

**Impact of Climate Change on the Production of Major Food and Commercial Crops in India: A five decadal study**

**Running Title:** Agroecosystems and Climate Change

**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 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

**Introduction**

Agricultural production of any country is directly dependent on its climate and weather conditions since minor changes in temperature, precipitation and CO<sub>2</sub> concentration can drastically impact its crop growth. Higher levels of CO<sub>2</sub> generally increase productivity of plants through enhancement in plant photosynthesis due to CO<sub>2</sub> fertilization effect but the long-term effects are uncertain and might involve negative effects on plant food web, decreased plant

29 nutritional values, reduced N content of plant etc (Nogia et al., 2016). Hence, to achieve the  
30 optimum plant productivity, a balance in atmospheric carbon level is primarily needed.

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

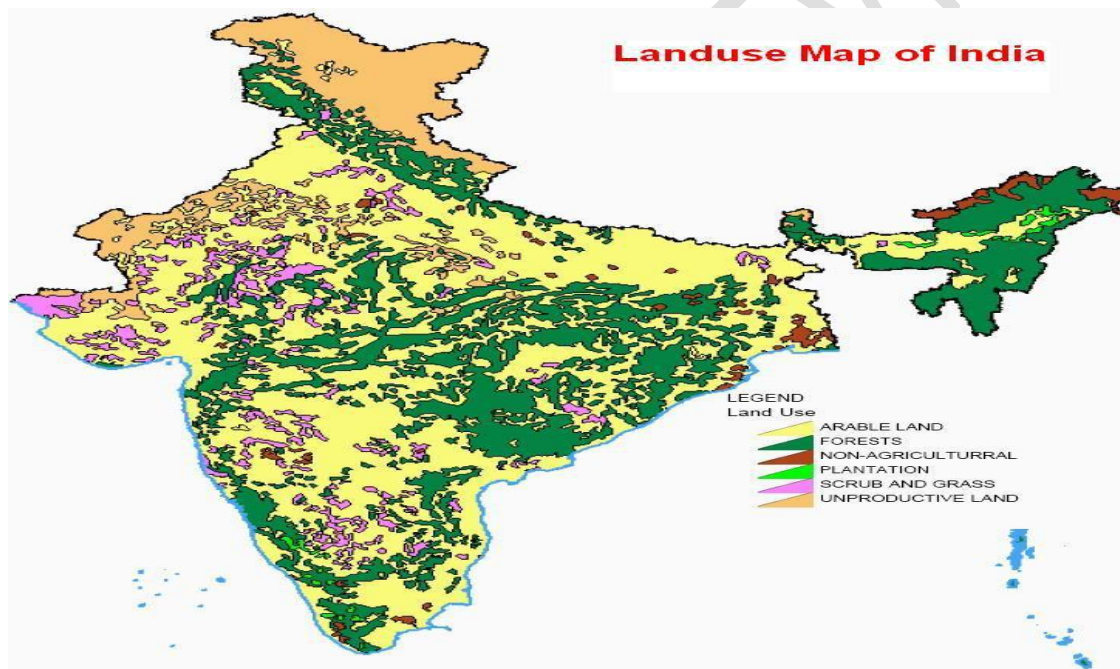
37 Climate change will have variable impacts across regions and cropping systems. There are  
38 concerns that climate change will hamper the world's ability to provide sufficient food for the  
39 global population (Hatfield et al., 2011). The impacts on agriculture and food security are more  
40 prominent especially in the agriculture oriented and developing countries like India. These  
41 countries have limited arable land but heavy dependence on agriculture (Mendelsohn *et al.*,  
42 2006; Stern, 2006; Nelson *et al.*, 2009) and also have poor technological and financial  
43 capabilities for mitigation and adaptation to climate change. **Banday and Aneja (2014) estimated**  
44 **that by 2080, agriculture output in developing countries may decline by 20% due to climate**  
45 **change, while output in industrial countries is expected to decrease 6% and yields in developing**  
46 **countries is expected to decrease by 15% on an average.**

47 India is facing major challenges to increase its food production to the tune of 300 mt by 2020 to  
48 feed its ever growing population by producing 50% more grain by 2020 (Kumar and Gautam,  
49 2014). Climate change also affects other factors of production agriculture, such as water  
50 availability, soil fertility, and pests (Porter, 2014). It will aggravate problems with soil loss  
51 through wind and water erosion in addition to environmental externalities, which are associated  
52 with current land use practices. The population of India as on March 1st, 2011 stood at 1,210.7  
53 million (623.2 million males and 587.5 million females) with a population density of 382 per  
54 sq.km (GoI, 2015). Cropland is the main occupation of the major population. The economy of  
55 the region is predominantly agrarian as it constitutes a measure of livelihood of a large portion of  
56 population.

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

## 60 **Materials and Methods**

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



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

68 The present study is based on the secondary data about crop production of major food crops  
69 (rice, wheat, coarse cereals, pulses), major commercial crops (ground nut, rapeseed & mustard,  
70 sugarcane, cotton (lint), raw jute & mesta), cultivation area and inputs used (Fertilizer, Pesticides  
71 & irrigation inputs) since 1960-61 to 2015-16. The data has been collected from the Handbook of  
72 Statistics on the Indian Economy (2015-16, 2016-17 and 2017-18) being published by Reserve  
73 Bank of India, and records of Ministry of Agriculture & Farmers Welfare, Government of India

74 (2016-17). The temperature and rainfall data of the country was retrieved from web portal of  
75 Indian Meteorological Department, Ministry of Earth Sciences for the selected study period. The  
76 analysis of data was made through descriptive statistics for better interpretation and description  
77 of various conditions or scenarios.

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

$$81 \quad Y = \alpha_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \mu$$

82 Where,

83 Y= Crop Production

84  $\alpha_0$ = Constant

85  $X_1$ = Temperature variations

86  $X_2$ = Rainfall variations

87  $X_3$ = variations in Cropping Area

88 Y is the observed Production due to temperature, precipitation and cropping area and  $\beta_1$ ,  $\beta_2$ , and  
89  $\beta_3$  are coefficients of the temperature, precipitation and cropping area, respectively. Similarly,  
90  $X_1$ ,  $X_2$  and  $X_3$  are the observed changes in the temperature, precipitation (rainfall) and cropping  
91 area respectively, during the study period.

## 92 **Results and Discussion**

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

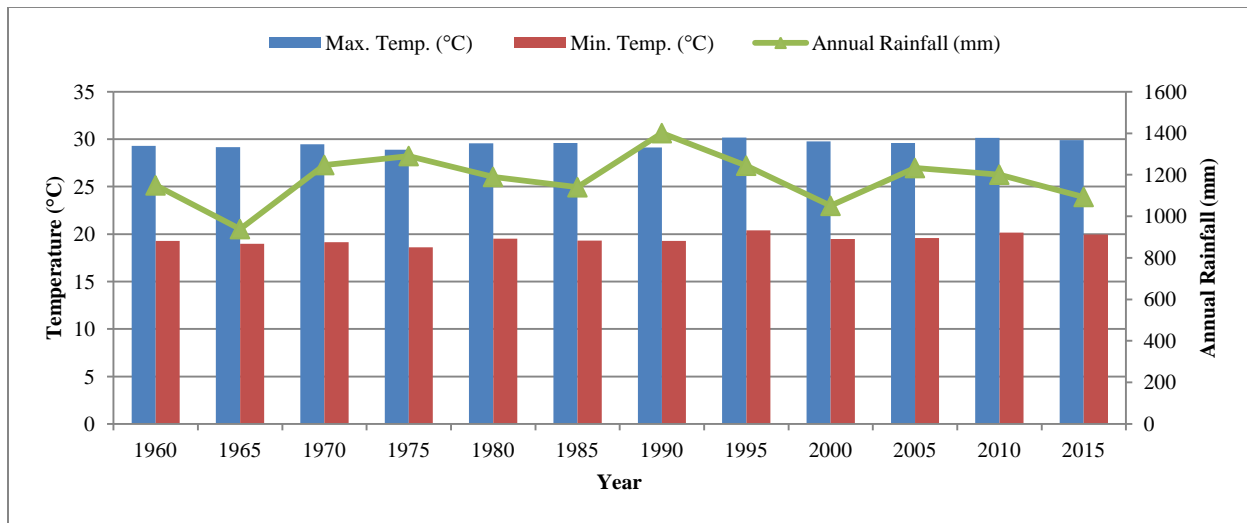


Fig 2. Climatograph for India since 1960 to 2015 ([www.imd.gov.in](http://www.imd.gov.in))

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101 The overall crop production of both food and commercial crops in India has increased since  
102 1960-61 with some fluctuations in between (Fig 3). Similar observations were inferred from the  
103 data on area under cultivation of different crops (Fig 4). Also, it was found that use of irrigation;  
104 consumption of fertilizers (N+P+K) and pesticides depicted an increasing trend towards 2015-16  
105 (Fig 5).

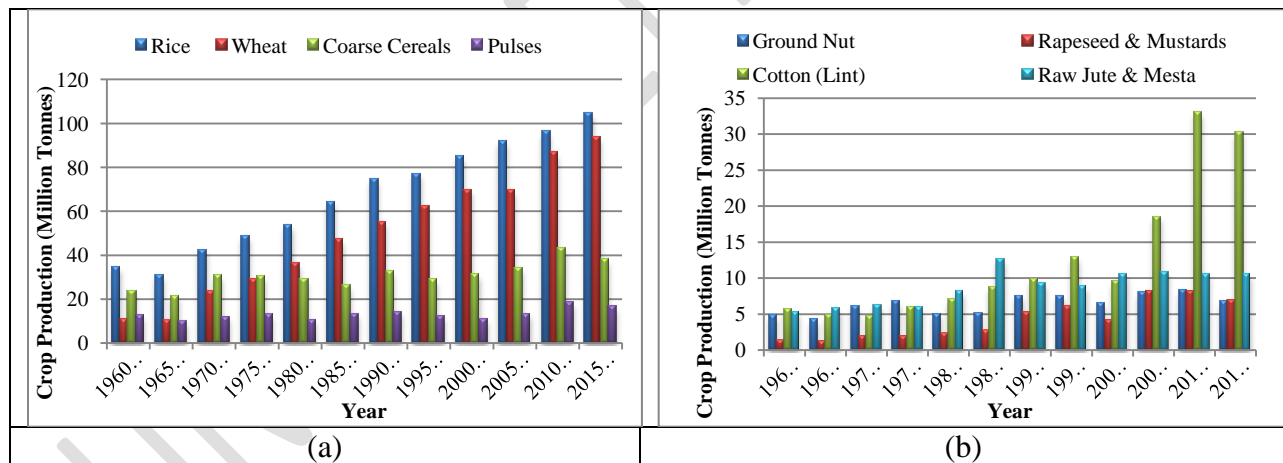
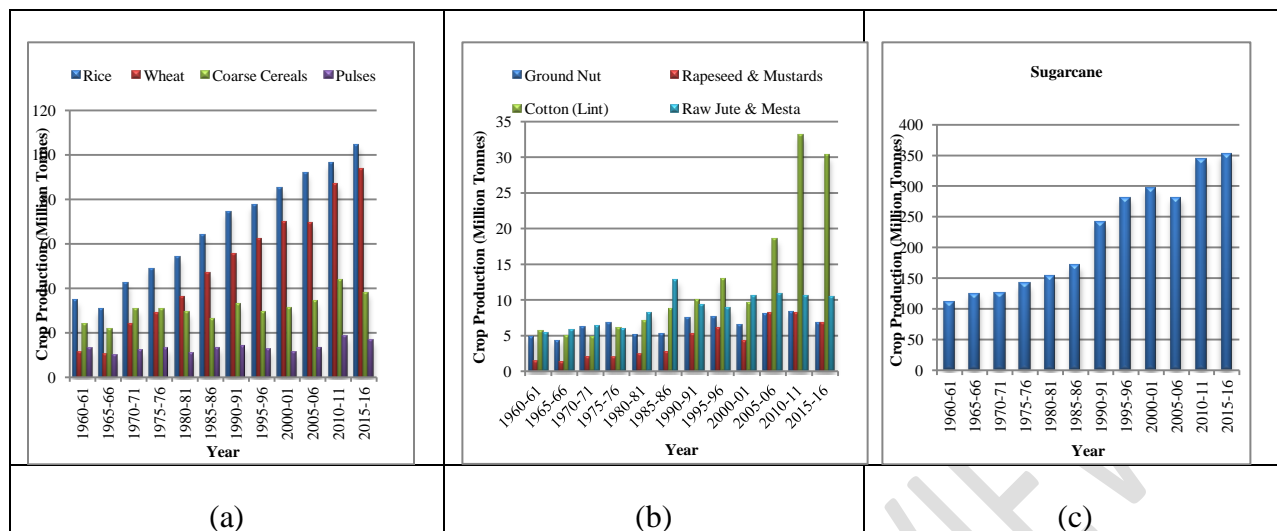


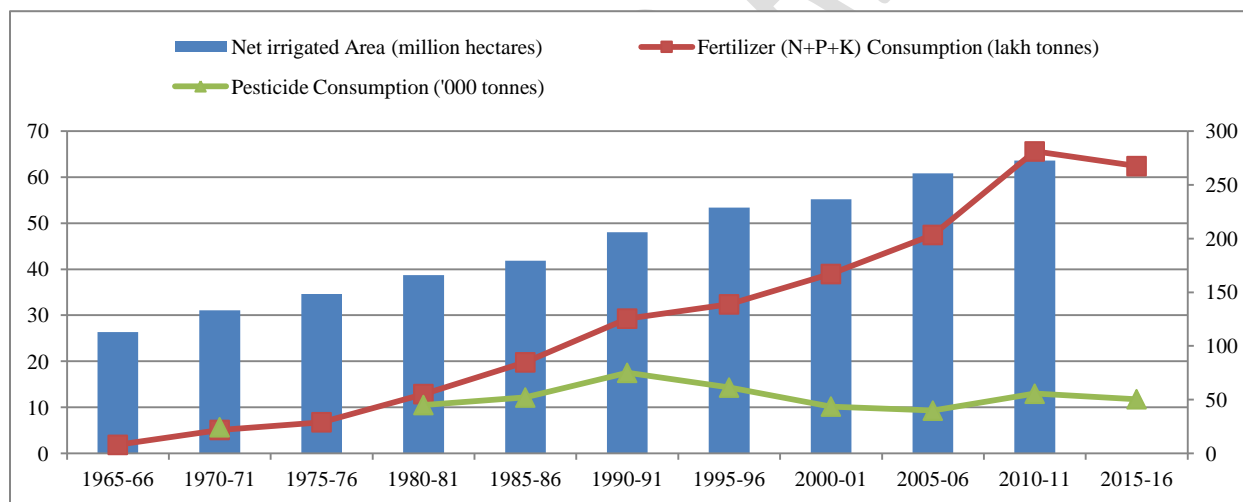
Fig 3. Crop production (million tonnes) of (a) major food crops and (b) major commercial crops over 55 years (RBI, 2017)

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

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

114 **Regression analysis for major food crops**

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

118 The effects of the climatic parameters, i.e. of temperature & rainfall were observed to be  
 119 detrimental for rice production as the increase in temperature & decrease in rainfall negatively

120 affected Rice crop production. But the increase in cropping area was observed to be combating  
121 this negative effect since it contributed positively with a significant increase in Rice crop  
122 production. The adjusted  $R^2$  value expressed that 88% variability in Rice production is explained  
123 by these variables.

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

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

### 136 **Regression analysis for major commercial crops**

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

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**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
<b>Intercept</b>	-408.68			-243.51			13.03			-		
<b>Max. Temp.</b>	-3.045	7.316	-0.416	-0.695	5.721	-0.121	2.713	3.112	0.871	3.632	1.367	2.656
<b>Min. Temp.</b>	16.905	6.374	2.651	11.691	5.016	2.330	-2.942	3.043	-0.966	-0.184	1.327	-0.138
<b>Rainfall</b>	-0.015	0.013	-1.18	-0.011	0.010	-1.071	0.014	0.005	2.576	0.002	0.002	0.878
<b>Cropping Area</b>	6.278	0.479	13.09	4.359	0.232	18.768	-0.607	0.105	-5.765	1.087	0.224	4.843
<b>R<sup>2</sup></b>	0.89			0.94			0.60			0.55		
<b>Adjusted R<sup>2</sup></b>	0.88			0.94			0.57			0.52		
<b>Observations</b>	56			56			56			56		

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**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
<b>Intercept</b>	-60.36			-40.85			-300.41			-209.17			-103.29		
<b>Max. Temp.</b>	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
<b>Min. Temp.</b>	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
<b>Rainfall</b>	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
<b>Cropping Area</b>	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
<b>R<sup>2</sup></b>	0.38			0.93			0.98			0.87			0.51		
<b>Adjusted R<sup>2</sup></b>	0.33			0.92			0.98			0.86			0.47		
<b>Observations</b>	56			56			56			56			56		

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

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

## 181 **Conclusion and Recommendations**

182 The technological advances along with investments in irrigation, infrastructure and institutions in  
183 last five decades have supported India to come out of the food security syndrome and promoted  
184 its level in the International agricultural market. However, curbing the problem of feeding ever  
185 increasing growing population still remains a challenge in terms of producing more and more  
186 food. Moreover, the projections of climate change impacts towards 2100 have suggested  
187 significant changes in temperature and rainfall will lower the rice yield **by**15% and wheat yield  
188 by 22% (Birthal *et al.*, 2014). For India with limited arable land, the situation can become much

189 worse if proper adaptation and mitigation measures in agriculture sector are not taken into  
190 consideration.

191 It has been suggested that local weather conditions (rain, temperature, sunshine and wind) in  
192 combination with locally adapted plant varieties, cropping systems, and soil conditions can  
193 maximize food production if plant diseases can effectively be controlled (Kumar and Gautam,  
194 2014). Adaptations to experienced and projected climate changes are already occurring (Moser  
195 and Ekstrom 2010). **However, the positive trend needs to continue** even if mitigation efforts are  
196 widely implemented (IPCC 2014).

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

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

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

218 From the results of the study, it is concluded that although the agriculture sector is able to  
219 combat the adverse impacts of climate change till now, however, in near future this situation **may**  
220 **be reversed**. This necessitates the implementation of appropriate measures to deal with the  
221 problems of climate change. The first and foremost need is to provide incentives to promote  
222 networks and/or to form clubs that bring likeminded farmers together on same platform for  
223 communication and adaptation strategies as a response to climate change (Tripathi and Mishra,  
224 2017). The knowledge about changes in climate especially the fluctuations in temperature and  
225 rainfall patterns should be spread at farmer level. Farmer decision making ability can have a  
226 significant effect on reducing on-farm vulnerability by addressing problems of soil loss and  
227 degradation and adoption of soil and water conservation practices (Lehman et al. (2015).  
228 Adoption of these practices can improve agro-ecosystem resilience (Kremen and Miles 2013) by  
229 increasing the production of a more diverse range of ecosystem services.

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

## 242 **References**

- 243 **Banday UJ, Aneja R. Deterioration of Agricultural Productivity Due to Climate Change in**  
244 **Haryana. MPRA Paper No. 72654. 2014.**
- 245 Birthal PS, Khan MT, Negi DS, Agarwal S. Impact of Climate Change on Yields of Major Food  
246 Crops in India: Implications for Food Security. *Agricultural Economics Research Review*. 2014;  
247 27 (2):145-155. DOI: 10.5958/0974-0279.2014.00019.6

248 GoI (Government of India). India 2015. Publication Division. Ministry of Information &  
249 Broadcasting. 2015.

250 Hatfield JL, Boote KJ, Kimball BA, Ziska LH, Izaurralde RC, Ort D, Thomson AM, Wolfe D.  
251 Climate impacts on agriculture: Implications for crop production. *Agronomy Journal*.  
252 2011;103(2):351-70.

253 Heinemann JA, Massaro M, Coray DS, Agapito-Tenfen SZ, Wen JD. Sustainability and  
254 innovation in staple crop production in the US Midwest. *Int J Agric Sustain*. 2013;  
255 doi:10.1080/14735903.2013.806408

256 IPCC. Summary for Policymakers. In: C.B. Field et al., editors. *Climate Change 2014: Impacts,*  
257 *Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working*  
258 *Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*  
259 Cambridge, UK and New York, NY: Cambridge University Press. Pp 1-32. 2014.

260 Kalra N, Chakraborty D, Ramesh PR, Jolly M, Sharma PK. *Impacts of Climate Change in India:*  
261 *Agricultural Impacts. Final Report, Joint Indo- UK Programme of Ministry of Environment and*  
262 *Forests, India, and Department for Environment, Food and Rural Affairs (DEFRA), United*  
263 *Kingdom. Indian Agricultural Research Institute, Unit of Simulation and Informatics, New*  
264 *Delhi. 2007.*

265 Kremen C, Miles A. Ecosystem services in biologically diversified versus conventional farming  
266 systems: Benefits, externalities, and trade-offs. *Ecology and Society*. 2012;17(4):40-65.

267 Kumar R, Gautam HR. Climate Change and its Impact on Agricultural Productivity in India. *J*  
268 *Climatol Weather Forecasting*. 2014; 2:109. doi:10.4172/2332-2594.1000109

269 Lehman RM, Cambardella CA, Stott DE, Acosta-Martinez V, Manter DK, Buyer JS, Maul JE,  
270 Smith JL, Collins HP, Halvorson JJ, Kremer RJ, Lundgren JG, Ducey TF, Jin VL, Karlen DL.  
271 Understanding and enhancing soil biological health: The solution for reversing soil degradation.  
272 *Sustainability*. 2015;7:988-1027.

273 Mendelsohn R, Dinar A, Williams L. The distributional impact of climate change on rich and  
274 poor countries. *Environment and Development Economics*. 2006;11:159-178.

275 Moser SC, Ekstrom JA. A framework to diagnose barriers to climate change adaptation. *PNAS*.  
276 2010;107(51):22026-31.

277 Nelson GC, Rosegrant MW, Koo J, Robertson R, Sulser T, Zhu T, Ringler C, Msangi S, Palazzo  
278 A, Batka M, Magalhaes M, Valmonte-Santos R, Ewing M, Lee D. *Climate Change: Impact on*  
279 *Agriculture and Costs of Adaptation. International Food Policy Research Institute. Washington,*  
280 *D.C. 2009.*

- 281 Nogia P, Sidhu GK, Mehrotra R, Mehrotra S. Capturing atmospheric carbon: biological and  
282 nonbiological methods. *International Journal of Low-Carbon Technologies*. 2016;11: 266–274.
- 283 Porter JR, Xie L, Challinor AJ, Cochrane K, Howden SM, Iqbal MM, Lobell DB, Travasso MI.  
284 Food security and food production systems. In: Field CB et al. editors. *Climate Change 2014:  
285 Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of  
286 Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate  
287 Change*. Cambridge, UK and New York, NY: Cambridge University Press. pp. 485–533. 2014
- 288 **RBI (Reserve Bank of India). Handbook of the Statistics on the Indian Economy 2016-17. Data  
289 Management and Dissemination Division, Department of Statistics and Information  
290 Management, Reserve Bank of India. 2017.**
- 291 Stern N. *The Economics of Climate Change: The Stern Review*. H.M. Treasury, London. 2006.
- 292 Tripathi A, Mishra AK. Knowledge and passive adaptation to climate change: An example from  
293 Indian farmers. *Climate Risk Management*. 2017;16: 195–207