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# Assessment of impacts of climate change on rice and wheat in the Indo-Gangetic plains

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## ABSTRACT

In this paper, the climate change scenarios of A2 and B2 for 2070-2100 time scale (denoted as 2080) for several key locations of India and its impact on rice and wheat crops based on regional climate model (PRECIS) were described. The PRECIS projects an increase in temperature over most parts of India especially in the IGP (Indo-Gangetic Plains), the region that presently experiences relatively low temperatures. Extreme high temperature episodes and rainfall intensity days are projected to become more frequent and the monsoon rainfall is also projected to increase. Rabi (mid Nov-March) season is likely to experience higher increase in temperature which could impact and hence become threat to the crops which really require low temperature for their growth. Climatic variability is also projected to increase in both A2 and B2 scenarios. All these projected changes are likely to reduce the wheat and rice yields in Indo-Gangetic plains of India. It is likely that there will be more number of years with low yields occurs towards the end of the century. Such yield reductions in rice and wheat crops due to climate change are mediated through reduction in crop duration, grain number and grain filling duration. The yield loss will be more in A2 scenario compared to B2. These quantitative estimates still have uncertainties associated with them, largely due to uncertainties in climate change projections, future technology growth, availability of inputs such as water for irrigation, changes in crop management and genotype. These projections nevertheless provide a direction of likely change in crop productivity in future climate change scenarios.

***Keywords:*** PRECIS, Info Crop, Indo-Gangetic plain, crop model, wheat, rice

In India, studies by several authors have shown that increasing trend in surface temperature during last century (Singh and Sontakke, 2002). Such changes may impair food production, particularly in developing countries, most of which are located in tropical regions with warmer baseline climates. Increase in temperature depending upon the current ambient temperature, can reduce crop duration (Challinor and Wheeler 2007; Zhang *et al.,* 2007), increase crop respiration rates, alter photosynthate partitioning to economic products (Albrizio and Steduto 2003; Wahid *et al.,* 2007). All of these can have a tremendous impact on agricultural production and hence food security of any region. Global production of the annual crops is expected to reduce significantly due to climate change by the end of 21$^{st}$ century. IPCC and some other global studies indicate considerable probability of loss in crop production in India with increases in temperature (IPCC 2014).

Rice and wheat are the major cereal crops of India. Therefore, primary food security concerns are focused on improving and sustaining their productivity. These two crops occupy a significant area in the IGP of South Asia, which extends from Pakistan in the west to Bangladesh in the east. The Climate change is a particular environmental concern for the region, as these have numerous direct and indirect links to agricultural production. Elevated $CO_2$ increases yields of important crops of the region such as wheat and rice, but the degree of change is modulated by changes in temperature and rainfall. Often, these interactions may result in production decline. The increased incidence of weather extremes such as onset of rainfall, and duration and frequencies of drought and floods will also have major effects, and preliminary reports indicate that the recent declines in yields of rice and wheat in the region could have been partly due to changes in weather extremes (Aggarwal *et al*., 2004).

Recent studies on the impacts of possible future climate over this region indicate spatio-temporal variations in impacts on rice and wheat crops in India (Naresh Kumar et al., 2011, 2013, 2014). Assessment of the

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vulnerability of crops requires spatial and temporal scenarios of future climate. These scenarios are generally derived from projections of climate change undertaken by Global Climate Models (GCMs). The GCMs have provided good representations of the planetary scale features, their application to regional studies is limited by their coarse resolution (~300 km) and hence they do not capture the local details often needed for impact assessments at a national and regional level. The Regional Climate Models (RCM) provide detailed information of future climate change at a smaller scale and are generally based on large-scale projections of a GCM. The present analysis was under taken to 1) quantify the changes in key weather parameters in A2 and B2 scenarios for 2071-2100 time scale and to 2) quantify the impacts of the above scenarios of climate change on wheat and rice crops in IGP. Analysis of the various weather parameters were made by comparing simulated baseline (1960-1990) precipitation and temperature patterns with those in the future (2071-2100) A2 and B2 scenarios.

## MATERIALS AND METHODS

The main climatic parameters rainfall, maximum temperature and minimum temperature were analysed. To characterize the current climatic risks, the daily weather data for the study regions were collected from India Meteorological Department (IMD), Pune and Indian Agricultural Research Institute (IARI), New Delhi. For characterizing climatic risks in future, climate change scenario data simulated by PRECIS, a regional climate model (RCM), was analysed. The extracted future weather data was used to simulate future climatic risk associated with the rice and wheat cultivation in the IGP using InfoCrop, a generic crop simulation model.

***PRECIS Outputs***

PRECIS is a regional climate model for the Global Circulation Model HadCM3 developed by the Hadley Centre, United Kingdom. PRECIS has high resolution of 50 km and can be applied to any area of the globe to generate detailed climate change scenarios. PRECIS provides a daily weather data for thirty years period of 2071-2100 with 1960-1990 as the baseline. Among these, two different socio-economic scenarios both characterized by regionally focused development but with priority to economic issue in one (A2 scenario) and to environmental issue in the other (B2 scenario) were used for the present study. The latitude and longitude of the regions and their corresponding grid points from the PRECIS outputs were taken for this study are given in Table 1. The data in respect of all three variables (rainfall, maximum temperature and minimum temperature) for baseline, A2 and B2 scenarios were extracted and analyzed to calculate deviations from baseline values (1961-1990), for the following parameters, which could be used as indicators of climatic risks, and to compare different regions:

1. Annual and seasonal Kharif (last week of June-Oct) and Rabi (mid Nov-March) means of maximum and minimum temperatures
2. Annual and seasonal (Kharif and Rabi) rainfall,
3. Average number of rainy days (rainfall >2.5mm/day) on seasonal (Kharif and Rabi) and annual basis.
4. Intensity of rainfall (total rainfall/number of rainy days) on seasonal (Kharif and Rabi) and annual basis.
5. Average number of rainy days with >15mm/day and >50mm/day rainfall on seasonal (Kharif and Rabi) and annual basis.
6. Average number of days with >45$^0$C and >50$^0$C mean maximum temperature in a year.
7. Average number of days with <20$^o$C mean maximum temperature in a year.
8. Average number of days with <5$^o$C mean minimum temperature

Apart from these, co-efficient of variation (C.V.) of rainfall, maximum and minimum temperatures were also calculated for A2, B2 scenario data.

***Impact assessment of climate change using InfoCrop***

Calibrated and validated InfoCrop –wheat and rice models were used to simulate the yields using observed weather data for 30 years period (1960-1990) and for future scenarios of A2 and B2 for 2071-2100 periods. Nine representative locations in the IGP, a major wheat (Rabi season) growing area with reasonable cultivation of rice (Kharif season), were selected. The locations were Ludhiana, Hisar, Karnal, Saharanpur (upper IGP-UIGP), Pantnagar, Lucknow, Varanasi (Middle IGP-MIGP) and Patna, Barrackpore (Lower IGP-LIGP). The wheat crop was sown in the second week of November while rice was transplanted on first week of July. Crop was managed by applying fertilizer @ 120kg N in two splits for wheat and

**Table1:** Change in number of days with extreme weather parameters in the future(2071-2100) A2 and B2 scenarios with respect to the baseline (each value represents the mean of 30 years)

| Location Name | Latitude | Longitude | Change in number of days with | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tmax>45$^0$C | | Tmax>50$^0$C | | Tmax<20$^0$C | | Tmin<5$^0$C | | Rainfall >15mm | | Rainfall >50mm | |
| | | | A2 | B2 | A2 | B2 | A2 | B2 | A2 | B2 | A2 | B2 | A2 | B2 |
| Barrackpore | 22.46 | 88.26 | 12 | 6 | 1 | 0 | -16 | -13 | -8 | -8 | 6 | 6 | 1 | 1 |
| Patna | 25 | 85 | 17 | 9 | 5 | 2 | -58 | -36 | -28 | -25 | 5 | 4 | 1 | 0 |
| Varanasi | 25.2 | 83 | 27 | 13 | 13 | 6 | -56 | -39 | -29 | -25 | 6 | 2 | 0 | 0 |
| Gwaliore | 26.14 | 78.1 | 34 | 18 | 11 | 5 | -41 | -26 | -46 | -38 | 5 | 2 | 0 | 0 |
| Lucknow | 26.76 | 80.87 | 26 | 14 | 10 | 6 | -63 | -41 | -37 | -32 | 5 | 3 | 1 | 1 |
| Delhi | 28.38 | 77.12 | 28 | 17 | 13 | 6 | -66 | -45 | -54 | -40 | 2 | 1 | 0 | 0 |
| Saharanpur | 29 | 77 | 24 | 13 | 10 | 7 | -63 | -41 | -55 | -66 | 7 | 5 | 1 | 0 |
| Pantnagar | 29.03 | 79.31 | 32 | 11 | 0 | 0 | -59 | -40 | -46 | -34 | 4 | 2 | 0 | 0 |
| Hisar | 29.1 | 75.46 | 52 | 42 | 14 | 6 | -57 | -40 | -59 | -42 | 2 | 2 | 0 | 0 |
| Karnal | 29.7 | 77.02 | 25 | 13 | 14 | 7 | -68 | -45 | -53 | -37 | 6 | 4 | 1 | 1 |
| Ludhiana | 30.9 | 75.8 | 26 | 16 | 21 | 11 | -68 | -43 | -52 | -33 | 4 | 4 | 0 | 0 |

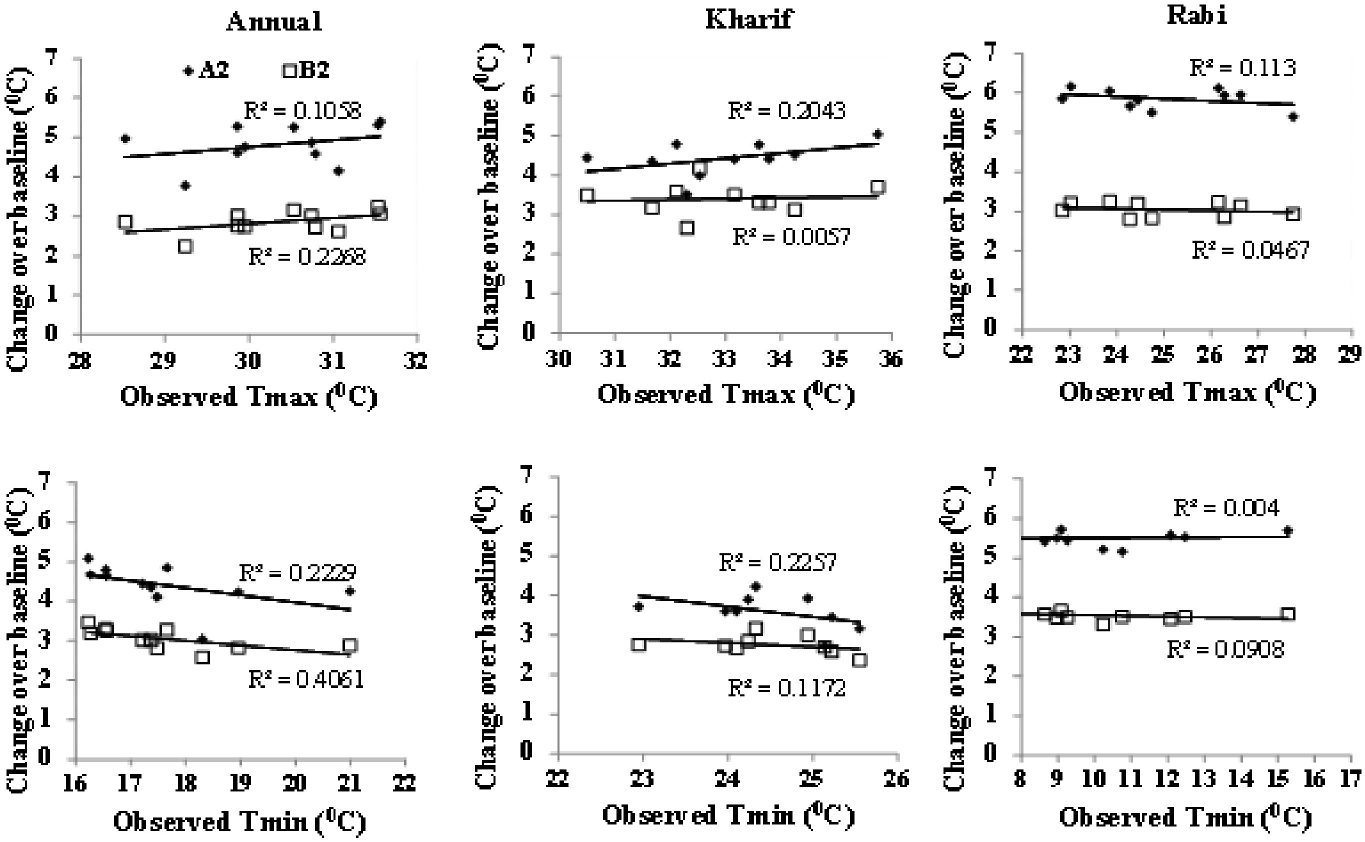


**Fig1:** PRECIS projected changes in mean maximum and minimum temperatures in 2080 scenario (2071-2100) as compared to observed temperature during baseline period (1961-1990) for 10 locations in IGP for kharif(last week of June-Oct)and rabi(mid November-March) seasons and for the whole year. Each data point represented the mean of 30 years.

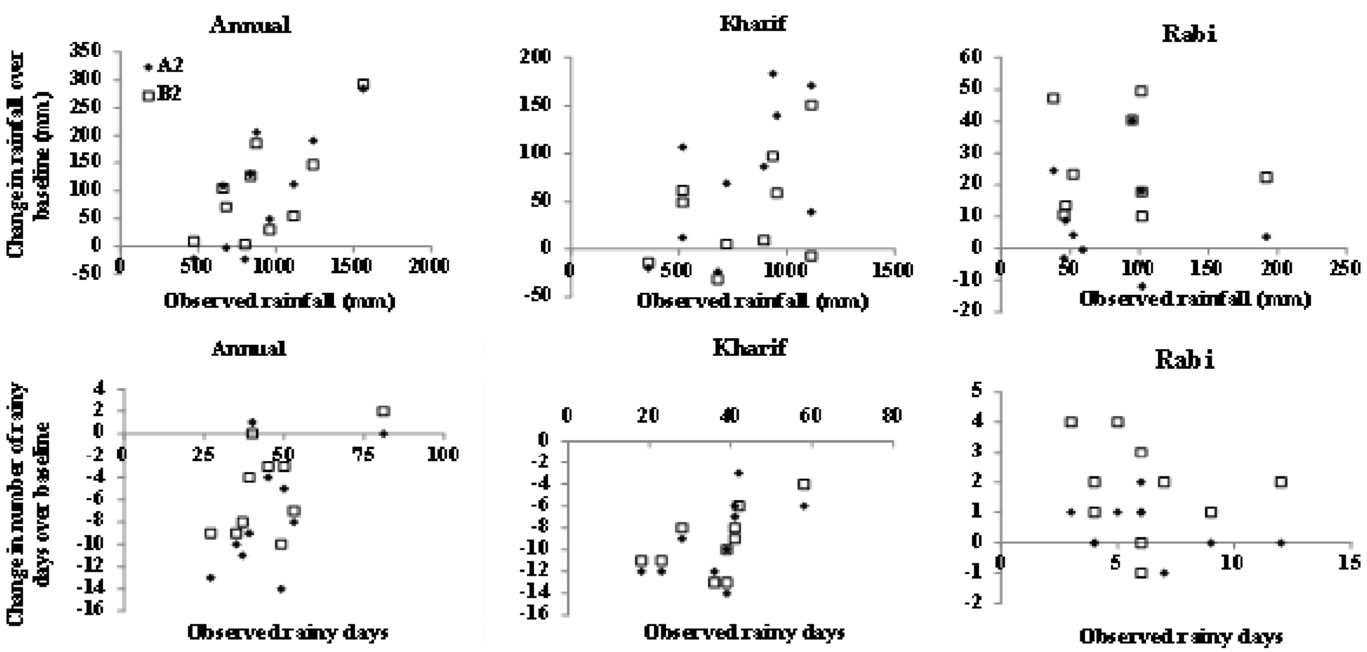


**Fig 2:** PRECIS projected changes in rainfall, rainy days and rainfall intensity in 2080 scenarios (2071-2100) as compared to observed rainfall and rainy days during baseline period (1961-1990) for 10 locations in IGP for Kharifm, Rabi season and for the whole year. Each data point represented the mean of 30 years.

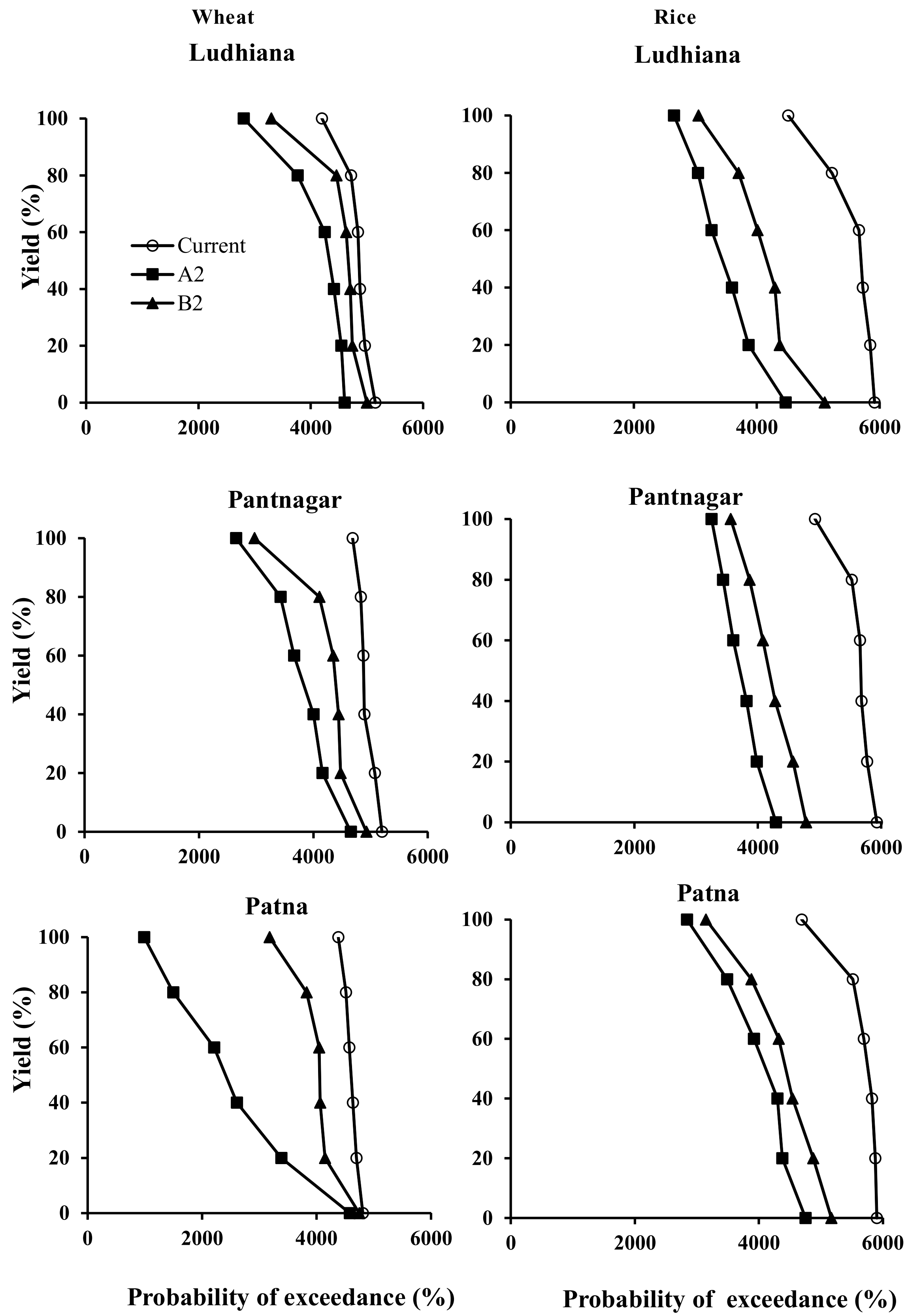


**Fig 3:** Cumulative probability distribution function of simulated wheat and rice yields for the current (1961-1990) and future (2071-2100) climate in the Indo Gangetic Plain region

@100kg N in three splits for rice in water non-limiting conditions.

For baseline yield values, simulations were done using the observed weather for the past (1960-1990) period. For scenario impact analysis, firstly, the deviations in minimum, maximum temperatures and rainfall was derived by subtracting the monthly mean values of scenarios from the model simulated baseline values. These monthly change fields in maximum temperature, minimum temperature and rainfall were coupled to the observed weather data for baseline period. In case of rainfall, month-wise percent-deviations were coupled to observed weather. The projected carbon dioxide levels for these scenarios were also included in the model for simulations. All other simulation conditions were maintained as explained earlier. To express the impacts on yield, the net change in grain yield in climate change scenarios was calculated and expressed as the percentage change from baseline mean. Yield, thus obtained were compared by frequency distribution analysis.

## RESULTS AND DISCUSSION

### *Climate change scenarios*

The baseline mean annual minimum temperature for nine locations in IGP ranged from 16.23ºC to 20.99ºC while mean maximum annual temperature ranged between 28.53ºC and 31.56 ºC. Annual rainfall ranged from 500 mm to 1600 mm with 22 to 81 rainy days.

***Annual trends:*** Analysis indicated an increase in temperature across IGP in A2 and B2 scenarios towards the end of the century (Fig. 1). Increase in temperature in A2 scenario is projected to be 1 to 2.5 ºC more than the increase in B2 scenario. In both the scenarios, increase in minimum temperature will be more in areas which are currently having low temperatures, making these areas warmer. However, currently warm areas are also projected to become warmer towards the end of the century. On the other hand, maximum temperatures are projected increase more in currently warmer areas. The slope of change indicates contrasting trends for the minimum and maximum temperatures.

The projections indicate that annual rainfall in current dry areas (with annual rainfall of about 600mm) may not witness any change, whereas, some of the areas with current annual rainfall of about 800 mm may receive substantially higher rainfall in 2080 scenario (Fig 2). Increase in rainfall is projected to be more in A2 (up to 31%) than in B2 (up to 27%) scenario. Further, the number of rainy days is projected to decrease in most of the areas across IGP in both the scenarios, suggesting an increase in intensity of rainfall. Even though, increase in rainfall intensity is projected for many areas of the globe, since all GCM outputs do not corroborate the projected change, the confidence level on rainfall projections is low (IPCC, 2007).

***Seasonal patterns****:* In India, agricultural crops are grown mainly during monsoon (Kharif) and winter (Rabi) seasons. Hence, the analysis was carried out to delineate the seasonal projections for temperature and rainfall across IGP. It is interesting to note that increase in temperature is projected to be higher during Kharif season in areas with already high temperatures (Fig 1). Whereas, during Rabi, the more increase in temperatures were projected in areas which are currently cooler. During Kharif season, increase in temperature will be 1ºC higher in A2 scenario than in B2 scenario, across the locations.

India receives bulk of its rainfall during monsoon season Kharif and hence, pattern of rainfall change in Kharif is similar to annual pattern. A significant increase in Rabi rainfall is projected in climate change scenarios (Fig 2). However, the total amount of rainfall received during the Rabi season is very low in most parts of the country. Corroborating with annual trends, number of rainy days are projected to decrease during Kharif and hence leading to an increase in intensity of rainfall (Table 1). In contrary, number of rainy days is projected to increase in Rabi season in some locations. Increase in intensity of rainfall, which followed a normal distribution curve, will be more in areas which have an intensity of about 20 mm rainy day$^{-1}$. Projections of both the scenarios were similar for reduction in number of rainy days and increase in rainfall intensity. Even though, an increase in the mean and inter-annual variability of temperature and monsoon rainfall due to climate change has been reported for Indian region (Turner *et al*., 2007), this paper emphasizes the spatio-temporal and seasonal patterns from an agricultural perspective.

***Extreme patterns of temperature and rainfall:*** Many of the earlier climate change studies have mainly focused on the changes in mean values. However it is now being increasingly recognized that the manifestations of climate change is more through increased frequency of extreme-weather events, particularly on regional and local scales.

Since the impact of these extremes is likely to be much higher, an analysis of projected extremes in temperature and rainfall in Indian region was performed. Analysis indicated that locations in IGP will experience more number of days with temperatures above 45°C (Table 1). Except locations in south India, all other regions were found with many days having maximum temperature 45°C and above annually. In fact, projections indicate that by 2080, substantial number of days will be having maximum temperatures above 50 °C, particularly in north India. Such trends are more in A2 scenario than in B2 scenario. Further, the maximum temperatures are projected to rise in winter season thus reducing the number of days with temperature less than 20°C. Similarly, number of cold days (days with Tmin $< 5$°C) are projected to decrease in IGP. Both of these projected trends have implication on Rabi crop productivity. Since the rainfall is projected to increase in most of the locations with a decline in number of rainy days, analysis on extreme intensity of rainfall indicated increase in number of rainy days with rain fall between 15-49 mm (Table 1). These extreme events are projected in A2 scenario than in B2 scenario.

***Impact of climate change on wheat and rice yields***

Quantification of the impact of projected changes in climatic parameters such as atmospheric $CO_2$, temperatures and rainfall on wheat crop production was assessed using simulation studies (using Info Crop model) for nine locations representing wheat growing regions of IGP. Results indicated that simulated mean current wheat yield varied between 4406 to 4919 kg ha$^{-1}$ across IGP. However, climate change is projected to lead to a decline in wheat yields, with more decrease in A2 scenario than in B2 scenario. The A2 scenario yields are projected to range from 1986 to 4311 kg ha$^{-1}$ while in B2 it may range from 3619 to 4639 kg ha$^{-1}$ in IGP. The cumulative frequency distribution analysis indicated that possibility of obtaining lower yields in future scenarios is high, particularly in middle and lower Indo-Gangetic plains (Fig. 3) . The probability of lower productivity in A2 scenario increased from UIGP to LIGP, with likely yields ranging from 3200 kg ha-$^{1}$ in UIGP to 3000 kg ha-$^{1}$ in MIGP and around 1000 kg ha-$^{1}$ in LIGP. However, in B2 scenario, probability of getting yields in the range of 3000 to 3500 kg ha-$^{1}$ is very high across IGP. Further, inter-annual variation for productivity is projected to increase in future, particularly in A2 scenario, with only a few years with high productivity.

As far as rice is concerned, the analysis was carried-out for a non water-limited crop. Simulated mean rice yield ranged between 5092 to 5756 kg ha$^{-1}$ in current, while in A2 it is projected to range from 2991 to 3999 kg ha$^{-1}$, and from 3668 to 4484 kg ha$^{-1}$ in B2, depending upon locations (Fig 3). As compared to wheat, rice crop exhibited higher inter-annual variability for yield even in current situations. This inter-annual variability is projected to increase in A2 and B2 scenarios. Thus, climate change is projected to increase the years with lower yields.

Wheat grown in middle and lower IGP is projected to be more sensitive to climate change impacts. On the other hand, the rice crop did not show such significant spatial pattern in its sensitiveness to climate change across IGP. Reduction in yields is attributed to the effect of changed climatic parameters on crop growth. In case of wheat, temperature is the major factor which influences the yield. Since wheat is grown as winter-irrigated crop, influence of rainfall is non-significant. Rice, the monsoon crop is simulated with assured irrigation in this study and hence minimizing the impact of rainfall variability, making temperature as the major factor deterring rice yields.

Climate change implication on crop growth are through elevated $CO_2$ concentrations, change in temperature and rainfall. Wheat and rice being C3 crops benefit from elevated $CO_2$ concentrations. However, increase in temperatures likely to offset this benefit due to $CO_2$ or even reduce the yields in future scenarios. Thus, simulation analysis indicated a net effect of increase in $CO_2$, temperature and change in rainfall. The influence of rainfall and its change is offset by growing the crop in water non-limiting conditions. However, increase in temperature affects crops in both vegetative and reproductive phase, and may ultimately cause reduction in yield as projected in this study. Temperature is the prime factor, in the absence of other limiting factor, which drives the plant growth rates. Thus increase in temperature is accompanied by reduction in crop growth duration. It was also observed that climate change is likely to reduce number of grains in both the crops due to increase in minimum and maximum temperature during the grain formation stage. The mean temperatures affects crop duration and the temperature extremes during flowering can reduce the grain or seed number by affecting the pollen viability, fertilization, seed set and grain filling. Temperatures exceeding 31 °C just before anthesis induce pollen sterility in wheat leading to reduced number of grains and thus low yield. Threshold high temperature for post-anthesis period in wheat is reported to be 26°C.

Similarly in rice also, very high temperature during reproductive stage induces spikelet sterility thereby affecting the seed setting and hence reducing yield (Cao Yun-Ying et al., 2009). The main cause of floret sterility induced by high temperatures at flowering is anther indehiscence. For setting high grain number cooler temperature is needed but any increase in minimum temperature causes decrease in fertilized spikelet number in rice (Prasad *et al.,* 2006; Cheng *et al.,* 2009). High temperatures during the grain formation stage affected the grain number and grain weight thus reducing the yield. Threshold high temperature for grain filling period in rice is reported to be 34°C (Morita *et al*., 2005). Hence, grain yield of rice declined by 10% for each 1°C increase in growing season minimum temperature(Peng *et al*., 2004), while the simulated yield potential in the major rice growing regions of Asia decreased by 7% for every 1 °C rise above the current mean temperature.

Therefore, increase in temperature not only may be accompanied with reduction in crop growth duration but also with increased pollen sterility, reduced seed set, and number of grains, and reduced grain weight causing yield reduction in climate change scenarios. Apart from this change in mean temperatures, occurrence of extreme temperature events cause yield reduction particularly if these events coincide with sensitive stages of crop growth. Apart from differential growth and yield responses of crop species to high thermal stress, they also show differential response to high temperature stress during various growth phases (Cheng *et al.,* 2009). Thus, the climate change is projected to reduce wheat and rice yields in Indo-Gangetic plains towards the end of the century. In fact earlier studies on climate change impacts on wheat also projected decrease in wheat yields. The results indicate that increase in temperatures adversely influences the crop performance and these negative impacts of temperature are not compensated enough by elevated $CO_2$ concentrations as evident from reduction in over all projected yields. Results also project occurrence of low yielding years more frequently due to climate change.

## CONCLUSION

Climate change is projected to increase temperature over most parts of India and the increase is projected to be higher in regions which are presently experiencing low temperatures. Extreme temperature and rainfall events are projected to be more frequent particularly with regards to high temperature and rainfall intensity. Climatic variability is also projected to increase in A2 and B2 2080 scenarios. All these projected changes are likely to reduce the wheat and rice yields in Indo-Gangetic plains of India. Yield reduction in rice and wheat crop due to climate change is mediated through reduction in crop duration, grain number and grain filling duration and the loss will be more in A2 scenario compared to B2. The scenarios presented in this study are indicative of the expected range of rainfall and temperature changes in the future and these projections provide a direction of likely crop productivity in climate change scenarios.

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**PAPER 2**