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Simulating the impact of projected climate change on rice (*Oryza sativa* L.) yield and adaptation strategies in major rice growing regions of India

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ABSTRACT

Global mean air temperatures are projected to increase by 1.8 to 4.0 °C by the end of this century. Higher temperatures coupled with increased CO_2 levels could result in altered growth and productivity of crops. Since rice is sensitive to high temperatures, a simulation analysis was carried out to quantify the impact of increased temperatures (1, 2, 3, 4 and 5 °C) and elevated CO_2 (369, 450,550 and 650ppm) alone and in combination on the yield using InfoCrop-RICE model. An assessment is also provided on the possible gains due to change in planting time and crop duration. Though elevated CO_2 alone increased the rice yields, increase in temperature by 1°C (even at 369 ppm CO_2 concentration) reduced irrigated rice yield by 6.6 to 11.1 % and rainfed rice yields by 4.6 % to 9.4 %. The combined impact of increased temperature and elevated CO_2 resulted in net decline in yield in spite of CO_2 fertilization. Planting cultivars in future with matching crop duration of current cultivars and change in planting time may reduce the adverse impacts of climate change on rice yields.

Key words: Rice, simulation, yield, CO_2, temperature, adaptation strategies

Global mean air temperatures are projected to increase by 1.8 to 4.0 °C by the end of this century (IPCC, 2007). Climate change exerts both positive and negative impact on crop yield, though its magnitude may differ from location to location. According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007a, b), in arid and semi-arid regions, warming beyond a certain limit may adversely affect the crop growth, development and finally the crop productivity. Among the climatic factors, temperature and CO_2 are important factors that significantly influence crop growth, development and yield. Cardinal temperatures influences crop physiological process and reproduction, thereby influencing grain yield. Not only different crops respond differently to increase in temperature, but also different genotypes show differential response in yield (Prasad *et al*, 2006). Increase in CO_2 concentrations further from current 393 ppm (NOAA, 2012), benefit the yield of C_3 plants due increase in photosynthetic rates. However, due to green-house effect, the increase in CO_2 concentration in atmosphere causes rise in temperature.

Rice is one of the main staple food crop in India and grown in about 42.56 million hectare area with a production of about 95.33 million tonnes (Agricultural Statistics at a Glance, 2012). Rice is reported to be influenced by temperature, especially during grain filling phase (Cao Yun-Ying, 2009). As it is a C_3 crop, CO2 fertilization effects on growth yield have been reported by Baker and Allen (1993). Several studies have reported the impact of climate change on rice in India (Mall *et al*., 2004, Aggarwal and Mall, 2002, Attri and Rathore, 2003, Hundal, *et al*., 1993 and Krishnan, *et. al*., 2007). However, they did not attempt to provide the adaptation gains. In the present study, an attempt has been made to assess the impact of elevated CO_2 and temperature alone and in combination on rice crop using 35 years (1970-2005) weather data from locations representing major rice-growing agro-ecological regions. Apart from quantifying the impacts, the adaptation gains by changing planting time and change in variety was also assessed.

MATERIALS AND METHODS

For this study, eight locations *viz*. Ludhiana, Patna, Cuttack, Raipur, Akola, Lucknow, Barrackpore, Rajamundry, differing in climatological and geographical features were selected.

Table 1: Model inputs of physical and chemical properties of soil and rice varieties at different locations.

Parameters	Rajamundry	Cuttack	Akola	Raipur	Barrakpur	Patna	Lucknow	Ludhiana
Latitude °N	16.9	20.3	20.99	22	22.45	25	25	30.9
Longitude °E	81.7	85	77.8	77	88.26	85	85	75.8
SAND (%)	16	79	17	16	47	38	42	40
CLAY (%)	56	10	55	55	21	21	22	23
BD (Cg/cc)	1.21	1.59	1.21	1.21	1.41	1.4	1.4	1.39
SOC (%)	0.75	0.53	0.75	0.75	0.82	0.63	1	0.56
pH (1:2.5 soil water suspension)	7.9	6.3	7.9	7.9	6.2	8	6.6	7.9
EC (ds mm^{-1})	0.2	0.1	0.2	0.2	0.1	0.3	0.1	0.8
KSAT (mm h^{-1})	48	237	48	48	141	114	126	120
WCST (%)	0.54	0.4	0.54	0.54	0.47	0.47	0.47	0.48
WCFC (%)	0.44	0.17	0.44	0.44	0.33	0.38	0.36	0.37
WCWP (%)	0.22	0.07	0.22	0.22	0.16	0.19	0.18	0.18
WCAD (%)	0.13	0.04	0.13	0.13	0.09	0.11	0.1	0.1
Rice Varieties	Samba Mashuri	Hazaridhan	Karjat 5	Vijeta	Shatabdi	Pant Dhan 12	Pant Dhan 12	PR-120

The point data on daily weather for 1970-2005 (Coordinating centers of the project, Central Research Institute for Dryland Agriculture, Hyderabad and Indian Meteorological Department, Pune), soil and data crop/ variety of these locations was collected. InfoCrop, a generic crop simulation model was used to carry out the present study. The temperatures were raised by 1°C, 2°C, 3°C, 4°C and 5°C over ambient and CO_2 concentrations used were 369 ppm, 450 ppm, 550 ppm and 650 ppm. These two factors were used in all possible combinations to get 20 combinations (5 x 4). Simulations were carried out for rainfed and irrigated conditions and at all locations. To cope with the yield losses due to rise in temperature, change in duration of crop (± 15 days to medium duration crop) and planting time (± 10 days to date of transplanting) was used as an adaptive measure as a part for adaptation strategy suggested by Attri and Rathore (2003) to reduce the climate change effects.

Model description

InfoCrop (Aggarwal etal., 2006) is a generic crop growth model that can simulate the effects of weather, soil, agronomic managements, nitrogen, and water on crop growth and yield. The model simulations are based on crop growth and development processes such as phenology, photosynthesis, partitioning, leaf area growth, source-sink balance, radiation use efficiency, transpiration, uptake, allocation and redistribution of nitrogen. The process like effects of temperature, CO_2, water stress, nitrogen stress, flooding and frost stresses on crop growth and development are also considered in the model.

Model inputs

Varietal characteristics: InfoCrop distinguishes varieties of a crop by their differences in phenology, growth and source- sink balance. In most cases, thermal times of three phenological phases, the sensitivity to photoperiod, early vigour (defined in the model as relative LAI growth rate during initial stages), index of storage organs formation, and the potential weight of the grain are sufficient to adequately characterize the varieties. Based on previous published studies (DRR 2009) and considering days to flowering and maturity (120-140 days), dominant variety of a region were selected for analysis assuming that farmers have optimized their variety (Table 1).

Table 2: Combined impact of increasing temperatures and elevated CO_2 (% change from 0 deg, 369 ppm) on rice yield in different locations

Location	Temp.	Irrigated			Rainfed		
		450 ppm	550 ppm	650 ppm	450 ppm	550 ppm	650 ppm
Rajamundry	1	5.2	10.5	13.8	9.4	16.6	22.6
	2	-2.4	4.6	8.4	0.6	10.5	17.8
	3	-16.4	-8.5	-2.6	-6.4	0.0	8.7
	4	-33.3	-25.9	-19.3	-19.4	-13.4	-4.6
	5	-48.4	-40.4	-34.8	-31.6	-23.8	-18.5
Cuttak	1	7.0	15.3	19.6	10.0	19.3	28.0
	2	-1.8	6.7	11.4	-3.3	6.6	15.3
	3	-16.1	-6.4	-0.4	-14.2	-5.1	2.8
	4	-30.4	-22.6	-16.2	-28.5	-20.4	-12.4
	5	-46.4	-38.1	-32.5	-42.4	-35.0	-28.5
Akola	1	7.2	13.2	18.0	14.1	28.2	43.3
	2	-0.1	7.7	12.4	4.8	18.7	32.6
	3	-13.1	-3.3	3.2	-1.0	10.4	23.4
	4	-24.2	-15.3	-9.1	-5.4	4.0	16.6
	5	-35.5	-28.2	-22.0	-14.8	-5.5	2.3
Raipur	1	7.5	14.4	19.6	9.9	17.5	23.4
	2	-2.4	4.8	9.3	3.7	11.0	17.2
	3	-13.5	-5.1	-0.4	-4.4	3.8	10.9
	4	-26.2	-17.8	-12.3	-15.3	-6.7	0.6
	5	-41.6	-34.0	-28.4	-27.5	-18.9	-11.5
Barrackpore	1	10.9	19.6	24.4	9.1	21.8	30.3
	2	-2.4	7.5	12.4	1.0	10.8	19.5
	3	-15.4	-5.9	1.2	-8.9	1.5	8.9
	4	-29.3	-19.7	-12.8	-22.0	-11.0	-3.5
	5	-44.0	-35.8	-29.2	-32.2	-25.3	-16.9
Patna	1	8.0	13.9	-19.9	5.5	15.4	23.2
	2	-3.5	4.8	9.8	-1.5	6.2	14.0
	3	-19.6	-10.5	-4.8	-13.9	-4.6	1.3
	4	-35.6	-27.7	-21.8	-24.5	-17.3	-11.6
	5	-49.6	-42.1	-36.7	-37.0	-28.6	-21.5
Lucknow	1	1.7	3.0	2.1	NA	NA	NA
	2	-3.6	1.4	2.9	NA	NA	NA
	3	-17.7	-9.5	-4.8	NA	NA	NA
	4	-32.9	-25.6	-20.3	NA	NA	NA
	5	-46.6	-38.4	-32.9	NA	NA	NA
Ludhiana	1	-0.1	1.1	0.4	NA	NA	NA
	2	-3.4	-1.6	0.2	NA	NA	NA
	3	-15.0	-9.3	-4.7	NA	NA	NA
	4	-27.6	-20.8	-16.2	NA	NA	NA
	5	-45.6	-40.4	-34.9	NA	NA	NA

NA- Not applicable

Soil parameters: The location-wise soil parameters used in InfoCrop are thickness of 3 soil layers, layer-wise sand, clay, bulk density, soil organic carbon and soil hydraulic characters. The soil pH, EC and slope also are required as inputs for different locations (Table 1).

Management: Rice was transplanted on the recommended time for each location during kharif season in irrigated conditions, while the rainfed crop transplanting was soil moisture dependent during kharif season. Irrigated crop received irrigation whenever the soil moisture went below 80%. The irrigated crop was supplied with 100 kg Nha^{-1} while rainfed crop received 50 kg Nha^{-1}. Crop was assumed to be free of pests and diseases.

RESULTS AND DISCUSSION

Impact of elevated CO_2 on rice yield.

The analysis indicated that the rice yields are sensitive to changes in CO_2 concentrations. The CO_2 increase was found to have significant effect on yield under both irrigated and rainfed conditions at all locations. Increasing yield trend was observed at all CO_2 concentrations (450 ppm, 550 ppm and 650 ppm) at current temperatures. In irrigated condition, at 450 ppm CO_2 level, the range of per cent change varied from 2.8 % (Ludhiana) to 20.8 % (Barrackpore), while the mean per cent change across all the locations was 13.4 %. In rainfed condition, the increase in yield ranged from 10.1 % (Lucknow) to 21.2 % (Barrackpore) with a mean per cent change of 17.6 % across all the locations. In irrigated condition, mean per cent change across all the locations was 17.8 % at 550 ppm and 19.6 % at 650 ppm, while in rainfed condition it was 27.9% at 550 ppm and 35.9 % at 650 ppm. The increasing yield with increase in CO_2 levels was attributed to greater LAI and net photosynthetic rates. Elevated CO_2 is reported to increase the rice yields (De Costa *et al*., 2006, Uprety *et al*., 2003 and Cheng *et al*., 2009).

Impact of temperature increase on rice yield

Rice yield decreased with each degree increase in temperature. However, the rate of decrease differed with location. The reduction rate in yield was low in rainfed than in irrigated condition. Increase in 1°C in temperature (at 369 ppm CO_2 concentration) may reduce irrigated rice yields by –6.6 % at Ludhiana, -8.6 % at Patna, 9.4 % at Cuttack, -9.4 % at Barrackpore and -11.1 % at Rajhmundry. On the other hand, in rainfed condition reduction was -4.6 % at Akola, -7.1 % at Patna, -8.6 % at Cuttack, -8.9 % at Barrackpore and -9.4 % at Rajhmundry. In irrigated condition, mean per cent change across all locations was between -8.9 % (at 1 °C rise) to -58.7 % (at 5 °C rise). In rainfed condition, corresponding decrease was between -1.6 % to -43.6 %. Decrease in crop duration is found to be the major factor for reduction in grain yield with increase in temperature. Rice yields are reported to be adversely affected by increase in atmospheric temperature (Aggarwal and Mall, 2002, Mathews *et al*., 1998, Lal *et al*., 1998 and Krishnan *et. al*., 2007).

Combined impact of temperature increase and elevated CO_2 on rice yield

The integrated effect of increased temperature and elevated CO_2 resulted in decline in yield in spite of the beneficial effects of high CO_2 concentrations (Table 2). For instance, in Ludhiana, across the temperature rise (1° to 5°C) conditions, the range of per cent reduction in yield was between -0.1 % to -45.6 % (at 450 ppm CO_2), 1.1 % to -40.4 % (at 550 ppm CO_2) and 0.4 % to -34.9 % (at 650 ppm CO_2) in irrigated condition. Since in Lucknow and Ludhiana, currently farmers do not go for rainfed rice, hence the simulation results are not showed. The results showed that, yield declined with increase in temperature, however at the same time the yield loss got reduced in elevated CO_2 condition. In rainfed situations, similar trends were observed at all the locations but the extent of yield loss was lesser. The irrigated crop showed significant decrease than the rainfed crop (Bouman, 2001). In rainfed rice, low rate of yield reduction may be due to rainfall changes and also because of the fact that the yields are already less due to low management and stress condition (Kumar *et al*., 2006 and Pantuwan *et al*., 2002).

Adaptation to temperature and CO_2 increase for irrigated condition

Change in crop duration (±15 days to medium duration crop) and planting time (±10 days to date of transplanting) was used as an adaptive measure to offset increase in temperatures and to harness the benefits of elevated CO_2. The adaptation gains were in comparison to the yields obtained at current climate with 369 ppm CO_2 at respective locations. The results (Fig. 1) showed that at Ludhiana, for an across the temperature rise (0°to 5°C), the range of change in yield was 6714 kg ha^{-1} to 5871 kg ha^{-1} (at 369 ppm CO_2), 6905 kg ha^{-1} to 6242 kg ha^{-1} (at 450 ppm CO_2), 7040 kg ha^{-1} to -6274 kg ha^{-1} (at 550 ppm

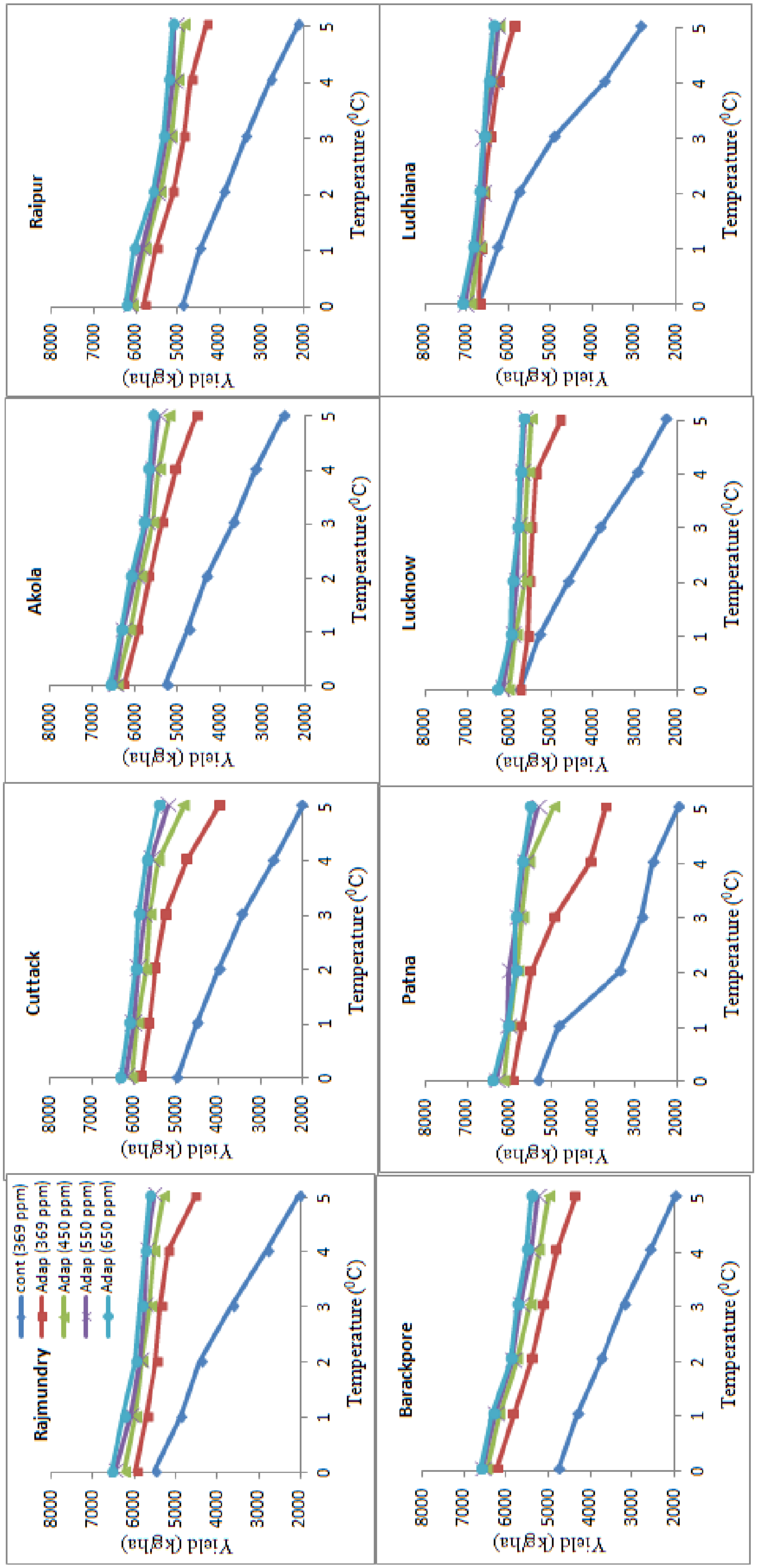

Fig 1: Current and adapted [change in duration of crop (+ 15 days to medium duration crop) and planting time (+ 10 days to date of transplanting) was used as an adaptive measure] irrigated yields at different temperatures and CO_2 levels for different locations.

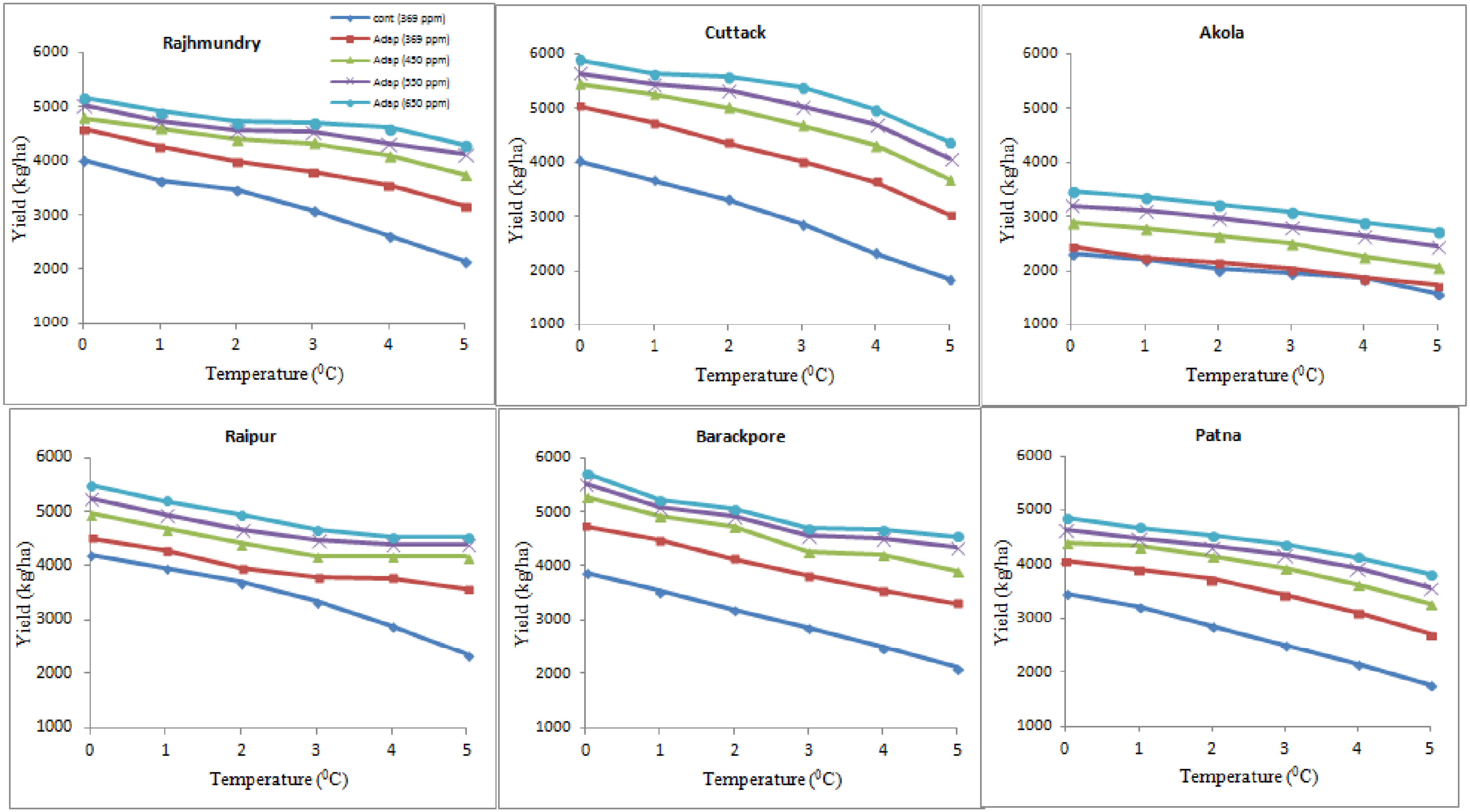

Fig 2: Current and adapted [change in duration of crop (± 15 days to medium duration crop) and planting time (± 10 days to date of transplanting) was used as an adaptive measure] rainfed yields at different temperatures and CO_2 levels for different locations

CO_2) and 7113 kg ha^{-1} to 6364 kg ha^{-1} (at 650 ppm CO_2). On the other hand in Cuttack, this ranged from 5840 kg ha^{-1} to 3982 kg ha^{-1} (at 369 ppm CO_2), 6049 kg ha^{-1} to 4830 kg ha^{-1} (at 450 ppm CO_2), 6189 kg ha^{-1} to 5187 kg ha^{-1} (at 550 ppm CO_2) and 6382 kg ha^{-1} to 5427 kg ha^{-1} (at 650 ppm CO_2). Least amount of adaptation gains were likely in Ludhiana at 1°C rise in temperature, since in Ludhiana, currently most of the farmers manage crop to maximize their yields. The results clearly proved that adaptation strategies reduced the yield loss. By changing the planting date from normal to early and by adopting long duration cultivar, yields can be improved in most of the rice producing areas. This increase in yield is attributed to high radiation use efficiency.

Adaptation to temperature and CO_2 increase for rainfed condition

The results (Fig. 2) showed that at Barrackpore, for an across the temperature rise (0° to 5°C), the range of change in yield was 4736 kg ha^{-1} to 3308 kg ha^{-1} (at 369 ppm CO_2), 5273 kg ha^{-1} to 3905 kg ha^{-1} (at 450 ppm CO_2), 5514 kg ha^{-1} to 4343 kg ha^{-1} (at 550 ppm CO_2) and 5707 kg ha^{-1} to 4548 kg ha^{-1} (at 650 ppm CO_2). At Cuttack, this range was 5044 kg ha^{-1} to 3028 kg ha^{-1} (at 369 ppm CO_2), 5450 kg ha^{-1} to 3689 kg ha^{-1} (at 450 ppm CO_2), 5653 kg ha^{-1} to 4066 kg ha^{-1} (at 550 ppm CO_2) and 5902 kg ha^{-1} to 4390 kg ha^{-1} (at 650 ppm CO_2). Change in planting date and long duration cultivar was found to produce more yield than the normal practice. Recent analysis indicated that adaptation to climate change can significantly improve the irrigated and rainfed rice yield in India in future climates (Naresh Kumar *et al*., 2013).

CONCLUSION

Among all the atmospheric factors, the increased temperature and CO_2 are the key factors of climate change, which are supposed to have immense influence on rice yield. In climate change, the higher temperature plays an important role than CO_2 in tropics. A significant increase in yield may be expected because of increase in CO_2 as rice is a C_3 plant. However, this impact study projects an overall reduction in productivity of both irrigated and rainfed crop in all the main producing states in India due to rise in temperature. However, adaptation options provide an opportunity to minimize the yield loss.

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