IMPACT OF CLIMATE CHANGE ON YIELDS OF MAJOR FOOD CROPS IN INDIA

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ABSTRACT:

The regional models of yield response to temperature (minimum, maximum and its diurnal range) and precipitation developed for meteorological (met) sub-divisions of India were used to study the impact of future climate change on major food crops viz. wheat, rice, potato and rapeseed-mustard. The area weighted averages of district-wise crop yield data were computed at met sub-division level for 1977–2007 for 9 major wheat (*Triticum aestivum L.*) producing met sub-divisions, 16 major rice (*Oryza sativa L.*) producing met sub-divisions, 6 major potato (*Solanum tuberosum L.*) growing sub-divisions of and 8 major rapeseed-mustard (*Brassica spp.*) growing sub-divisions. Fortnightly correlation weighted weather parameters like minimum and maximum temperature and precipitation for the respective met sub-division and periods of the crop season were used to develop the empirical relationships. A negative response of yields to increased minimum temperatures was observed for all the crops. In general, the reduction in crop yields upto 13.4 % was observed with unit increase in minimum temperature. The crop yield also showed negative response to increased maximum temperature and its unit increase reduced the yields upto 10.3 % and 5.3 % for rice and wheat crop, respectively. The crops like potato and rapeseed-mustard showed positive response to increased maximum temperature, which might be due to their strong positive correlations with diurnal temperature range (DTR). The estimated impacts of diurnal temperature range (DTR) changes on yields were generally less (< 5% change in yields) for wheat and rice crops while more upto 8.6 % for potato and rapeseed-mustard crops. Based on A2 scenario of temperature and precipitation change, as derived from PRECIS (Providing Regional Climates for Impacts Studies) regional climate model, it was found that, during the period 2071-2100, the rice yields in irrigated regions would reduce upto 32 % in Haryaana followed by 18 % in Punjab while it may increase in rainfed regions upto 28 % in Orissa followed by 18 % in Madhya Pradesh. The reduction in wheat yields will be 21 % in East Rajasthan followed by 18 % in West Rajasthan and 14 % in East Madhya Pradesh. The climate change scenario may lead up to 39 % reduction in rapeseed-mustard and 19 % reduction in potato yields. However, the yield change projection uncertainties were large due to the uncertainties associated with the yield model.

1. INTRODUCTION

Climate change is one of the most important global environmental challenges facing humanity with implications for food production, natural ecosystems, freshwater supply, health, etc. (Sathaye et al., 2006). The impacts of climate change on food production have its due focus of research over the past few decades (Adams et al., 1990; Cubasch et al., 2001; Parry et al., 2005; Rosenzweig and Parry, 1994, Lobell et al., 2006, Lobell, 2007, Mall et al, 2006, Kalra et al., 2008). Mostly all of these studies have utilized climate model projections of temperatures and rainfall on a monthly or annual average basis. A smaller number of studies have also considered other aspects of climate change, such as changes in daily and inter-annual variability of climate (Mearns et al., 1997), increased frequency of heat spells or other extreme events (Rosenzweig et al., 2002), and changes in humidity and solar radiation (Brown and Rosenberg, 1997).

Since most of the studies have used crop simulation models calibrated with the inputs from the experiments on existing popular varieties, the outputs of these studies is difficult to extrapolate at regional scale. In contrast, the use of statistical yield models developed at regional scale with regional inputs like historical weather and crop yield have advantage that they intrinsically account for a wide variety of mechanisms that can influence yields

in a changing climate (Lobell, 2007). The goal of this study was to evaluate the impact of climate change using a combination of historical datasets and regional climate model projections under A2 scenario of Intergovernmental Panel on Climate Change (IPCC).

Rice (*Oryza sativa L.*) and wheat (*Triticum aestivum L.*) are two major food crops of India contributing around 42.5 and 34.5 per cent, respectively to the total food grain production of the country (DES, 2007). Rice is mostly grown in *Kharif* (June October) season, while wheat is mostly grown in *Rabi* (December-April) season. The other major crops grown during *Rabi* season are Rapeseed-Mustard (*Brassica spp.*) and Potato (*Solanum tuberosum* L.). These crops are also studied under the FASAL programme of the Department of Space (Parihar & Oza, 2006). Due to importance of these crops in the national agricultural scenario, it is important to study the impact of climate change on these crops.

All the analysis was carried at meteorological (met) sub-division level, because of easy availability of weather data at this scale. For any particular crop, only those met sub-divisions were considered, where it has large distribution. The regional models of yield response to temperature (minimum, maximum and its diurnal range) and precipitations developed for met sub-divisions were used to study the impact of future climate on these food crops. Here, weighted impacts of climate change in different phonological

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phases (considering each phase of fortnightly interval) were studied using the empirical models developed based on correlation weighted climate parameters.

2. MATERIALS AND METHODS

2.1 Study Area

The major crop growing regions of the above four crops are presented in Figure 1. Wheat is mostly grown in 9 met subdivisions covering the states of Haryana, Punjab, Rajasthan, Uttar Pradesh, Bihar and Madhya Pradesh. Rice is more extensively grown in the country, covering 16 met sub-divisions. Potato growing is mostly restricted to 6 met sub-divisions, covering the states of Punjab, Uttar Pardesh, Bihar and West Bengal. 8 met sub-divisions were considered for rapeseed-mustard.
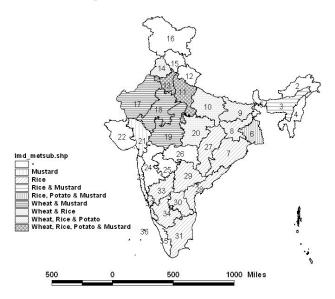

Figure 1. Major Crop-Growing Regions for Wheat, Rice, Potato and Rapeseed-Mustard in India

2.2 Regional Yield Models

The regional models of yield response to temperature (minimum, maximum and its diurnal range) and precipitation developed at meteorological sub-division level were used to study the impact of climate change on major food crops viz. wheat, rice, potato and rapeseed-mustard. First, the growing season months were selected based on state-wise crop calendars available with India Meteorological Department (IMD). Then, the spatial distribution of crops within the country were defined based on census data where the district having crop area more than 5 per cent of its geographical area is considered for the area of a particular crop. District-wise data on crop yields were obtained from the Department of Economics and Statistics (DES), Ministry of Agriculture, India. The area weighted averages of crop yield were computed at met sub-division level for 1977–2007 for the selected met sub-divisions for different crops (Chaudhuri et al., 2001, Chaudhari and Dadhwal, 2002a).

The weekly weather data of minimum and maximum temperature and precipitation for the respective met sub-division were collected from the India Meteorological Department (IMD). The diurnal temperature range (DTR), which is an indirect indicator of solar radiation (Bristow and Campbell, 1984), was computed by subtracting minimum temperature (Tmin) from maximum temperature (Tmax). The fortnightly averages of temperatures and totals of the precipitation were computed for the respective crop seasons and meteorological sub-divisions.

To remove the influence of technology trends on crop yields, a first difference time series was computed for both the yields and climate variables by subtracting the previous year's value from each year (Nicholls, 1997, Lobell, 2007). To evaluate the varying effects of these first differences of weather variables (Δyield, ΔTmax, ΔTmin, ΔDTR, and ΔRF) in each fortnight of the crop season on crop yields, correlation weighted regression based models (Bhagia et al., 2005, Chaudhari and Dadhwal, 2002b, Chaudhari and Patel, 2009) were used. The general form of these correlation weighted models, is like:

$$y = a + \sum_{k=1}^{k} \beta_k Z_k + e \qquad (1)$$

Where,

$$Z_k = \frac{\sum_{n=1}^{n} r_{kn} X_{kn}}{\sum_{n=1}^{n} r_{kn}} \qquad (2)$$

Zk is the sum of correlation coefficient (rkn) weighted kth weather parameter (Xkn) normalized by sum of correlation coefficients of that weather parameter in different fortnights of crop season with crop yield; rkn is the linear correlation coefficient of crop yield with kth (k = 1, 2 ,3 & 4 for ΔTmax, ΔTmin, ΔDTR, and ΔRF, respectively) first order differences of weather parameter in the nth fortnight; Xkn is the value of kth weather parameter (first order differences) in the nth fortnight for a particular year or crop season, a and bk are the regression constants and e is the model error.

The DTR has strong correlations with either Tmax and/or Tmin. It may not be needed to use it as a separate variable. However, in this study it was additionally used as in many cases it had strong relation with the crop yield and its effect was more dominant than either of Tmax or Tmin. Though, precipitation mostly occurs only during south-west monsoon period (June-September) in India and it has key role for the kharif crops like rice, it was also considered for the rabi season crops like potato and rapeseed-mustard because of its indirect influence on occurrences of disease and pest as well as supplement of moisture in rainfed regions such as Madhya Pradesh and Rajasthan.
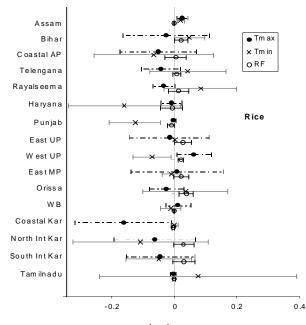
2.3 Estimates of Climate Change Impacts

To evaluate the potential impact of ΔTmax, ΔTmin, ΔDTR, and ΔRF changes in climate change scenario, projections of daily Tmin and Tmax were obtained from the output of HadCM3 GCM, available at IPCC Data Distribution Centre. It has a spatial resolution of 3.75^o Longitude x 2.5^o Latitude (Carter, 2007),. The daily precipitation change values were obtained from the high resolution regional climate change scenarios for India using PRECIS (Providing Regional Climates for Impacts Studies) RCM (Rupa Kumar et al., 2006), available at 0.44^o x 0.44^o grid size. Temperature projections were available for several IPCC SRES scenarios for the period 2071-2100. However, we used results for the A2 scenario, a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other secnarios (Cubasch et al., 2001). Changes in Tmin, Tmax and Precipitation were computed for each fortnight by subtracting the climate model average for 1961–1990 from the corresponding average for 2071-2100 and the grid-wise differences were integrated over the met-sub division level to use in the model for impact studies. The fortnightly DTR values were obtained by subtracting corresponding values of Tmin from Tmax for each respective fortnight and met-sub division.

The correlation weighted weather parameter based multiple linear regression yield models derived above (Section 2.2) were used to estimate the impact of projected climate parameters on crop yield. The crop yield impacts due to each weather parameter were estimated separately using projections of a particular parameter keeping other parameters as no-change. Finally, overall crop yield impacts were also computed using all the weather parameters together.
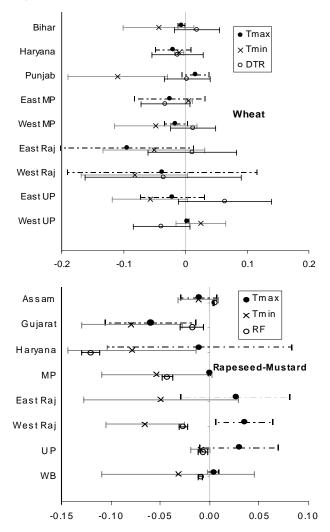
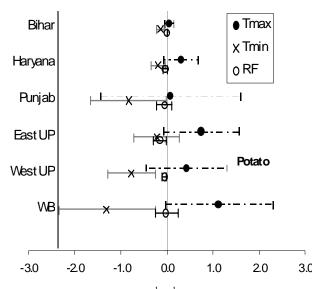### 3. RESULTS AND DISCUSSION

3.1 Regional Yield Models

A negative response of yields to increased minimum temperatures was observed for all three rabi crops: wheat, potato and rapeseed-mustard while mixed response was observed for *kharif* rice (figure 2). In general, the reduction in crop yields upto 13.4 % was observed with unit increase in minimum temperature. The reduction impact was high for rabi crop as compared to *kharif* rice. The yield also showed negative response to increased maximum temperature and its unit increase reduced the yields upto 10.3 % and 5.3 % for rice and wheat crop, respectively. The yield of crops like potato and rapeseed-mustard showed positive response to increased maximum temperature, which might be due to their strong positive correlations with diurnal temperature range (DTR).

Regression Coefficient, β (t ha^{-1} C^{-1})

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Figure 2. Estimated Coefficient for Response of Δyield (in kg/ha) per unit Change in Tmax, Tmin & DTR (°C) and RF (mm) in a Multiple Linear Regression Model. Error Bars Show ± 95 % Confidence Interval

The increased DTR is associated with clear sky condition and increased radiation, which enhance the photosynthesis (Fischer, 1985) and provides unfavorable condition to pest and diseases of these two crops. The mixed impact (increase and decrease both) was observed on rice yield for the increased precipitation. The rainfed rice regions (Orissa, Madhya Pradesh, eastern Uttar Pradesh, Bihar etc.) showed positive impacts on yield while negative or no impact was observed for irrigated regions (Punjab, Haryana, West Bengal etc.). The estimated impacts of diurnal temperature range (DTR) changes on yields were generally less (< 5% change in yields) for wheat and rice crops while more upto 8.6 % for potato and rapeseed-mustard crops with the unit increase in the DTR. There were also strong correlations of DTR with Tmax and in-season rainfall.

3.2 Estimates of Future Impacts

3.2.1 Climate model projections: The seasonal met-sub division level average projections computed from HadCM3 GCM (Tmax and Tmin) and PRECIS RCM (Precipitation) outputs are shown in Figure 3. The projected rise in Tmin is more as compared to Tmax in both the seasons i.e. *kharif* and *rabi* and hence it shows a decrease in DTR. Overall the projected rise was higher (> 5° C) in Tmin while very low (<3° C) in Tmax in Northwest India. The PRECIS precipitation projections also showed increased trend in all the met-sub divisions except Punjab and Western Rajasthan. The parts of eastern and central India, showed increase of 50-300mm in rainfall in *kharif* season, which may benefit the rainfed kharif agricultural production.
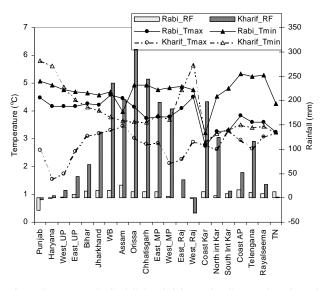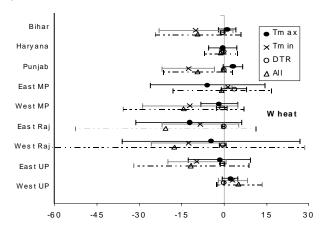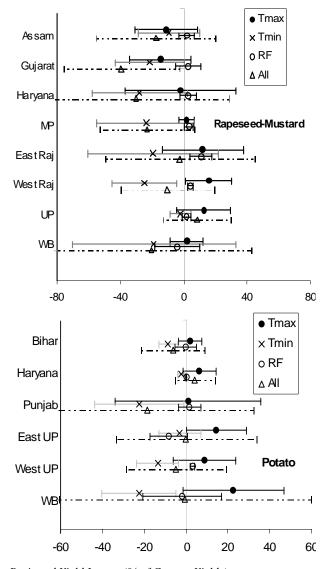

Figure 3. Meteorological Sub-Division-Wise Seasonal Projected Changes (2071-2100 Versus 1961-1990) in Temperatures and Precipitation

3.2.2 Yield responses to future climate: The anticipated responses of crop yield in terms of per cent change was estimated for *rabi* crops (Figure 4) and *kharif* rice (Figure 4), based on the values of regression coefficients (Figure 2) and the projected changes in temperature and precipitation (Figure 3). As expected from the negative values of β (Tmin), the decrease in yields were found for most cases. The decrease was more in *rabi* crops particularly in Northwest region of India as the increase in Tmin was very high in this region. Kalra et al (2008) also observed negative response to temperature for *rabi* crops like wheat, barly, chickpea and rapeseed-mustard in this region. The increase in Tmax has showed positive response to rapeseed-mustard and potato crop in most of the cases. This may be due to strong positive correlation of Tmax with DTR and thereby clear sky condition may have increased the Tmax. Lobell (2007) also observed strong correlations of DTR with Tavg and thereby inverse relations with crop yield.

The projections show very less increase in DTR in *rabi* season (< 1 °C, Fig. 3) and had strong correlations with in-season rainfall and Tmax in both the seasons and its impacts were also less (< 4 %) for all the crops. This is shown only for wheat as an example (Figure 4).
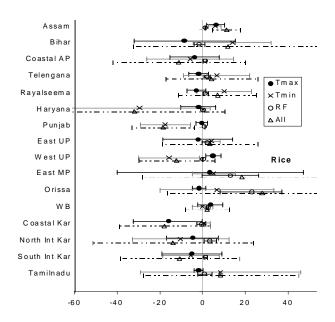
Projected Yield Impact (% of Current Yields)

Figure 4 : Impact of Projected Changes by 2071-2100 in Tmax, Tmin, DTR and Rainfall (Individual and all Together) on Crop Yield (in % change) of rabi Crops. Error Bar Indicate ± 95% Confidence Interval

For *kharif* rice, projected increase of both, Tmax and Tmin, showed reduction in yield. The reduction were more due to Tmin (upto 35% in Haryana) as compared to Tmax (upto 18% in Coastal Karnataka). The RCM projected increased rainfall showed increase in rice yield mostly in all the met-sub divisions except Bihar and Coastal Karnataka, which may be because of both the regions have very low or negative β values in responses to rainfall.

Overall, future projected climate may reduce the rice yields in irrigated regions like upto 32 % in Haryaana followed by 18 % in Punjab while it may increase the rice yields in rainfed regions like upto 28 % in Orissa followed by 18 % in Madhya Pradesh (Figure 5).

Projected Yield Impact (% of Current Yields)

Figure 5. Impact of Projected Changes by 2071-2100 in Tmax, Tmin and Rainfall (Individual and All Together) on Crop Yield (in % Change) of kharif Rice. Error Bar Indicate ± 95% Confidence Interval

4. CONCLUSION AND FUTURE DIRECTION

The study showed that, there was a clear negative response of yields to increased minimum temperatures for all three *rabi* crops: wheat, potato and rapeseed-mustard while mixed response was observed for *kharif* rice. The reduction impact was high for *rabi* crop as compared *kharif* rice. The crop yield also showed negative response to increase in maximum temperature. The crops like potato and rapeseed-mustard showed positive response to increased maximum temperature might be due to its strong positive correlations with diurnal temperature range (DTR). The mixed impact (increase and decrease both) was observed on rice yield for the increased precipitation. The estimated impacts of diurnal temperature range (DTR) changes on yields were generally less for wheat and rice crops while more for potato and rapeseed-mustard crops with the unit increase in DTR.

Since, the crop yield is a complex entity and affected by different biotic and abiotic factors and all the factors were not considered in this study, the impacts shown here may not the ultimate results. The uncertainties in these projections will also   be caused by the uncertainties of yield models. In future, the district level yield impacts may be computed and vulnerable climatic regions may be delineated using high-resolution RCM projections.

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