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Climate change impacts on productivity of rice (*Oryza sativa*) in Bihar

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ABSTRACT

To asses the impacts of probable changes in climate with time, on yield of long duration rice commonly grown in Bihar an experiment was done in which growth and yield data from the field experiment were analysed during *kharif* from 2006 to 2008 at Patna, Bihar. This study was done to find out the effect of projected change in climate on rice growth and yield through INFOCROP model. Model was calibrated and validated with 57% coefficient of efficiency. Using the factors from HADCM3 (Hadley Centre Coupled Model ver.3) GCM (General Circulation Model) predictions, rice yield was simulated for future scenarios. The results showed an increase in rice yields for 2020 scenario to the tune of 2.7% decrease upto 0.3% for 2050 and a decline of 31.3% in 2080 from baseline with the current agronomic practices. Sensitivity analysis done through simulations for combinations of CO_2 and temperature changes indicated that the potential yield of rice increased with elevated levels of CO_2 and decreased with increasing temperature. The simulation studies revealed that an increase in minimum temperature in future could be more detrimental for long duration rice variety (MTU-7029) in terms of yield.

Key words: Climate change, CO_2 level, INFOCROP model, Scenarios

World food security is a major issue with ever increasing population. The situation is worsened by variability in climate that has become predominant in recent years. Climate and agriculture are interrelated and climate change over the next century may have significant effects on crop productivity and thus the availability of food. Crop production is affected biophysically by meteorological variables like precipitation regimes, increasing temperatures and CO_2 levels. It is expected that the increasing concentration of greenhouse gases in the atmosphere will affect the climate; global mean surface temperature is projected to increase by 1.4^0 to 5.8^0C over the period from 1990 to 2100 (Houghton *et al.*, 2001). Predicted changes in global climate may affect the production of food crops like rice (*Oryza sativa*) which is the most important cereal crop and staple food for more than half of world's population. In India, it is grown in an area of 43.81 m ha with a production of 93.36 m t. Bihar is the VIII largest rice producing state in India with an area of 3.36 m ha producing 4.99 m t in 2006-07. Crop growth simulation models can be used in assessing relationships between productivity of crops, environmental factors and management practices. Crop model use daily weather, soil and plant data in simulating crop yields, have the potential to assess the risk of producing a given crop in a particular soil-climate regime and for assisting in management decisions that minimize the risk of crop production (Tsuji *et al.*, 1998). A model can be applied in different ways that include estimation of crop productivity, assessment of impacts of climate variability and vulnerability of crop production system, adaptation options and strategies for managing the negative impacts of climate change thus minimizing the losses that might be incurred through climate change beforehand (Adejuwon, 2004). Mechanistic crop models are frequently employed to estimate crop yields in climate change studies, as they attempt to represent the major processes of crop environmental responses (Reilly *et al.*, 1996). Model parameters may be determined either in controlled environments or under field conditions.

The objective of this study undertaken at ICAR-RCER, Patna as part of the "Network Project on Climate Change" is to assess the impacts of probable changes in climate with time, on the yield of long duration rice commonly grown in Bihar. In this study INFOCROP model developed at IARI, Pusa by Aggarwal *et al.* (2004) is used. Infocrop is a decision support system, based on a generic crop model, is user friendly, targeted to increase applications of crop models in research and development, and has simple and easily available input requirements. Model is calibrated and validated based on field experiments data and used for generating projected yield under different future scenarios.

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MATERIALS AND METHODS

Detailed data for calibrating and validating the INFOCROP Model (Aggarwal *et al.,* 2004) were obtained from field experiments conducted on rice 'MTU-7029' at WALMI farm, Patna (Agroecological Zone III A, Latitude-25°58' N; Longitude-85°25'E; Altitude-41m) for 2006, 2007 and 2008. 'MTU-7029' rice is a popular long duration variety (150 to 160 days) grown in Bihar. Soil is of clay loam type having a near neutral pH of 7.4, organic carbon content 0.65%, the sand, silt and clay percent is 35, 28 and 37, respectively. The bulk density and saturated hydraulic conductivity are 1.47 Mg/m^3, 74.4 mm/day respectively. Rice was transplanted after 30 days of sowing and the spacing adopted was 20 cm × 15 cm. Nitrogen was applied @ 120 kg/ha in three splits, 50% as basal dose and rest in two equal splits as top dressing at 25 and 50 days after transplanting and two irrigations at active tillering stage and booting @ 60 mm.

The INFOCROP model used in the study requires daily weather data (maximum temperature, minimum temperature, rainfall etc.), soil information (soil type, pH, organic matter, bulk density etc.), and varietal parameters (thermal time, specific leaf area, potential storage organ weight, etc.) for determining growth and yield. Thermal time, grain weight, potential storage organ number and specific leaf area data (Table 1) were used from the observed values and for other parameters default values in the model were used. Future scenarios of climate-based on GCM outputs from Hadley Center's HADCM3 model were used for the study. Changes in the yield of rice were examined for A2 scenario from the model, which represents continuously increasing population and emission characteristics more suited to Indian conditions. Scenario assumes a future atmospheric CO_2 concentration of 414, 522 and 682 ppm for 2020, 2050 and 2080, respectively. Based on GCM outputs, factors for rainfall, maximum and minimum temperature were incorporated into the observed weather data of the period 1961-1990 for generating weather scenario of 2020, 2050 and 2080s (equations 1 and 2).

Table 1. Varietal parameters used as input for the model

	Value
Thermal Time (degree days)	
Sowing to germination	83
Germination to 50% flowering	2,050
Flowering to maturity	450
Slope of storage organ number/m^2 to dry matter during storage organ formation (storage organ/kg/day)	60,000
Potential storage organ weight (mg /grain)	19.5
Specific leaf area (dm^2/mg)	0.0021

Expected changes in Temperature = Baseline temperature + Expected change in temperature obtained from HADCM3 outputs ... (1)

Expected changes in Precipitation = Baseline daily rainfall x (1+ % change in rainfall) ... (2)

Model was calibrated for 2006 by adjusting timing of growth stages and crop coefficients, after calibration was accomplished, model was validated for 2006, 2007 and 2008. Sensitivity analysis of the model was performed by raising the temperature from 1^0 to 4^0 C combined with elevated CO_2 level (682 ppm) after validation to test the model behavior for probable changes in temperature and CO_2 levels. The model was then run for baseline (1961 to 1990), 2020, 2050 and 2080 time periods with the practices based on validation. Any future changes in pest and disease incidence and changes in management practices due to climate change are not considered in this study.

RESULTS AND DISSCUSION

Model calibration and validation

The results from 2006, 2007 and 2008 field experiments were used to calibrate and validate the crop model. A comparison between observed and simulated yield is given in Table 2 and on this basis, the crop yield for future scenarios is generated. Model is validated for 'MTU-7029' with coefficient of efficiency of 57% calculated on the basis of model given by Hubbard *et al.* (2003).

$$E = 1.0 - \left(\frac{\sum_{i=1}^{N} (o_i - p_i)^2}{\sum_{i=1}^{N} (o_i - o)^2} \right)$$

where O is observed and P is yield predicted by the model and N is the number of observations.

Table 2. Observed and simulated grain yield of rice at Patna

Parameter	2006	2007	2008
Observed grain yield (kg/ha)	4,835	3,366	5,528
Simulated grain yield (kg/ha)	4,802	3,404	6,550
RMSE (kg/ha)		591	
MAE (kg/ha)		364	
R^2		0.93	
Coefficient of Efficiency (%)		57	

Sensitivity analysis

Potential yields were simulated by incorporating the changes in maximum and minimum temperature data of 1961 to 1990 and CO_2 levels, by increasing maximum, minimum and mean temperature in the observed temperature of baseline period by 1, 2, 3, and 4°C with present level of CO_2 (370 ppm) and then at elevated level (682 ppm). At current levels of CO_2 (370 ppm), maximum temperature above 1°C resulted in decreased potential grain yield of rice at Patna, an increment in grain yield is observed with elevated level of CO_2 (Fig. 2). With increase of mean temperature by 4 °C, yield may decrease upto 29%. Simulations for combinations of CO_2 and temperature changes indicated that the potential yield of rice increased with elevated levels of CO_2 and decreased with increasing temperature. Simulation studies on potential yield show that the yield will be affected more by increase in minimum and mean temperature as compared to maximum temperature.

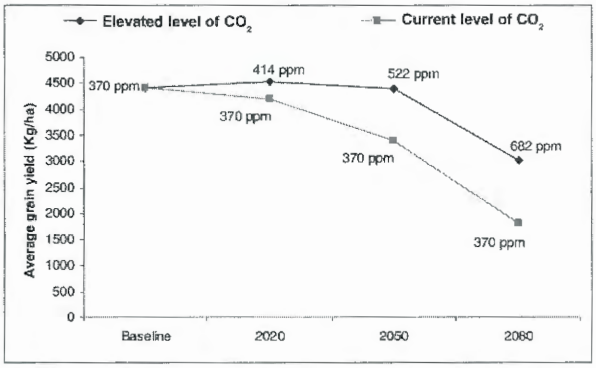

Fig 1. Effect of temperature on potential grain yield of rice (MTU-7029) at current and elevated level of CO_2

Growth and yield scenarios

Overall analysis of simulated yield data (1961 to 1990) for the selected station, taken for study, showed an increase in rice yields for 2020 scenario to the tune of 2.7% that decreases up to 0.3% for 2050 and a major decline of 31.3% in 2080 (Table 3) with the agronomic practices based on validation. Further analysis of simulation studies show that grains/m² and grain yield for 2020 is maximum, may be due to optimum or near optimum temperature values; however, in 2050 and 2080 the above mentioned parameters showed a downward trend with increasing temperature. The duration of the crop and days to anthesis increased for 2050 and 2080 scenarios as compared to the duration of the crop simulated for baseline weather. This result is in agreement with the previous findings, reported by Matthews *et al.* (1995) that in rice crop, duration decreases with temperature increase till 30°C but, with an increase in temperature beyond it, the duration of crop growth increases, this may be due to decreasing growth rate. Higher total dry matter (TDM) values for 2080, period obtained through simulation studies, may also be attributed to increased CO_2 levels, leaf area index (LAI) value is highest for 2050 followed by 2080, may be due to higher CO_2 concentration for these two time periods as pointed out by Peng *et al.* (1995) that higher temperatures under elevated CO_2 promotes net assimilation rate and leaf area. However, yield reduction in 2080 scenario is due to lesser number of grains/m² indicating higher spikelet sterility (Table 4).

To study the effects of increased level of CO_2, the model was run for a hypothetical scenario by keeping the level of CO_2 constant at current level i.e. 370 ppm and all other factors as per the HADCM3 GCM predictions. The results of the simulation study are presented in Fig. 1. It is possible that increasing levels of CO_2 is able to compensate the ill effects of increased temperature upto 2050 scenario, but later on temperature is becoming the limiting factor for yield of rice crop.

Table 3. Grain yield of rice simulated by INFOCROP Model for HADCM3 A2 Scenarios

	Simulated yield (kg/ha)					
	Baseline	2020	2050	2080	Standard deviation (kg/ha)	Coefficient of variation (%)
Average grain yield (kg/ha)	4411.2	4531.7 (2.7)	4396.8 (-0.3)	3031.7 (-31.3)	710.02	17.35

Note: Figures in parentheses indicates % change in yield from baseline

Table 4. Crop growth and yield parameters of rice simulated by model for Patna conditions

Scenarios	Days to anthesis (days)	Days to physiological maturity after sowing (days)	Maximum Leaf area index (panicle emergence)	Total dry matter (kg/ha)	Grain weight (mg/grain)	Number of grains (grains/ha)
Baseline	126	155	3.09	8610	15.3	245027217
2020	125	152	3.20	9061	14.6	261581737
2050	128	153	3.28	9851	14.8	257785003
2080	138	162	3.21	10856	17.5	151670262
Standard deviation	6.1	4.8	0.08	985	1.32	52047750
Coefficient of variation (%)	4.7	3.1	2.46	10.3	8.49	22.73

Table 5. Average maximum and minimum temperature during crop growing period (June-November) generated with HADCM3 factors

	Months	Baseline	2020	2050	2080
Maximum temperature	June	35.83	35.52	37.59	39.24
	July	32.55	32.43	34.00	35.40
	August	32.20	32.60	33.81	35.37
	September	31.96	33.13	34.00	36.00
	October	31.05	32.36	34.37	37.23
	November	28.43	29.29	30.54	33.68
Minimum temperature	June	26.23	26.98	28.67	30.92
	July	25.85	26.46	27.57	29.01
	August	25.93	26.57	27.61	28.95
	September	25.20	26.21	27.03	28.96
	October	21.50	22.65	24.45	26.17
	November	14.71	16.22	17.72	18.97

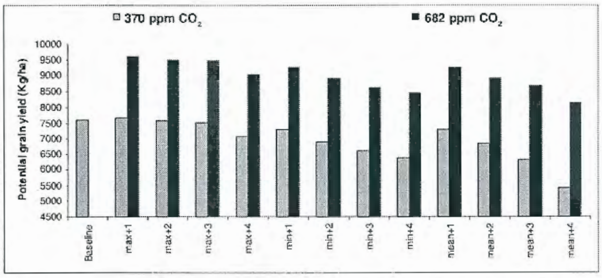

Fig 2. Simulated grain yield of rice (MTU-7029) at Patna for current and increasing levels of CO_2 under HADCM3 scenarios

Thus it can be concluded that 'MTU 7029' rice, may perform satisfactority upto 2050, with current agronomic practices and levels of temperature and CO_2 as per the HADCM3 projections, indicated by simulation studies. This drastic reduction of yield of long duration variety after 2050 may be attributed to predicted increase in mean temperature of above 5°C in 2080 with respect to baseline temperature during the crop growth period (Table 5). The result is in agreement with the sensitivity analysis described earlier showing that the effect of minimum and mean temperature is more pronounced on yield as compared to maximum temperature (Fig.2) as indicated in sensitivity analysis.

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