Impact of Climate Change on the Production of Major Food and Commercial Crops in India: A Five Decadal Study

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Original Research Article

ABSTRACT

Climate change is posing a great threat to agriculture and food security, especially in the agriculture oriented and developing countries like India. The present study was carried out to critically study the impact of climate change on productivity of major cereal and commercial crops by statistically analyzing the time series data. The analysis inferred that crop production of both food and commercial crops in India has increased since 1960-61. It was observed that major food crops (rice & wheat) were adversely affected by increase in maximum temperature and decrease in rainfall. The alternative measures such as area under cultivation, irrigation, fertilizer and pesticide consumption were observed to be nullifying that negative impact of climate change by enhancing the overall production. However, the commercial crops were observed to be positively affected by the increasing temperature. The study suggested that although the agriculture sector is able to withstand the adverse impact of climate change till now, but in near future this situation can become reversed. This necessitates the implementation of appropriate adaptation and mitigation

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measures to deal with the problems of climate change and to ensure the food security and food safety along in long run.

Keywords: Agriculture; crop production; climate change; adaptation; mitigation; India.

1. INTRODUCTION

Agricultural production of any country is directly dependent on its climate and weather conditions since minor changes in temperature, precipitation and CO_2 concentration can drastically impact its crop growth. Higher levels of CO_2 generally increase productivity of plants through enhancement in plant photosynthesis due to CO_2 fertilization effect but the long-term effects are uncertain and might involve negative effects on plant food web, decreased plant nutritional values, reduced N content of plant etc (Nogia et al., 2016). Hence, to achieve the optimum plant productivity, a balance in atmospheric carbon level is primarily needed.

Since agriculture relies greatly on adequate water supply, temperature, and a balance of gases in the atmosphere, farming is most vulnerable to the effects of climate change. Also 80% of the world's arable land is progressively being planted with a handful of crop commodities (corn, soybean, wheat, rice, and others) and that too are grown under "modern monoculture systems", which due to their ecological homogeneity are particularly vulnerable to climate change as well as biotic stresses (Heinemann et al. 2013).

Climate change will have variable impacts across regions and cropping systems. There are concerns that climate change will hamper the world's ability to provide sufficient food for the global population (Hatfield et al., 2011). The impacts on agriculture and food security are more prominent especially in the agriculture oriented and developing countries like India. These countries 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. Banday and Aneja (2014) estimated that by 2080, agriculture output in developing countries may decline by 20% due to climate change, while output in industrial countries is expected to decrease 6% and yields in developing countries is expected to decrease by 15% on an average.

India is facing major challenges to increase its food production to the tune of 300 mt by 2020 to feed its ever growing population by producing 50% more grain by 2020 (Kumar and Gautam, 2014). Climate change also affects other factors of production agriculture, such as water availability, soil fertility, and pests (Porter, 2014). It will aggravate problems with soil loss through wind and water erosion in addition to environmental externalities, which are associated with current land use practices. The population of India as on March 1st, 2011 stood at 1,210.7 million (623.2 million males and 587.5 million females) with a population density of 382 per sq.km (GoI, 2015). Cropland is the main occupation of the major population. The economy of the region is predominantly agrarian as it constitutes a measure of livelihood of a large portion of population.

The present study was carried out to investigate the impacts of climate change on productivity of major cereal and commercial crops by statistically analyzing the time series data. This research has been conducted taking India as a case study.

2. MATERIALS AND METHODS

India is the seventh largest country with 2.4% of total area of the world with great physical diversity. The major land use/land cover of the country can be categorized as cropland, built-up, forest, open forest, pine forest, scrub land, barren land and water (Fig 1, National Institute of Hydrology). Mainly *rabi* and *kharif* crops are grown with paddy (rice) as kharif crop and Wheat as *rabi crop*.

The present study is based on the secondary data about crop production of major food crops (rice, wheat, coarse cereals, pulses), major commercial crops (ground nut, rapeseed & mustard, sugarcane, cotton (lint), raw jute & mesta), cultivation area and inputs used (Fertilizer, Pesticides & irrigation inputs) since 1960-61 to 2015-16.The data has been collected from the Handbook of Statistics on the Indian Economy (2015-16, 2016-17 and 2017-18) being published by Reserve Bank of India, and records of Ministry of Agriculture & Farmers Welfare, Government of India (2016-17). The temperature and rainfall data of the country was retrieved from web portal of Indian Meteorological Department, Ministry of Earth Sciences for the selected study period. The analysis of data was made through descriptive statistics for better interpretation and description of various conditions or scenarios.

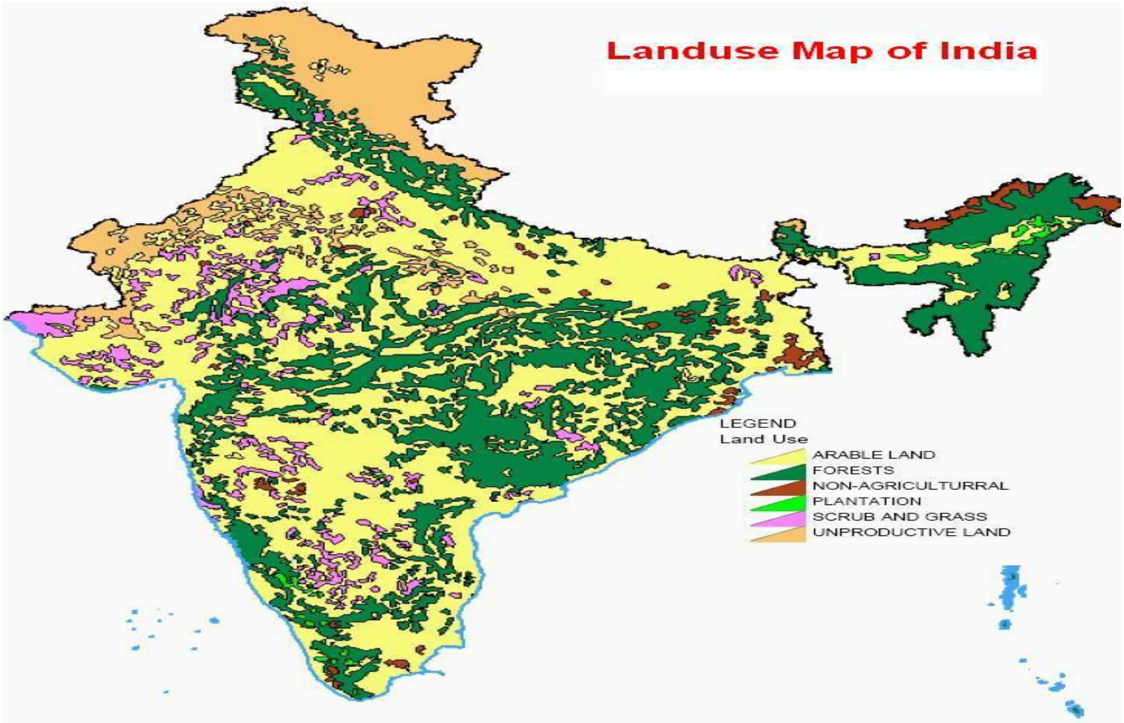


Fig. 1. Landuse Map of India (Source: National Institute of Hydrology)

Multivariate regression analysis (Banday and Aneja, 2014) was performed to confirm the percentage of the response variable variation from the predictor variable that is explained by a linear model in Equation:

$$Y = \alpha_o + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \mu$$

Where,
Y= Crop Production
α_o= Constant
X_1= Temperature variations
X_2= Rainfall variations
X_3= variations in Cropping Area
Y is the observed Production due to temperature, precipitation and cropping area and β_1, β_2, and β_3 are coefficients of the temperature, precipitation and cropping area, respectively. Similarly, X_1, X_2 and X_3 are the observed changes in the temperature, precipitation (rainfall) and cropping area respectively, during the study period.

3. RESULTS AND DISCUSSION

The analysis of meteorological data revealed an average increment of 0.3°C in annual maximum temperature and an average increment of 35.17 mm in annual rainfall of the country since 1960. Rainfall expressed more fluctuations than temperature during the selected study period. These fluctuations in main climatic variables in countries like India can be an alarming sign for agricultural activities (Fig. 2).

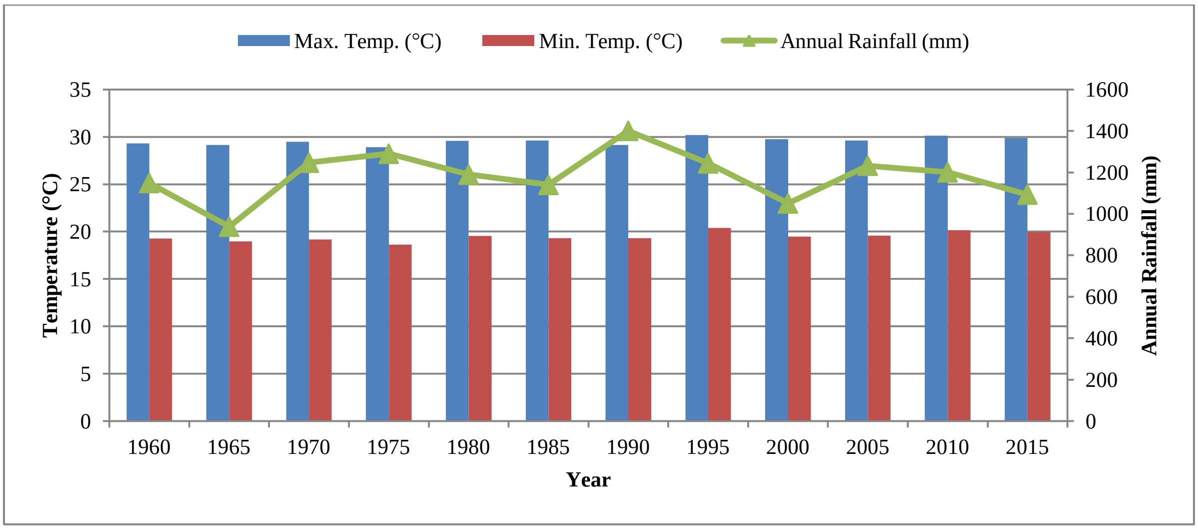


Fig. 2. Climatograph for India since 1960 to 2015 (www.imd.gov.in)

The overall crop production of both food and commercial crops in India has increased since 1960-61 with some fluctuations in between (Fig. 3). Similar observations were inferred from the data on area under cultivation of different crops (Fig. 4). Also, it was found that use of irrigation; consumption of fertilizers (N+P+K) and pesticides depicted an increasing trend towards 2015-16 (Fig. 5).

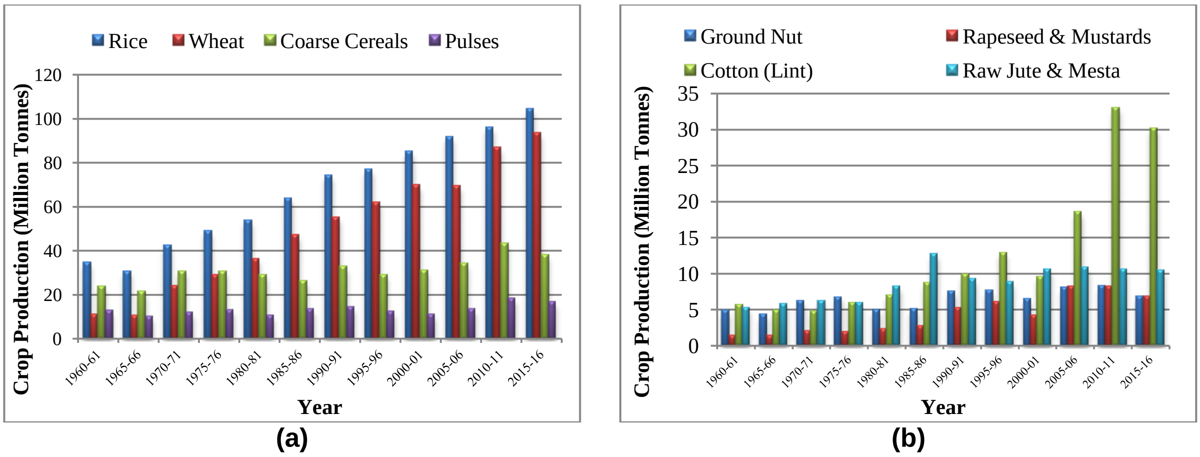
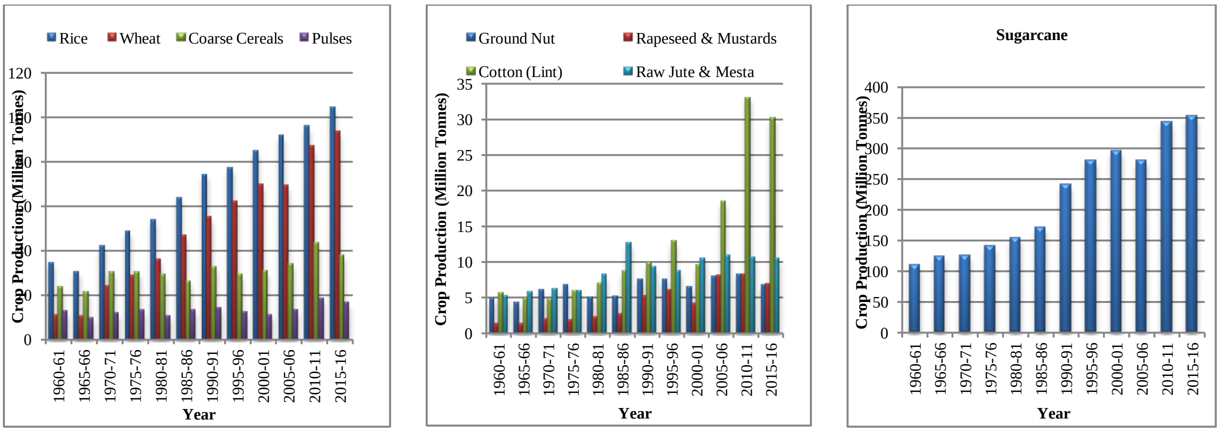


Fig. 3. Crop production (million tonnes) of (a) major food crops and (b) major commercial crops over 55 years (RBI, 2017)

3.1 Regression Analysis for Major Food Crops

Multivariate regression analysis method was applied to identify the impact of various factors on Crop production of different crops in India over the past 55 years. The findings revealed that different variables affected the production of different crops differently (Table 1).

The effects of the climatic parameters, i.e. of temperature & rainfall were observed to be detrimental for rice production as the increase in temperature & decrease in rainfall negatively affected Rice crop production. But the increase in cropping area was observed to be combating this negative effect since it contributed positively with a significant increase in Rice crop production. The adjusted R^2 value expressed that 88% variability in Rice production is explained by these variables.



(a) (b) (c)

Fig. 4. Area under cultivation (million hectares) of (a) major food crops and (b & c) major commercial crops over 55 years (RBI, 2017)

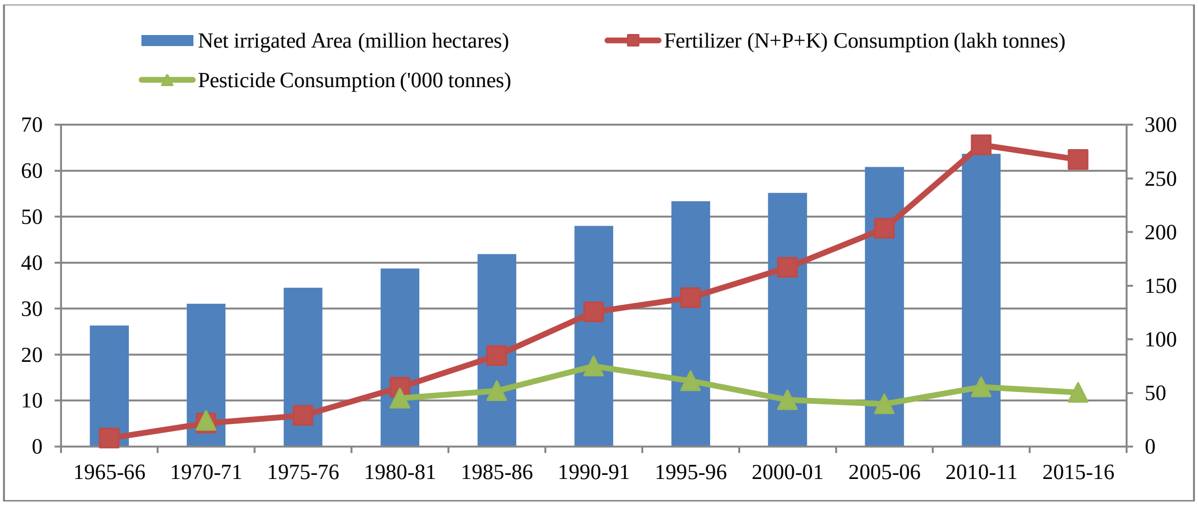


Fig. 5. Net irrigated area (million hectares), Fertilizer consumption (lakh tonnes) and pesticide consumption (‘000 tonnes) over 55 years (RBI, 2017)

The regression analysis for wheat indicated that increase in maximum temperature and decrease in rainfall affected negatively the production up to some extent while increase in cropping area had positive impact on the Wheat production. The adjusted R^2 value expressed that all these three variables, i.e. temperature, rainfall and cropping area were contributing to 94% variability in Wheat crop production. The increase in minimum temperature, however, was found to be positively affecting the production of both cereal crops.

The increase in maximum temperature as well as decrease in rainfall did not have significant effect on the production of coarse cereals and pulses. These crops are not much dependent on rainfall pattern for their growth. The area under coarse cereals crops was observed to be decreasing and thereby negatively affecting the production of cereals. Adjusted R^2 value expressed that the studied variables were explaining only 57% of the variability of the cereal crop production and 52% in case of production of pulses.

Table 1. Regression results for major food crops

Variables	Rice			Wheat			Coarse Cereals			Pulses		
	Coeff.	Std. error	t-stat	Coeff.	Std. error	t-stat	Coeff.	Std. error	t-stat	Coeff.	Std. error	t-stat
Intercept	-408.68			-243.51			13.03			-118.385		
Max. Temp.	-3.045	7.316	-0.416	-0.695	5.721	-0.121	2.713	3.112	0.871	3.632	1.367	2.656
Min. Temp.	16.905	6.374	2.651	11.691	5.016	2.330	-2.942	3.043	-0.966	-0.184	1.327	-0.138
Rainfall	-0.015	0.013	-1.18	-0.011	0.010	-1.071	0.014	0.005	2.576	0.002	0.002	0.878
Cropping Area	6.278	0.479	13.09	4.359	0.232	18.768	-0.607	0.105	-5.765	1.087	0.224	4.843
R^2	0.89			0.94			0.60			0.55		
Adjusted R^2	0.88			0.94			0.57			0.52		
Observations	56			56			56			56		

Table 2. Regression Results for major commercial crops

Variables	Groundnut			Rapeseed & Mustard			Sugarcane			Cotton (Lint)			Raw Jute & Mesta		
	Coeff.	Std. Error	t-stat	Coeff.	Std. Error	t-stat	Coeff.	Std. Error	t-stat	Coeff.	Std. Error	t-stat	Coeff.	Std. Error	t-stat
Intercept	-60.36			-40.85			-300.41			-209.17			-103.29		
Max. Temp.	1.435	0.985	1.457	1.332	0.541	2.457	7.240	2.766	2.729	7.549	1.263	1.657	2.094	11.052	0.655
Min. Temp.	0.717	0.973	0.730	-0.053	0.533	-0.100	-2.417	2.879	-1.043	-3.004	1.166	2.072	2.417	10.342	-0.233
Rainfall	0.006	0.001	3.435	9.52E-05	0.001	0.092	0.023	0.005	1.931	0.010	0.002	0.535	0.001	0.019	1.182
Cropping Area	0.415	0.223	1.864	1.360	0.082	16.409	91.827	0.405	13.180	5.345	1.497	1.304	1.954	2.927	31.371
R^2	0.38			0.93			0.98			0.87			0.51		
Adjusted R^2	0.33			0.92			0.98			0.86			0.47		
Observations	56			56			56			56			56		

3.2 Regression Analysis for Major Commercial Crops

Changes in studied variables did not have significant effect on Groundnut production as they only determined 33% (adjusted R^2) of the variability in crop production. Temperature, rainfall variability and increase in cropping area were observed to have some positive impact on the production of mustard according to the regression results with high adjusted R^2 value (91%). Similar results were obtained in case of Sugarcane and Cotton crop production with high R^2 values of 98% and 86% , respectively. Although, temperature, rainfall and cropping area seemed to have been positively affecting the production of Raw Jute & Mesta production, their determination potential towards production was only 47%. Here, the increase in minimum temperature was observed to be negatively affecting the production of rapeseed and mustard, sugarcane and cotton (Table 2).

The results of the study indicate that impact of the climatic factors is different in context of different crops in the last 55 years. In case of Rice, variation in climatic factors affected negatively the crop production as indicated by the regression model result. It was observed 1°C unit rise in temperature can affect Rice production by 3% decrease and one-unit decrease in rainfall will affect it with slight decrease in production by 0.01%. The reason behind it is the availability of other sources of irrigation to the cultivators as indicated by the Irrigation pattern results (Fig. 5). And as such, there is not much dependence on rainfall directly for Rice production. For Wheat, temperature has negative significance as 1°C increase in temperature will lead to around 0.64% decrease in production as Wheat is a winter season (when temperature remains around 10ºC) crop. Through the analysis of the impact of climatic factors on commercial crops it was observed that, changes in climatic factor do not have significant impact in case of groundnut, while increase of 1°C in temperature may lead to 7.24% and 7.54% increase in sugarcane and cotton production, respectively.

But here, the important thing to note is that some other factors also affect the overall production of crops. In case of India, by the analysis of crop production of various crops over the past 55 years has considered all the possible factors. It was estimated that overall production of many crops has increased despite of negative impacts of climatic factors on certain crops as these are combated by other adaptation measures such as increase of irrigation, fertilizer, pesticides inputs and increase in the area under the cultivation of crops (Figs. 5 and 3). The various other studies (Kalra *et al.* 2007, Birthal et al., 2014) also supported the findings of this study.

4. CONCLUSION AND RECOMMENDATIONS

The technological advances along with investments in irrigation, infrastructure and institutions in last five decades have supported India to come out of the food security syndrome and promoted its level in the International agricultural market. However, curbing the problem of feeding ever increasing growing population still remains a challenge in terms of producing more and more food. Moreover, the projections of climate change impacts towards 2100 have suggested significant changes in temperature and rainfall will lower the rice yield by15% and wheat yield by 22% (Birthal et al, 2014). For India with limited arable land, the situation can become much worse if proper adaptation and mitigation measures in agriculture sector are not taken into consideration.

It has been suggested that local weather conditions (rain, temperature, sunshine and wind) in combination with locally adapted plant varieties, cropping systems, and soil conditions can maximize food production if plant diseases can effectively be controlled (Kumar and Gautam, 2014). Adaptations to experienced and projected climate changes are already occurring (Moser and Ekstrom 2010). However, the positive trend needs to continue even if mitigation efforts are widely implemented (IPCC 2014).

The overall findings of this study indicated that climate variables have differential impact on the production of different crops. It was observed that major food crops (rice & wheat) were adversely affected by increase in maximum temperature and decrease in rainfall. However, the commercial crops were observed to be positively affected by the increasing temperature. These conditions may also lead to increased weed & pest proliferations. Moreover, increased temperature quickly ripens the crop, which results in malnourished crop and less nutrient food. Further, the study concluded that area under the cultivation of different crops, use of selective inputs such as irrigation, fertilizer, pesticides etc. has also increased during the last 55 years.

Thus, it can be concluded that although climatic variables have significant impacts on various food and commercial crops, the alternative measures are nullifying the negative impact by enhancing the overall production. Further, there is an urgent need to take coordinated steps in direction of adaptation and mitigation towards climate change to ensure the food security and food safety in long run.

The Government of India has launched its National Mission for Sustainable agriculture with a focus on soil and water conversation, water use efficiency, soil health management, and rain-fed area development. Also, two other programs viz., agro-meteorology advisory service and farmers' awareness program have been launched to scale up sustainable agriculture program (Tripathi and Mishra, 2017).To meet the pledges schedule India has to change existing production norms, by encouraging technological innovations that ensure better output with decreased costs and decreased pollution and increased quality through participatory management.

From the results of the study, it is concluded that although the agriculture sector is able to combat the adverse impacts of climate change till now, however, in near future this situation may be reversed. This necessitates the implementation of appropriate measures to deal with the problems of climate change. The first and foremost need is to provide incentives to promote networks and/or to form clubs that bring likeminded farmers together on same platform for communication and adaptation strategies as a response to climate change (Tripathi and Mishra, 2017). The knowledge about changes in climate especially the fluctuations in temperature and rainfall patterns should be spread at farmer level. Farmer decision making ability can have a significant effect on reducing on-farm vulnerability by addressing problems of soil loss and degradation and adoption of soil and water conservation practices (Lehman et al. (2015). Adoption of these practices can improve agro-ecosystem resilience (Kremen and Miles 2013) by increasing the production of a more diverse range of ecosystem services.

Farmers should also be provided with crop specific incentives and insurance against climate risks. There is a limited scope left for the expansion of cropping area in context of enormously increasing population in the country. Also, the agricultural land is facing various types of degradation. So there is an utmost urgency to give a boost to research and development in the fields for development of high temperature and drought resistant new crop varieties along with the promotion of sustainable agricultural practices. Adoption of some other important measures such as mixed/intercropping, change in planting dates, water harvesting, micro-irrigation, agroforestry etc. should be emphasized. It is further recommended that any programs that are working to minimize the adverse impact of climate change on food crops production should first consider the important cereal crops such as rice and wheat that are the staple food diet for major Indian population and are being most affected by the higher temperatures relative to the other food crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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