Agricultural Economics Research Review
Vol. 27 (No.2) July-December 2014 pp 145-155
DOI: 10.5958/0974-0279.2014.00019.6

Impact of Climate Change on Yields of Major Food Crops in India: Implications for Food Security

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Abstract

The study has analysed changes in climate variables, viz. temperature and rainfall during the period 1969-2005 and has assessed their impact on yields of important food crops. A significant rise was observed in mean monthly temperature, but more so during the post-rainy season. The changes in rainfall, however, were not as significant. While an increase in maximum temperature was found to have an adverse effect on the crop yields, a similar increase in minimum temperature had a favourable effect on yields of most crops, but it was not sufficient to fully compensate the damages caused by the rise in maximum temperature. Pigeonpea, rice, chickpea and wheat were more vulnerable to rise in temperature. Rainfall had a positive effect on most crops, but it could not counterbalance the negative effect of temperature. The projections of climate impacts towards 2100 have suggested that with significant changes in temperature and rainfall, the rice yield will be lower by 15 per cent and wheat yield by 22 per cent. Coarse cereals will be affected less, while pulses will be affected more than cereals. If the changes in climate are not significant, damages to crops will be smaller. In the short-run too climate impacts will not be so severe.

Key words: Climate change, crop yield, food security, India

JEL Classification: Q18, Q51, Q54

Introduction

The technological changes in food crops supported by investments in irrigation, infrastructure and institutions during the past four decades have propelled India out of food insecurity syndrome. However, the growing population keeps the challenge of producing more food as significant as in the past. The food production systems are now under the confluence of a number of biotic and abiotic stresses including the climate change. The impacts of climate change are likely to be severe for the countries like India that have limited arable land but heavy dependence on agriculture (Mendelsohn *et al*., 2006; Stern, 2006; Nelson *et al*., 2009) and also have poor technological and financial capabilities for mitigation and adaptation to climate change. In India, the agricultural sector despite a significant decline in its share in national income (<15% in 2010-11 from 37% in 1970-71), remains an important segment of the economy because of its strategic importance to food security, employment generation and poverty alleviation. The sector still engages about 54 per cent of the country's workforce.

In the past four decades (1969-2005), India's surface temperature has increased by 0.3 °C or by 0.08 °C per decade. In recent years, the climate change has been accompanied by increased incidence of natural calamities such as droughts, floods, cyclones and heat waves (Goswami *et al.*, 2006). Such extreme events can cause a drastic decline in the agricultural output, exacerbating the problems of food insecurity and rural poverty. Bhandari *et al.* (2007) in their study in a few eastern states of India have estimated a 24-58 per cent

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decline in household income and 12-33 per cent rise in farm-household poverty in a drought year. Small farmers are likely to be more affected by the climate change because of their poor access to technologies, inputs, information and finances for mitigation and adaptation. Note that, in India landholdings measuring less than or equal to 1.0 hectare comprise close to two-thirds of the total holdings. Given the agrarian structure and potential threats of climate change to sustainable agricultural development and food security in the country, no other topic has attracted the attention of scientists and policymakers as has been done by the climate change.

The literature on climate change impacts has proliferated in the recent past (Sinha and Swaminathan, 1991; Lal *et al.*, 1998; Saseendran *et al.*, 2000; Aggarwal and Mall, 2002; Mall *et al.*, 2006; Kalra *et al.*, 2007; World Bank, 2006; Aggarwal, 2009). However, the climate change impacts reported in these studies are based on controlled experimentation, wherein a crop is exposed to varying degrees of temperature; and crop yields are then compared across temperature levels so as to assess the impact of change in temperature. This approach though is based on the sound understanding of agronomic science, it ignores adaptations that farmers follow to minimize the harmful effects of climate change. Economists have estimated the climate change impacts on agriculture using Ricardian theory of land rent (Mendelsohn *et al*., 1994; Sanghi *et al.*, 1998; Sanghi and Mendelsohn, 2008; Kumar and Parikh, 2001; Mendelsohn and Dinar, 2009) assuming that farmers maximize profits by allocating land to different crops in a declining order of fertility and climate, and everything else remaining constant, the regional differences in land value or productivity are due to differences in the climatic conditions. In most of these studies land value or net revenue per unit of land from a cross-section of heterogeneous units, has been regressed on climate normal. A major criticism of this approach is the assumption of no variation in the crop choices and production technology over time, regardless of the climate change.

With this backdrop, the present paper examines (i) changes in weather variables, viz. temperature and rainfall, (ii) impact of climate change on yields of important food crops; and (iii) implications of climate change for food security.

Data and Methodology

To establish the empirical relationship between crop yields and weather variables, panel data approach, suggested by Deschenes and Greenstone (2007), was followed. This approach captures the effects of time-invariant variables (e.g., soil characteristics, elevation, etc.) and of farmers' autonomous adaptations (changes in planting dates or variety, input use, etc.) in response to year-to-year fluctuations in weather variables. The spatial fixed effects in panel data absorb the location-specific time variant determinants of crop yields that may be correlated with weather variables.

Our panel consisted of district-level data on crop yields, rainfall and temperature from 1969 to 2005 for 200 districts across the country at their 1970 boundaries. The crops subjected to empirical analysis included five cereal crops (rice, wheat, sorghum, maize and barley), two pulse crops (chickpea and pigeonpea) and two oilseed crops (groundnut and rapeseed-mustard). The data on area and production of these crops were taken from the database at website of International Crops Research Institute for the Semi-Arid Tropics (http://vdsa.icrisat.ac.in/vdsa-database.htm).

The data on rainfall and temperature for the districts were extracted from 1×1 degree high resolution daily gridded data obtained from the India Meteorological Department, Government of India. The daily temperature, minimum and maximum, was transformed into the average crop-growing period temperature, and the daily rainfall was summed-up to represent the cumulative rainfall during the crop-growing period. India has two main crop seasons, viz. *kharif* (June to September) and *rabi* (October to March). Rice, sorghum, maize, pigeon pea and groundnut are the *kharif* season crops; and wheat, chickpea, barley and rapeseed-mustard are grown in the *rabi* season. It may be noted that fixed growing period in this paper is an approximation based on the average period of crops grown, and may not correspond exactly to the actual duration of different crops grown in the season in a district.

The fixed effect panel model for climate impacts is specified as:

$$\ln y_{it} = D_i + T_t + \beta X_{it} + \gamma Z_{it} + \varepsilon_{it} \quad \ldots(1)$$

Table 1. Mean and standard deviations of monthly temperature and annual rainfall during crop-growing periods, 1969-2005

Particulars	Maximum temperature (°C)	Minimum temperature (°C)	Mean temperature (°C)	Rainfall (mm)
		Kharif		
Mean	32.71 (2.22)	24.03 (1.57)	28.37 (1.81)	873.72 (605.04)
% Annual change	0.0104***	0.0063***	0.0083***	-0.6190**
Change (°C)	(0.38)	(0.23)	(0.31)	(-22.9)
		Rabi		
Mean	28.63 (2.18)	14.80 (3.36)	21.72 (2.59)	146.36 (170.33)
% Annual change	0.0066***	0.0137***	0.0102***	0.0153
Change (°C)	0.24	0.51	0.38	0.57

Notes: Figures within the parentheses are standard errors.
***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent levels, respectively.

The subscripts i and t in Equation (1) denote district and time, respectively. The dependent variable y is the crop production per hectare or crop yield, and D represents the district fixed effects. It is presumed that district fixed effects absorb all the unobserved district-specific time-invariant factors; for example, soil and water quality that influence crop yields, and also reduce bias due to omitted variables. T represents time fixed effects controlling the difference in crop yields which could be due to the changes in technology, infrastructure, human capital, etc; X is a vector of weather variables and Z is a vector of non-weather variables such as irrigated area, fertilizer use, etc. But, because of their possible endogeneity with yield, we have included only irrigated area in Equation (1). We have assumed irrigation as an exogenous variable that represents farmers' response to climate change. β and γ are parameters on weather and irrigation variables, respectively; and ε is the error-term.

The effect of temperature and rainfall on crop yield is generally non-linear (Schlenker and Roberts, 2006; Guiteras, 2007; Jacoby *et al.*, 2011). To account for the non-linear effects, we have included the average minimum and average maximum temperatures, and the squared-term of rainfall in Equation (1).

Equation (1) was estimated as log-linear to reduce excessive variation in the dependent variable that is crop production per hectare. The coefficients of this functional form are easily interpretable as proportionate changes.

Results and Discussion

Trends in Climate Variables

Table 1 presents the summary statistics of weather variables for *kharif* and *rabi* cropping seasons. The *kharif* is a hot and humid season. During the study period of 1969 to 2005, daily mean temperature was 28.4 °C with a minimum of 24.0 °C and maximum of 32.7 °C. The mean *rabi* temperature was about 6.5 °C lower than the *kharif* mean temperature. However, the difference between minimum and maximum temperatures during *rabi* season was almost twice of the corresponding difference in *kharif* season. On average, the country received 1020 mm annual rainfall during 1969-2005, but mostly during the *kharif* season.

To understand the behaviour of climate variables, mean growing-period temperature and cumulative rainfall were plotted for the period 1969-2005 in Figures 1 and 2, respectively. A look at Figure 1 reveals a clear rise in temperature in both *kharif* and *rabi* seasons; the trend being somewhat stronger in the *rabi* season. This was confirmed by the estimated trend coefficients also[1]; during 1969-2005, the *rabi*

[1] To estimate trends in temperature and rainfall, we regressed these (natural logarithm) on time with district fixed effects as controls for time invariant factors.

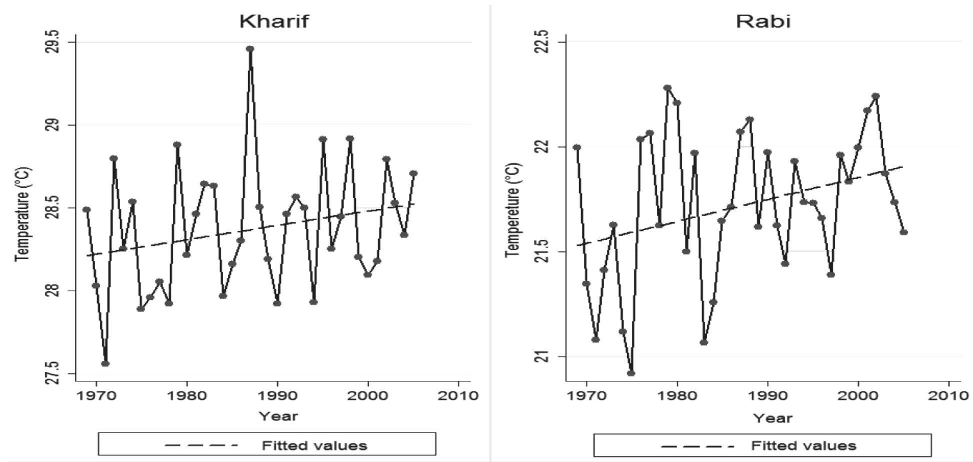

Figure 1. Trend in mean temperature during *rabi* and *kharif* seasons in India, 1969-2005

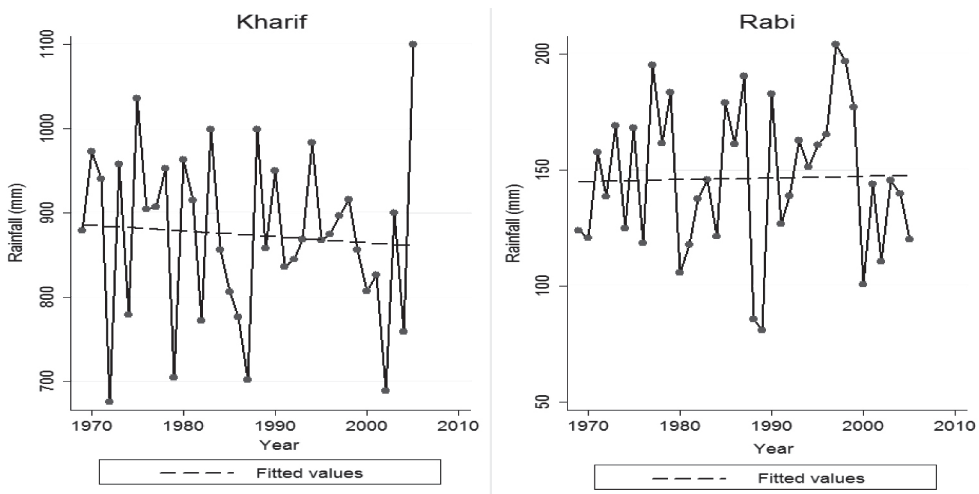

Figure 2. Trend in rainfall during *rabi* and *kharif* seasons in India, 1969-2005

temperature increased by 0.38 °C, which is about 0.07 °C more than the *kharif*-temperature rise. In both the seasons, minimum as well as maximum temperatures have shown a rising trend. However, it is the minimum temperature in *rabi* season and the maximum temperature in *kharif* season that have driven the change in mean temperature.

A perusal of Figure 2 and Table 1 does not reveal any significant trend in rainfall during the *rabi* season. On the other hand, there is a negative trend in the *kharif* rainfall; it declined by 22 mm during the period 1969-2005. Further, *rabi* rainfall has been more erratic (CV= 116%) than *kharif* rainfall. These long-term changes in weather variables suggest that the climate change impacts in India are largely driven by the rise in temperature, and not much by the change in rainfall.

Impacts of Climate Change on Crop Yields

Regression Results

Table 2 presents the estimated equations for *kharif* and *rabi* crops. The geographical or district fixed effects have been found significant in all the crops, indicating that inclusion of spatial fixed effects in climate model is important for controlling time-invariant location-specific characteristics, which might be correlated with the climate variables. The time fixed effects are also significant, suggesting the importance of farm-level adjustments in agronomic and cropping practices consequent to the climate change.

The irrigation coefficient has been found significant and had the expected signs in the case of rice, groundnut, wheat and rapeseed-mustard, implying

Table 2. Regression results corresponding to Equation (1) for *kharif* and *rabi* crops

Variable	*Kharif* crops				
	Rice	Maize	Sorghum	Pigeon pea	Groundnut
Minimum temperature	0.0556***	0.0873***	0.0908***	0.0269	0.0363
	(0.0166)	(0.0188)	(0.0231)	(0.0195)	(0.0224)
Maximum temperature	-0.1169***	-0.0887***	-0.1232***	-0.1168***	-0.0923***
	(0.0135)	(0.0179)	(0.0229)	(0.0187)	(0.0186)
Rainfall	0.0004***	-0.0001	0.0002*	0.0003***	0.0003***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Rainfall (Square)	-7.60e-08***	-3.53e-08	-1.11e-07**	-8.85e-08***	-8.05e-08***
	(1.38e-08)	(2.91e-08)	(4.89e-08)	(2.60e-08)	(2.45e-08)
Irrigation	0.0055***	0.0017	-0.0010	-0.0008	0.0035*
	(0.0014)	(0.0019)	(0.0021)	(0.0021)	(0.0020)
Constant	8.5900***	7.4042***	8.1448***	9.5019***	8.6906***
	(0.4754)	(0.5530)	(0.8663)	(0.6675)	(0.5928)
District	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes
No. of observations	6260	5886	5821	5808	5753

	Rabi crops			
	Wheat	Barley	Chickpea	Rapeseed-mustard
Minimum temperature	0.0389***	0.0881***	-0.0370**	0.0741***
	(0.0129)	(0.0179)	(0.0166)	(0.0175)
Maximum temperature	-0.0976***	-0.1161***	-0.0285*	-0.0700***
	(0.0144)	(0.0177)	(0.0154)	(0.0158)
Rainfall	0.00001	-0.0001	0.0002	-0.0003***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Rainfall (Square)	-2.47e-07	2.32e-07	-2.39e-07	1.09e-07
	(2.11e-07)	(2.37e-07)	(1.66e-07)	(2.16e-07)
Irrigation	0.0085***	-0.0022	0.0024	0.0068***
	(0.0016)	(0.0016)	(0.002)	(0.0018)
Constant	8.0919***	8.6346***	7.3523***	6.7163***
	(0.4043)	(0.4448)	(0.4748)	(0.4268)
District	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes
No. of observations	5639	3155	5981	4541

Notes: District and time dummies included but not shown, whereas dependent variable is log-yield of each respective crop.
***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent levels, respectively.
Figures within the parentheses are standard errors.

that irrigation is important to counterbalance the harmful effects of climate change on these crops. For other crops, the coefficients were not statistically significant.

Returning to the effect of weather variables, we find that a rise in maximum temperature has a negative and significant effect on yields of *kharif* as well as *rabi* crops. On the other hand, a rise in minimum temperature has a significantly positive impact on yields of most crops. The opposing effects of rise in minimum and maximum temperatures suggest that temperature has a non-linear effect on the crop yields. In the case of chickpea, the rise in minimum as well as maximum temperatures causes a significant reduction in yield. The experimental evidence suggests that a rise in day or night temperature beyond its optimum level has a harmful effect on production of cool season legume crops such as chickpea (Ahmed *et al.*, 1992; Devasirvatham, 2012). Further, for most crops, the negative effect of maximum temperature is larger than the positive effect of minimum temperature, indicating that the positive effect of minimum temperature may not fully compensate the damages due to rise in maximum temperature.

The effect of rainfall has been found positive and significant on most *kharif* crops. The quadratic term of rainfall is negative and significant meaning thereby that its effect is non-linear with excess rainfall having a damaging effect on the crop yields. The *rabi* crops, except rapeseed-mustard, however, are not significantly influenced by the rainfall as most crops during this season are grown with irrigation.

Marginal Effect

In the presence of non-linear and interaction effects, the interpretation of regression coefficients is not straightforward. Therefore, to quantify the true effect of changes in temperature and rainfall, their marginal effects were calculated at their mean values, that are changes in crop yield due to rise of 1 °C in mean temperature or 1 mm in rainfall using Equation (2). The expected marginal impact of a single climate variable, X_i on yield evaluated at the mean is:

$$E\,[\partial\prod/\partial X_i] = \alpha_{1,i} + 2\alpha_{2,i} * E[X_i] \qquad \ldots(2)$$

Table 3 presents the marginal effect of climate change in terms of temperature and rainfall. A 1 °C rise in the maximum temperature in *kharif* season reduces the yield of rice, sorghum and pigeonpea by 11-12 per cent and of maize and groundnut by around 9 per cent. However, the effect of a similar increase in the minimum temperature is opposite but is not sufficient enough to fully compensate the loss due to rise in maximum temperature. The sorghum and maize crops benefit more from the rise in minimum temperature. The net effect of change in temperature is observed negligible in the case of maize. In the *rabi* season, barley is most affected by the rise in maximum temperature, but is benefited from the rise in minimum

Table 3. Marginal effect of climate change on *kharif* and *rabi* crops, 1969-2005

Variable	*Kharif* crops				
	Rice	Maize	Sorghum	Peagon pea	Groundnut
Minimum temperature	0.0526***	0.0864***	0.0820***	0.0309	0.0385*
	(0.0164)	(0.0183)	(0.0220)	(0.0195)	(0.0213)
Maximum temperature	-0.1189***	-0.0894***	-0.1133***	-0.121***	-0.0938***
	(0.0130)	(0.0166)	(0.0208)	(0.0183)	(0.0176)
Rainfall	0.0002***	-0.0001***	0.0001	0.0002***	0.0002***
	(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0000)
Irrigation	0.0053***	0.0017	-0.0008	-0.0010	0.0035*
	(0.0014)	(0.0019)	(0.0020)	(0.0021)	(0.0020)

Variable	*Rabi* crops			
	Wheat	Barley	Chickpea	Rapeseed-mustard
Minimum temperature	0.0337***	0.0873***	-0.0329*	0.0725***
	(0.0130)	(0.0179)	(0.0170)	(0.0175)
Maximum temperature	-0.0927***	-0.1050***	-0.0392**	-0.0675***
	(0.0155)	(0.0166)	(0.0175)	(0.0161)
Rainfall	-0.00003	-0.00005	0.00012	-0.0003***
	(0.00008)	(0.0001)	(0.0001)	(0.00009)
Irrigation	0.0084***	-0.0019	0.0023	0.0067***
	(0.0015)	(0.0015)	(0.0020)	(0.0017)

Notes: ***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent levels, respectively
Figures within the parentheses are standard errors.

temperature. The yield loss due to maximum temperature has been found considerable in the case of wheat, but the net effect after accounting for the positive effect of rise in minimum temperature remains significant (5.9%). The marginal effect of 1 °C rise in minimum temperature on yield of rapeseed-mustard is positive and almost equivalent to the negative effect of a similar increase in the maximum temperature. For chickpea, the marginal effect of 1 °C rise in minimum and maximum temperatures is negative but almost equal in magnitude.

The marginal effect of rainfall on *kharif* crops, except maize, has been found positive and significant. However, in the *rabi* season, its effect was not significant, except on rapeseed-mustard where it was negative and significant. The non-significant effect of rainfall in the *rabi* season is expected as the quantum of *rabi* rainfall is not only less but more variable also. In general, the marginal effect of rainfall is much smaller than of temperature. These results suggest that the climate change impact on Indian agriculture will be largely driven by temperature change.

Let us now see how these results compare with those compare with those from other studies? Mall *et al.* (2006) have assessed the sensitivity of wheat, rice sorghum, maize and groundnut and found that a rise of 1 °C in temperature reduces the yield of wheat by 8.1 per cent; of rice by 5.4 per cent, of maize by 10.4 per cent, of sorghum by 18 per cent and of groundnut by 8.7 per cent. Kalra *et al.* (2007) have reported that a 1 °C increase in temperature reduces the yield of rice by 5-8 per cent, of maize by 10.0 per cent and of sorghum by 7 per cent. For some crops, such as wheat and rice, the net marginal effect of temperature is closer to those reported by Mall *et al.* (2006) and Kalra *et al.* (2007). It may be noted that evidence in these studies are based on the production function approach or controlled experimentation, which usually overestimates the negative impacts and underestimates the positive impacts. In a recent study Pattanayak and Kumar (2013) have estimated that in the absence of climate change the rice production in India during 1969-2007 would have been 8 per cent higher.

Projected Impacts of Climate Change

The effects of climate change on crop yields have been projected for three time-slices viz. 2035, 2065 and 2100 at minimum and maximum changes in temperature and rainfall (IPCC, 2013). The IPCC has predicted the changes in temperature and rainfall for the quarters June-August, and December-February (Appendix Table I). There is a lack of concordance between IPCC defined quarters and the growing periods used in this paper. For projecting crop yields, we have considered the change in climate during June-August to represent the change in climate during *kharif* season, and the change in climate during December-February as representative of the change in *rabi* season. Accordingly, by 2100 the *kharif* season temperature is expected to rise by a minimum of 0.7 °C and a maximum of 3.3 °C. The changes in rainfall during this period are projected to be in the range of -7 per cent to 37 per cent. The *rabi* temperature is expected to increase in the range of 1.4-3.7 °C and *rabi* rainfall in the range to -14 per cent to 28 per cent. The changes in temperature and rainfall towards 2035 are not so glaring. The crop yields at the minimum and maximum changes in temperature have been projected using Equation (3).

$$\Delta Y = [(\partial Y/\partial R) * \Delta R + (\partial Y/\partial T) * \Delta T] * 100 \quad \ldots(3)$$

where, Y is the yield, *R* is the rainfall, T is the temperature, and $(\partial Y/\partial R)$ and $(\partial Y/\partial T)$ were determined by the model equations. The projected climate change impacts on crop yields are given in Table 4. The production of pulses will be affected more by the climate change than of any other crop. By the year 2100, with a significant change in climate, the yield of chickpea and pigeonpea will be lower by around 25 per cent vis-a-vis without climate change. The climate impacts on cereals will vary widely in *kharif* as well as *rabi* seasons. In the *rabi* season, wheat yield will be less by about 22 per cent, almost three-times that of barley. Likewise, among *kharif* cereals, rice will be affected more than maize and sorghum by the climate change. The rice yield will decline by over 15 per cent with significant changes in climate as compared to loss of 7 per cent in sorghum and of 4 per cent in maize. Groundnut also stands to lose, but rapeseed-mustard is likely to gain at the margin. If the climate does not change significantly, yield losses will be much smaller. The climate impacts will not be so severe in the short-run that is, towards 2035. It is also possible that in the long-run too, the climate impacts may not be so severe because of continuous adaptation.

Table 4. Projected change in crop yields by 2035, 2065 and 2100

(in per cent)

Crop	2035		2065		2100	
	Minimum ΔT and ΔR	Maximum ΔT and ΔR	Minimum ΔT and ΔR	Maximum ΔT and ΔR	Minimum ΔT and ΔR	Maximum ΔT and ΔR
***Kharif* crops**						
Rice	-2.5	-7.1	-6.5	-11.5	-5.9	-15.4
Maize	0.2	-1.2	0.0	-3.7	0.4	-4.2
Sorghum	-1.2	-3.3	-3.1	-5.3	-2.8	-7.1
Pigeonpea	-3.2	-10.1	-8.6	-17.7	-7.5	-23.3
Groundnut	-2.2	-5.6	-5.5	-8.6	-5.1	-11.8
***Rabi* crops**						
Wheat	-0.5	-8.3	-3.5	-15.4	-8.2	-22.0
Barley	0.0	-2.5	-0.9	-4.7	-2.4	-6.8
Chickpea	-1.1	-10.0	-4.6	-18.6	-10.4	-26.2
Rapeseed-mustard	0.9	0.3	1.1	0.7	1.4	0.5

Implications for Food Security

Food security is an outcome of the food production process. The climate change will affect food security by influencing the availability of food, access to food, stability of food supplies and volatility in food prices. Rice and wheat are the main staple foods for a majority of Indian population, and our findings suggest a considerable decline in their yields with significant changes in climate. Likewise, the effects of climate change on pulses production appear to be quite large.

India faces significant land constraint in raising food supplies. During the past four decades, its net sown area has almost stabilized at 140 million hectares, indicating extremely limited scope for area expansion. Moreover, agricultural lands suffer from various types of degradations. According to an estimate, about 120 million hectares of land in the country suffers from one or the other form of degradation (NAAS, 2010 cited in Singh, 2011). Like land, water resources will also be under great stress. Groundwater in the intensively-cultivated north-western region of the country has already reached its limits of exploitation (GoI, 2011). Intensification of agriculture will further strain these resources. Increasing competition for land and water will intensify due to their pressing demands for housing and industrialization; and thus there is a high probability of their diversion away from agriculture.

The effects of climate change on food production are not limited to crops. It will affect food production and food security via its direct or indirect impact on other components of the agricultural production systems, especially livestock production which is closely linked with crop production. Livestock in India are raised under mixed crop-livestock systems deriving a substantial share of their energy requirements from crop by-products and residues. Any decline in crop area or production will reduce fodder supplies. Heat stress on animals will reduce rate of feed intake. The higher temperatures and changing rainfall patterns may cause increased spread of the existing vector-borne diseases and macro-parasites, alter disease pattern, give rise to new diseases and affect reproduction behaviour. All these factors will affect performance of the livestock.

By 2065 India' population is likely to cross 1.7 billion mark demanding more and diversified foods. Our findings indicate with climate change producing more food with limited resources will be a big challenge in the absence of adaptation and mitigation strategies. It is therefore imperative to promote uptake of sustainable agricultural practices to overcome the potential threats to food security. The literature provides a wide range of adaptation measures — autonomous and planned, and short-term and long-term. Some important measures that hold promises of reducing harmful effect of climate change include mixed/ intercropping; afforestation, growing drought-tolerant crops, changes in planting dates and crop varieties. Aggarwal (2009) has reported that if farmers plant earlier than usual then climate-induced damages to wheat can be reduced by 60-75 per cent. Other important adaptations include water harvesting, its conservation and efficient use through micro-irrigation techniques such as sprinkler and drip irrigation. According to an estimate, micro-irrigation, watershed management and insurance cover can avert 70 per cent of the avoidable loss due to drought (ECA, 2009). Laser land levelling and zero tillage too have proven effective in conserving land and water resources.

Breeding for stress-tolerance has been an important thrust area of agricultural research, and the returns to investment on drought-tolerant breeding have been estimated to be quite attractive, ranging from 29 to 167 per cent (Pray *et al.*, 2011; Gautam, 2009; Mottaleb *et al.*, 2012). An *ex-ante* assessment of the benefits of drought-tolerant wheat and maize (Kostandini, 2008) and groundnut (Birthal *et al.,* 2012) has shown that adoption of drought-tolerant varieties can reduce production risks by 30-50 per cent. Besides these, it is equally important to improve delivery of credit and crop insurance products to farmers to strengthen their capacity to adopt adaptation and mitigation measures.

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Received: March, 2014; Accepted June, 2014

Appendix Table 1

Predicted changes in climate by 2035, 2065 and 2100

Period	Temperature		Rainfall	
	Minimum Δ	Maximum Δ	Minimum Δ	Maximum Δ
		2035		
Dec-Jan-Feb	0.1	1.4	-18	8
Jun-July-Aug	0.3	1.3	-3	9
Annual	0.2	1.3	-2	7
		2065		
Dec-Jan-Feb	0.6	2.6	-17	13
Jun-July-Aug	0.9	2.6	-3	33
Annual	0.8	2.5	-2	26
		2100		
Dec-Jan-Feb	1.4	3.7	-14	28
Jun-July-Aug	0.7	3.3	-7	37
Annual	1.3	3.5	-3	27