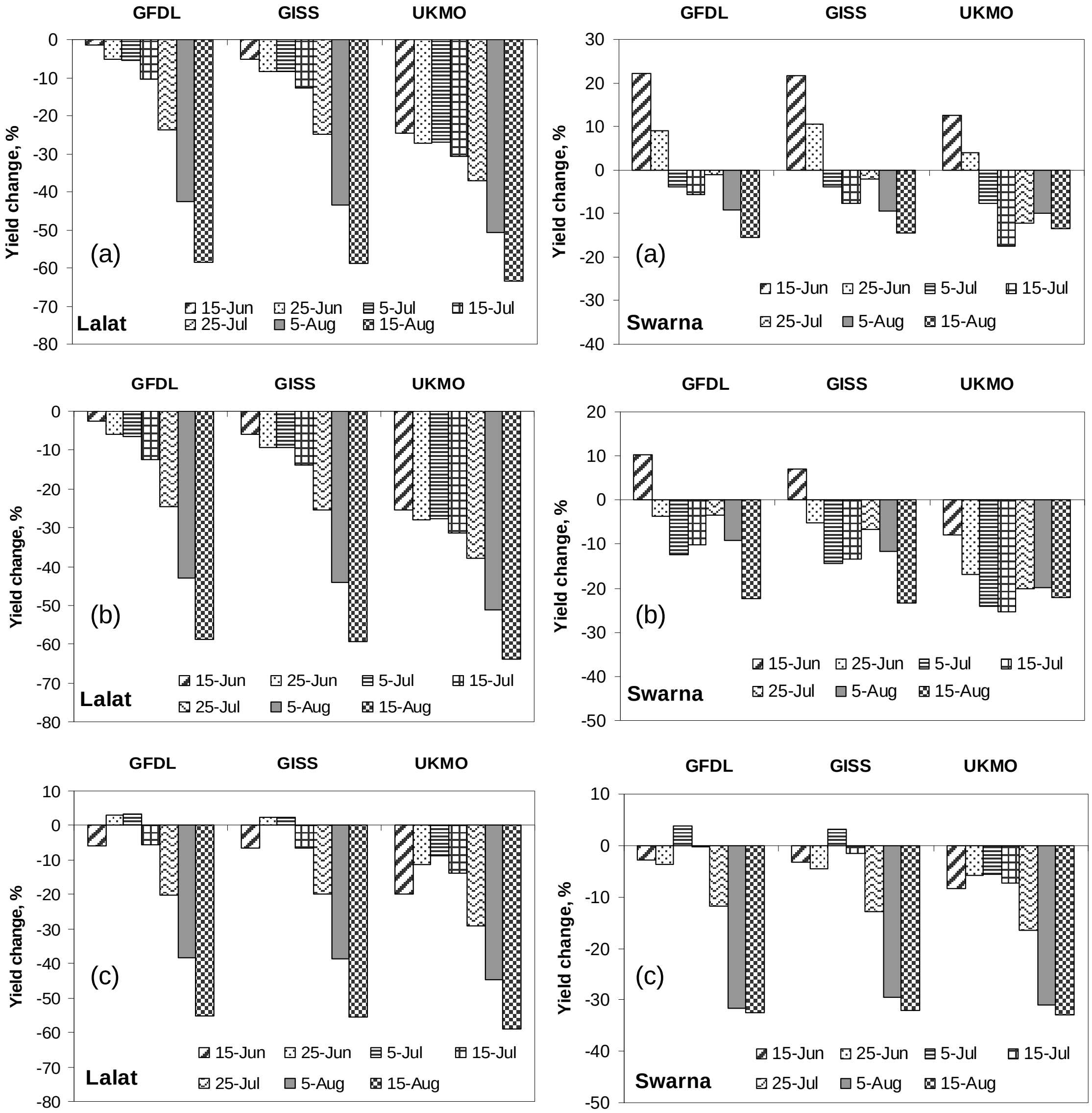

Figure 3. Change in rice grain yield under the GCM scenarios (GFDL, GISS and UKMO) for different planting dates of the cultivars Lalat and Swarna at (a) Kharagpur, (b) Dumdum, and (c) Purulia of eastern India.

3.3. Adaptation Measures

The grain yield was simulated for various planting dates starting on 15 June at 10 days interval up to 15 August to find the optimum planting dates of both the cultivars Lalat and Swarna at the three locations in eastern India. Adjusting the planting dates is one of the most effective ways of adaptation measure. The adverse effect of climate change can be mitigated to an extent by changing the planting dates. Karla et al. (2008) studied the effect of increase in temperature on grain yield of some winter crops (wheat, mustard, barley and chickpea) in northwest India on the basis of historic records through a dynamic crop growth model, WTGROWS and the model output indicated that increase in temperature by 1 to 3 °C is likely to advance the optimal sowing dates by 5 to 8 days per degree rise in temperature.

In the present study, the planting date evaluation of both the cultivars (Figure 3) was done for the GCM scenarios at Kharagpur, Dumdum and Purulia. At Kharagpur, among the different planting dates, the 15 June planting simulated highest grain yield whereas planting on 15 August simulated the lowest grain yield of both the cultivars for all the GCM scenarios. With all the GCM scenarios, and for all planting dates, Lalat simulated decreased yield noting the lowest reduction on 15 June planting. Whereas, for Swarna, the planting on 15 and 25 June simulated increased grain yield for all the GCM scenarios. The yield changes on 15 June planting were -1.55, -5.19 and -24.76% for Lalat and 22.2, 21.56, and 12.67% for the Swarna under GFDL, GISS and UKMO scenarios, respectively. Similar results were obtained when Alexandrov and Hoogenboom (2000) studied the impact of climate variability and change of crop yield in Bulgaria, where sowing date of maize for the experimental station should occur at least 2 weeks earlier in the 2080s under the ECHAM4 scenario, relative to the current climate conditions.

Similar to Kharagpur, at Dumdum, among the different planting dates, the planting on 15 June simulated highest grain yields and planting on 15 August simulated the lowest grain yields of both the cultivars for all the GCM scenarios. The yield changes on 15 June planting were -2.44, -6.05 and -25.44% for Lalat and 10.24, 7.02, and -7.79% for the Swarna under GFDL, GISS and UKMO scenarios, respectively.

Unlike Kharagpur and Dumdum, at Purulia, among the different planting dates, the planting on 5 July simulated the highest grain yield of both the cultivars for all the GCM scenarios, where 15 August planting continued to simulate the lowest grain yield. With the GCM scenarios; GFDL and GISS, higher grain yield was simulated for the planting on 5 July and lower grain yields after or before 5 July planting when compared to the normal climate for both the cultivars. Whereas, the UKMO scenario showed decreased grain yields for all the planting dates. The yield changes on 5 July planting were 3.32, 2.36 and -8.92% for Lalat and 3.74, 3.25, and -5.66% for Swarna under GFDL, GISS and UKMO scenarios, respectively.

4. Conclusions

The future climate change, because of rise in temperature and variability in rainfall pattern, will have adverse effect on rice yield of eastern India, particularly under rainfed agro-ecosystem. Crop simulation analysis with the use of past climate and future scenarios of climate change forecasted less rice grain yield reduction with advanced planting. An advanced planting time of 10 to 30 days from current farmers' planting time (15 July) is expected to mitigate the adverse effect of climate change on rice yield of eastern India. For future climate change scenarios, the long duration cultivar "Swarna" fitted better than the medium duration cultivar "Lalat" in simulating lower grain yield reduction. Cultivar selection and plating time adjustment could be suitably managed for better adaptation to minimize the risk of yield loss due to climate change.

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