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Climate change and its impact on productivity of major *kharif* and *rabi* crops in Punjab

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सार – इस अध्ययन में पंजाब में प्रमुख रबी और खरीफ फसलों के लिए उत्पादकता पर जलवायु परिवर्तन के प्रभावों का आकलन किया। तापमान और वर्षा का उपयोग करके जलवायु परिवर्तन के प्रभाव का अनुमान लगाने के लिए पूरे पंजाब में 5 फसलों का उपयोग करते हुए 35 वर्षों (1986-2020) के लिए डेटा का संकलन किया गया है। हमारे परिणाम बताते हैं कि अधिकांश फसलों में औसत तापमान में वृद्धि के साथ उत्पादकता घट जाती है। कृषि उत्पादन पर जलवायु परिवर्तन का प्रतिकूल प्रभाव कृषक समुदाय के लिए खाद्य सुरक्षा के लिए खतरा दर्शाता है। अध्ययन के निष्कर्ष जलवायु जोखिमों के प्रभावी समाधान के लिए जलवायु-स्मार्ट कृषि पर ध्यान देने का सुझाव देते हैं।

ABSTRACT. This study assessed the climate change impacts on productivity for major *rabi* and *kharif* crops in Punjab. The data has been complied for 35 years (1986-2020) using 5 crops across Punjab to estimate the impact of climate change by using temperature and rainfall. Our results indicate that productivity decreases with an increase in average temperature in most of the crops. The adverse impact of climate change on agricultural production indicates food security threat to the farming community. The findings of the study suggest to focus on climate-smart agriculture for effective solutions to climate risks.

Key words – Climate change, Temperature, Rainfall, Yield loss.

1. Introduction

The climate of Punjab State has been changing and it has a detrimental effect on the agricultural yields (Kumar and Kaur, 2019). 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 (Birthal *et al.*, 2014). It is anticipated that the climate change would continue to be long-standing and will have a great bearing on the livelihood of the farmers and overall economy of the sector. Recently, the Intergovernmental panel on Climate Change (IPCC, 2021) published the sixth assessment report, in which global surface temperature is projected by the year 2100 and it is very likely to be higher by 1.0 °C to 1.8 °C under the very low GHG emissions scenario considered (SSP1-1.9), by 2.1 °C to 3.5 °C in the intermediate GHG emissions scenario and by 3.3 °C to 5.7 °C under the very high GHG emissions scenario. The projected changes in temperature and rainfall reveal a decline in yield of all major crops in the range of 1 to 10% by 2035, 3 to 18% by 2065 and 4 to 26% by the year 2100 (Birthal *et al.*, 2014). Given the predictions of a significant change in future climate, a quantitative assessment of the climate of different crops in Punjab is essential. For this purpose, we use panel data of crop yields and major climatic variables such as temperature and rainfall of different districts of Punjab, then this dataset is subjected to a fixed effect panel model technique to generate the estimates of the impact of temperature and rainfall on yield of major *rabi* and *kharif* crops in Punjab. This study makes an important contribution to the literature on the adverse effects of climate change on important crops in Punjab. While, the traditional measures have been focused on rice and wheat, in this study, we have also considered cotton, maize and

TABLE 1

Description of the explanatory variables used in fixed effect panel model

Crops	Period	Panel Districts	No of years	Variables Considered
Rice	June to September	• Ludhiana • Patiala • Faridkot • Bathinda • SBS Nagar	35 years (1986 to 2020)	• Maximum Temperature (°C) • Minimum Temperature (°C) • Mean Temperature (°C) • Rainfall (mm) • Net Irrigated Area • Rice Yield
Maize	May to October	• Ludhiana • Patiala • SBS Nagar	35 years (1986 to 2020)	• Maximum Temperature (°C) • Minimum Temperature (°C) • Mean Temperature (°C) • Rainfall (mm) • Net Irrigated Area • Maize Yield
Cotton	April to December	• Ludhiana • Faridkot • Bathinda	35 years (1986 to 2020)	• Maximum Temperature (°C) • Minimum Temperature (°C) • Mean Temperature (°C) • Rainfall (mm) • Net Irrigated Area • Cotton Yield
Wheat	November to March	• Ludhiana • Patiala • Faridkot • Bathinda • SBS Nagar	35 years (1986 to 2020)	• Maximum Temperature (°C) • Minimum Temperature (°C) • Mean Temperature (°C) • Rainfall (mm) • Wheat Yield
Potato	October to January	• Ludhiana • Patiala • Faridkot • Bathinda • SBS Nagar	35 years (1986 to 2020)	• Maximum Temperature (°C) • Minimum Temperature (°C) • Mean Temperature (°C) • Rainfall (mm) • Potato Yield

potato crop, which contributed 6.02 per cent, 2.80 per cent and 2.57 per cent, respectively. Such an analysis is useful in guiding agricultural policy in the prioritization of climate risks. These findings give a robust path to improving productivity, sustainability and resilience in the community.

2. Methodology

The present study is entirely based on secondary data from the year 1986 to 2020. The climate data on temperature and rainfall has been collected from five weather observatories of Punjab Agricultural University, Ludhiana, *i.e.*, Ludhiana, Patiala, Faridkot, Bathinda and SBS Nagar. The article ascertains the impact of climate change on the productivity of major five crops that is, Rice, Maize, Cotton, Wheat and Potato. The daily data of temperature and rainfall was converted into monthly data covering different months for making crop periods. For making crop period, we have covered the months 1 June to 30 September for the rice growing period, for maize 1 May to 31 October, for Cotton 1 April to 31 December, for wheat 1 November to 31 March and for potato 1 October to 31 January (Table 1).

The secondary data on the productivity of different crops have been obtained from various issues of the Statistical Abstract of Punjab. The paddy yield was converted into rice productivity by a conversion factor of two-thirds (Kumar and Kaur, 2019). The panel data

TABLE 2

Various tests to check the stationarity in the data

Variables	Levin-Lin-Chu unit root test			Im-Pesaran-Shin unit root test		Fisher-Type unit root test	
	Unadjusted *t*	Adjusted *T*	*p*-value	*z-t*-tilde-bar	*p*-value	Chi-sq (pm)	*p*-value
	H_0 : Panel contain unit root H_1 : Panel are stationary			H_0 : All panel contain unit roots H_1 : Some panel are stationary		H_0 : All panel contain unit roots H_1 : At least one panel is stationary	
RT (min)	-8.37	-4.77	0.00	-7.26	0.00	29.17	0.00
RT (max)	-5.02	-2.04	0.00	-4.51	0.00	10.41	0.00
RR	-7.73	-3.4	0.00	-7.42	0.00	33.39	0.00
MT (min)	-5.14	-2.83	0.00	-4.52	0.00	13.67	0.00
MT (max)	-6.25	-3.84	0.00	-5.27	0.00	18.45	0.00
MR	-6.5	-3.23	0.00	-6.11	0.00	29.70	0.00
Lag CT (min)	-3.39	-1.42	0.07	-2.36	0.00	4.49	0.00
CT (max)	-6.77	-4.53	0.00	-4.75	0.00	14.37	0.00
CR	-5.66	-2.18	0.00	-5.58	0.00	25.75	0.00
WT (min)	-4.66	-1.65	0.05	-4.11	0.00	10.59	0.00
WT (max)	-5.96	-1.47	0.07	-6.04	0.00	18.77	0.00
WR	-7.78	-2.66	0.00	-6.31	0.00	22.34	0.00
Lag PT (min)	-4.5	-1.41	0.07	-5.05	0.00	15.48	0.00
PT (max)	-7.63	-4.44	0.00	-5.33	0.00	13.79	0.00
PR	-8.93	-4.59	0.00	-6.88	0.00	25.42	0.00
Ln (yield Rice)	-3.65	-1.44	0.07	-2.13	0.02	2.19	0.01
Ln (yield Maize)	-2.15	-0.91	0.18	-1.3	0.09	1.06	0.14
Ln (yield Cotton)	-4.66	-2.01	0.02	-3.09	0.00	5.49	0.00
Ln (yield Wheat)	-4.62	-3.42	0.00	-1.68	0.04	1.68	0.04
Ln (yield Potato)	-4.88	-2.17	0.01	-2.84	0.00	4.05	0.00

RT, MT, CT, WT, PT and PT represent the Rice temperature, Maize temperature, Cotton temperature, Wheat Temperature and Potato Temperature, respectively

RR, MR, CR, WR, PR and PR represent the Rice rainfall, Maize rainfall, Cotton rainfall, Wheat rainfall and Potato rainfall, respectively

approach has been used to illustrate the impacts due to temperature and rainfall. Different panels have been constructed for different crops. The panel has been constructed as per the highest area in selected districts. For crop rice, the study has considered all the selected five districts (Table 1). The panel for the rice crops has 175 observations (35 years' data of five districts). Additionally, the maize and cotton crop have 105 observations (35 years' data of three districts) however, the selection of districts in each panel of the crop is different and the districts have been mentioned in Table 1. In *rabi* season, we have taken two important crops, in which the panel of both crops has 175 observations to assess the impact of temperature and rainfall. The panel data approach captures the effects of time-invariant variables (soil characteristics, elevation) and farmers' autonomous adaptations (changes in planting dates of variety, input use) in response to year-to-year fluctuations in weather variables (Kumar and Kaur, 2019).

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

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

TABLE 3

Annual change in temperature and rainfall during *kharif* and *rabi* growing season in Punjab, 1986-2020

Particulars		Maximum Temp (°C)	Minimum Temp (°C)	Mean Temp (°C)	Rainfall (mm)
Mean	Rice growing period	34.84	25.22**	30.03***	519.56*
Change		0.21	1.25	0.73	-107.34
Annual change		0.01	0.04	0.02	-3.07
Mean	Maize Growing Period	34.37***	23.36***	28.72***	741.94***
Change		0.70	0.71	0.71	-257.13
Annual change		0.02	0.02	0.02	-7.35
Mean	Cotton Growing Period	32.89	20.39**	26.64	479.6
Change		-0.13	1.16	0.51	-4.13
Annual change		0.00	0.03	0.01	-0.12
Mean	Wheat Growing Period	23.1	9.16***	16.14	90.82
Change		-0.15	0.87	0.36	0.43
Annual change		0.00	0.02	0.01	0.01
Mean	Potato Growing period	24.55**	10.40***	17.48***	51.37
Change		-0.48	0.92	0.22	-5.08
Annual change		-0.01	0.03	0.01	-0.15

Notes : *** denote the level of significance at 99 per cent level, Figures in parentheses are standard errors

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

$$\ln y_{it} = D_i + T_t + \beta X_{it} + \epsilon_{it} \qquad (2)$$

where, i represents district and t represents time.

The dependent variable y is the respective crop productivity of their respective model, D represents the district fixed effect. The district fixed impact is considered to absorb all of the unobserved district-specific time-invariant elements that influence crop yield and enable to reduce error owing to omitted variables in the model. Time fixed effects are represented by T in the model that controls the variation in crop yield, which might be originated due to changes in infrastructure, technological factors and human capital, etc; X represents weather variables. In equation 1, Z accounts for non-weather variables such as the net irrigated area of the concerned crop.

However, in equation 2, we have not considered the net irrigated area, as these wheat and potato crop has the least importance of irrigation. β is the coefficient of the weather variable in both equations. While γ is a parameter associated with the net irrigated area in equation I; and ϵ is the random term. The study used the squared term of rainfall in the model. Due to this reason, the coefficients have a non-linear influence on the yield of all the crops in the model. The explanations of regression coefficients are not clear. Therefore, the marginal effects of climate variables were calculated to measure the exact relationship between crop yield and weather variables at their mean values and, accordingly, the variation in crop yield due to a 1 mm rise in rainfall and a 1 °C increase in temperature. Furthermore, we have generated the natural log value of all the selected crop yields in the equations to reduce the excessive variation in the data.

There is a possibility that the dependent variable $Y_t$is non-stationary, bringing in the issue of autocorrelation. The autocorrelation might be serious if the series of explanatory variables (temperature and rainfall) are non-stationary. To test for stationarity, panel unit root tests-Levin-Lin-Chu; Im, Pesaran and Shin; and the Fisher-type tests-are utilised and the null hypothesis is rejected for almost all the series except the minimum temperature of cotton and potato growing period (Table 2). To make the series stationary, we have used the series of first differencing and calculated the impacts. After first differencing, data are stationary for all the weather variables including the series of the yield of all the crops.

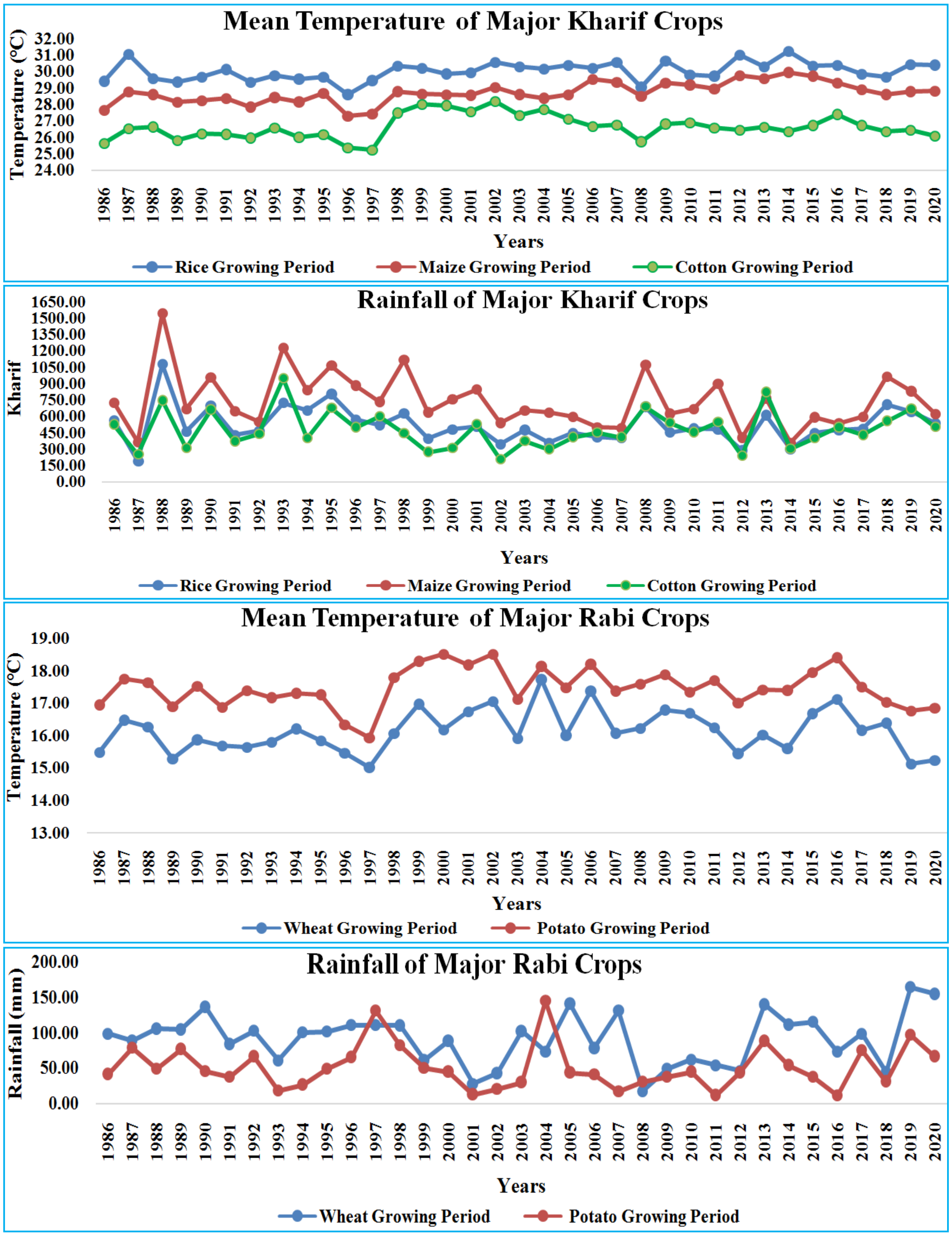

Fig. 1. Mean temperature and rainfall of *kharif* and *rabi* crops

3. Results and discussion

The paper has been organised into four sections. The first section gives a brief overview of the trend analysis of climatic variables in Punjab (Table 3 and Fig. 1). The coefficients and marginal effects have been presented in the second section, while climate prediction and yield loss have been discussed in the third section. The review related to the impact of climate has also been outlined in the fourth section. The last section concludes with the policy implications.

3.1. *Climate trends*

Table 3 shows how temperature (maximum and lowest) and rainfall changed over time for different rice,

TABLE 4

Regression estimates of the impact of temperature and rainfall on yield of major *kharif* crops in Punjab, 1986-2020

Particulars	Coefficient	SE	*p*-value	Coefficient	SE	*p*-value	Coefficient	SE	*p*-value
	Rice Growing Period			Maize Growing Period			Cotton Growing Period		
T_{min} (°C)	-0.008*	0.001	0.106	-0.137**	0.06	0.024	-0.050**	0.026	0.053
T_{max} (°C)	0.011	0.008	0.203	0.046	0.055	0.401	-0.066	0.052	0.214
RR (mm)	0.000	0.000	0.670	0.000	0.000	0.438	0.000	0.000	0.241
RR (Square)	0.000	0.000	0.700	0.000	0.000	0.87	0.000	0.000	0.48
Net Irrigated Area	0.001***	0.000	0.000	0.007*	0.004	0.072	0.017***	0.004	0.000
Constant	7.487***	0.309	0.000	3.126	1.882	0.100	8.893***	1.786	0.000
District	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No of Observations	175	175	175	105	105	105	105	105	105

Note : ***, ** and * denote level of significance at 99, 95 and 90 per cent levels, respectively, T_{min} = Minimum temperature, T_{max} = Maximum temperature, RR = Rainfall

TABLE 5

Regression estimates of the impact of temperature and rainfall on yield of major *rabi* crops in Punjab, 1986-2020

Particulars	Coefficient	SE	*p*-value	Coefficient	SE	*p*-value
	Wheat Growing Period			Potato Growing Period		
T_{min} (°C)	0.016**	0.008	0.033	0.009	0.007	0.224
T_{max} (°C)	-0.048***	0.011	0.000	-0.017**	0.001	0.07
RR (mm)	-0.002***	0.001	0.004	0.000	0.001	0.907
RR (Square)	0.000**	0.000	0.031	0.000	0.000	0.453
Constant	9.429***	0.272	0.000	10.303***	0.308	0.000
District	Yes	Yes	Yes	Yes	Yes	Yes
Time	Yes	Yes	Yes	Yes	Yes	Yes
No of Observations	175	175	175	175	175	175

Note : ***, ** and * denote significance at 1, 5 and 10 per cent levels, respectively, T_{min} = Minimum temperature, T_{max} = Maximum temperature, RR = Rainfall

maize, cotton, potato and wheat growing seasons. During the study period from 1986 to 2020, the average mean temperature during the rice growing period was 30.03 °C with a minimum of 25.22 °C and a maximum of 34.84 °C. Likewise, during the cotton and maize growing period, the average mean temperature was 28.72 °C and 26.64 °C, respectively. The average mean temperature during these *kharif* crops was almost in between the range of 26.64 °C to 30.02 °C. However, during the wheat growing period and potato growing period (major *rabi* crop in Punjab), the average mean temperature was at least lower than 10.0 °C than the average mean temperature of rice, maize and cotton growing periods. One of the study's most intriguing findings is that changes in minimum temperature have resulted in changes in mean temperature throughout all growing seasons.It means that the minimum temperature has shown a rising trend. The rainfall pattern has been shown in Table 3, in which each crop growing period has different intensity of rainfall. The maize growing period and rice growing period received the highest rainfall among all the selected crops. On average, Punjab state received 580 mm annual rainfall during the rice, maize and cotton growing period from the year 1986 to 2020. However, the change in rainfall during

TABLE 6

Marginal Effects of temperature and rainfall on major *kharif* crops in Punjab agriculture 1986 through 2020

Variable	Coefficient	SE	*Z*-value	*P*-value	Coefficient	SE	*Z*-value	*P*-value	Coefficient	SE	*Z*-value	*P*-value
	Rice Growing period				Maize growing period				Cotton Growing Period			
T_{min}(°C)	-0.008*	0.002	-4.070	0.104	-0.137**	0.060	2.290	0.022	-0.050**	0.026	-1.96	0.05
T_{max}(°C)	0.011	0.008	1.280	0.202	0.046	0.055	0.840	0.399	-0.066	0.052	-1.25	0.21
RR (mm)	0.000	0.000	0.43	0.67	0.000	0.000	-0.78	0.436	0.000472	0.000	1.18	0.23

Notes:***, ** and * denote significance at 1, 5 and 10 percent levels, respectively, NS: Non-Significant,T_{min}=Minimum temperature, T_{max}= Maximum temperature and RR= Rainfall

TABLE 7

Marginal Effects of temperature and rainfall on major *rabi* crops Punjab agriculture 1986 through 2020

Variable	Coefficient	SE	*Z*-value	*P*-value	Coefficient	SE	*Z*-value	*P*-value
	Wheat Growing period				Potato growing period			
T_{min}(°C)	0.016**	0.008	2.15	0.032	0.009	0.007	1.22	0.222
T_{max}(°C)	-0.048***	0.011	-4.29	0.000	-0.017**	0.001	-3.43	0.07
RR (mm)	-0.002***	0.001	-2.92	0.004	0.000	0.001	0.12	0.907

Notes:***, ** and * denote significance at 1, 5 and 10 percent levels, respectively, NS : Non-Significant, T_{min} = Minimum temperature, T_{max} = Maximum temperature and RR = Rainfall

the wheat growing period and potato growing period was insignificant during the same period. During the last 35 years, rainfall has decreased by 107 mm and 257 during rice and maize, however, the decline in rainfall during the cotton growing period was insignificant. In the wheat and potato growing period, the decline in rainfall was less than 5 mm. These long-term changes in climatic variables, such as temperature and rainfall, show that the rise in temperature is driving most of the changes, rather than the change in rainfall.

3.2. *Impact of Climate on the productivity of kharif and rabi crops*

Detailed analysis was carried out on the relationships between climatic variables and the productivity of various crops. Table 4 and 5 illustrate the regression estimates of the impact of temperature and rainfall on the productivity of *kharif* and *rabi* crops, respectively. A Fixed effect panel model was used to analyze the impact. An attempt was made to explore how temperature and rainfall would impact the various *kharif* and *rabi* crops in Punjab. It is hypothesized that the probability of the location-specific characteristics, might be associated with climatic factors. To control those conditions, the study included the district fixed effects which were found significant in all the crops in both seasons, indicating that the inclusion of spatial fixed effects in the present model is significant for controlling the time-invariant characteristics. The regression estimates of minimum temperature during the rice, maize and cotton growing period, maize are negative. This means that the rise in minimum temperature is harmful to the yield of rice, maize and cotton. However, a rise in maximum temperature has a positive and weak impact on yields of paddy and maize, as the estimates were insignificant. This non-significant effect of the rise in maximum temperature has been weakened through the overuse of groundwater resources. This might be one of the reasons for the overuse of groundwater resources that have dwindled. In the case of cotton, the rise in maximum temperatures causes a reduction, as the regression coefficient shows a positive value however it was non-significant.

A rise in the maximum temperature has a significant detrimental effect on wheat and potato yield (Table 5). On the contrary, the excess minimum temperature is beneficial for potato and wheat yield, though the regression estimate is weak in potato crops. Rainfall is another coefficient that has been considered in the model and it was expected that higher rainfall is beneficial to all the *kharif* crops. Returning to the regression estimates of rainfall, its beneficial effect appears to have slowed down, as the coefficients showed a non-significant impact on all

TABLE 8

Projected changes in climate by 2050 and 2080 in India

Period	Temperature (°C)		Rainfall (%)	
	Lowest	Highest	Lowest	Highest
		2050		
Annual	2.23	2.87	5.36	9.34
Dec-Jan-Feb	2.54	3.18	-9.22	3.22
June-July-Aug-Sep	1.81	2.37	7.18	10.52
		2080		
Annual	3.53	5.55	7.48	9.9
Dec-Jan-Feb	4.14	6.31	-4.5	-19.97
June-July-Aug-Sep	2.91	4.62	11.12	14.96

Note : The projections on temperature and rainfall were calculated according to four scenarios (namely A_1, A_2, B_1 and B_2) which cover a wide range of the main demographic, technological and economic driving forces of future emissions. In the study, we have selected the highest and lowest scenarios depicting temperature and rainfall in each of the years that is 2050 and 2080, respectively, (Source: Lal *et al*., 2001)

the crops in *kharif* season. In the *rabi* season, as expected, rainfall has shown a negative significant impact on wheat yield, which means that rainfall during wheat growing period is detrimental to wheat yield.

The regression coefficients of temperature (minimum and maximum) and rainfall variables cannot be directly interpreted because the study has used the square of rainfall in the model. Their marginal effects estimated using below mentioned Equation (3), provide for their true effects (Table 6 and Table 7). The expected marginal impact of a single climate variable, Xion yield evaluated at the mean is:

$$E\ \{\partial \pi / \partial X_i\} = \alpha_{1,\,i} + 2\alpha_{2,\,i} * E\ [X_i] \qquad (3)$$

For the *kharif* crops, *i.e.*, rice, maize and cotton, the marginal effect of minimum temperature is negative but differs in magnitude and level of significance. The marginal effect of minimum temperature is almost similar for rice and cotton, but it is larger for maize. In the maize growing season, the marginal coefficient of minimum temperature is 0.137, indicating that a 1 °C increase in the minimum temperature reduces rice yield by 13.70%. However, the effect of a similar increase (1 °C) in the maximum temperature is opposite but it is not sufficient to fully compensate for the loss due to rise in minimum temperature except for the cotton crop. In this crop, the marginal effect of maximum temperature is negative with a value of 0.0667, which implies that an increase in 1 °C of maximum temperature, would lead to a decrease in cotton yield by 6.67 per cent. Likewise, in *rabi* season, the marginal effect of the wheat crop is more responsive (with a value of marginal coefficient 0.048) to excess maximum temperature as compared to the potato crop (with a value of marginal coefficient 0.017), which implies that the 1 °C rise in the maximum temperature would reduce the yield of wheat and potato by 4.80 and 1.70 percent, respectively. The marginal effect of rainfall has been found positive, but the impact was non-significant on rice, maize and cotton. On the contrary in *rabi* season, the wheat crop has a significant impact on temperature. The effect of rainfall on wheat is expected as the quantum of rainfall is not only less but more variable also. The value of the marginal effect of the wheat crop is 0.002, which implies that an increase in 1 mm of rainfall, would lead to a decrease in wheat yield by 0.20 per cent.

3.3. *Projected yield loss*

We have calculated the future crop losses by using the projections calculated by Lal *et al.*, 2001. This study predicted temperature and rainfall variations from June to September, December to February and on a yearly basis. These predictions had been calculated in the study for the year 2050 and 2080. In the study, we have selected the highest and lowest scenarios depicting temperature and rainfall in each year 2050 and 2080, respectively. The study assumed the period from June to September for change in temperature and rainfall to reflect the change in *kharif* crops, *i.e.*, rice, maize and cotton and temperature change from December to February that represents the change in wheat and potato growth season. We assume a comparable change in India calculated by the study Lal *et al.*, 2001 represents the change in temperature and rainfall across different agro-climatic zones in Punjab. To

TABLE 9

Projected yield loss of major *kharif* and *rabi* crops (Per cent) in Punjab agriculture by year 2050 and 2080

Season	Crops	2050		2080	
		Lowest	Highest	Lowest	Highest
Kharif	Rice	-1.2	-1.69	-1.88	-2.71
	Maize	-9.84	-13.13	-15.72	-24.36
	Cotton	-8.87	-11.36	-14.36	-23.41
Rabi	Wheat	-2.39	-5.67	-5.81	-6.47
	Potato	-1.63	-4.72	-4.56	-4.58

calculate yield loss, we have used the marginal coefficients. The predicted temperature and rainfall have been shown in Table 8.

We have used these projected temperatures and rainfall in our equation (4).

$$\Delta Y= [(\partial Y/\partial R)*\Delta R+ (\partial Y/\partial T)*\Delta T]*100 \quad (4)$$

where, Y is the crop yield, $R$is the rainfall, T is the temperature and ($\partial Y/\partial T$) and ($\partial Y/\partial R$) are elasticities w.r.t. temperature and rainfall, which were calculated by the model equations. The structure of agriculture is assumed to be constant. This is a rather limiting assumption, as a variety of economic and non-economic variables may amplify agricultural changes.

The information on yield loss has been mentioned in Table 9. The climate impacts on crops will vary widely in *kharif* as well as *rabi* seasons. Amongst the *kharif* crops, maize yield is the most responsive to temperature and rainfall than rice and cotton. By the year 2050, maize yield would be reduced by 13 per cent followed by cotton (about 11 %) and rice (about 1 %). However, the negative impact would accumulate with time. The yield loss will be increased from 13 to 24 per cent for the maize crop. Cotton and maize yield losses would also be increased, from about 11 to 24 percent for cotton and 1 to 2 percent for rice, respectively. The yield response of wheat and potato would be pretty much the same (about 5 % each) for the year 2050. By the year 2080, with a significant change in climate, the yield of wheat and potato will be higher by around 1 per cent each.

3.4. *Social implications*

In India, many studies across the states have given empirical evidence on the effects of climate change on agriculture during the recent decade. In Punjab (Northern state of India), the study (Hundal and Kaur, 2007) concluded that an increase in minimum temperature up to 1.0 °C to 3.0 °C above normal has led to a decline in productivity of wheat and rice by 10 per cent and 3 per cent, respectively. While the estimates based on the southern state of India, *i.e*., Tamil Nadu, concluded that the productivity of the rice crop has declined up to 41 per cent with a 40 °C increase in temperature (Geethalakshmi *et al*., 2011). Kaul and Ram (2009) found that excessive rains and extreme variation in temperature have adversely affected the productivity of Jowar crop in Karnataka. However, an increment in temperature up to 50 °C can lead to a continuous decline in the yield of rice and every one-degree increment in temperature will lead up to 6 per cent decline in yield in Kerala (Saseendran *et al*., 2000). Kumar *et al*. (2011) mentioned that a decline in the irrigated area for maize, wheat and mustard in north-eastern and coastal regions and for rice, sorghum and maize in Western Ghats of India may cause a loss of production due to climate change. However, estimates on non-food grain (commercial) crops showed that any increments in maximum temperature have a negative and statistically significant impact on sugarcane, cotton and Sesamum crops (Singh, 2012). Thus, in the empirical literature, there are considerable negative impacts of climate change, especially on farm income, as all the food and non-food crops across the states get negatively affected due to climate sensitivity. 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 (Birthal *et al*., 2014). Ninan and Bedamatta (2012) reported that climatic vulnerability makes the livelihood of the people more susceptible, especially in India as they are already vulnerable to conventional problems like less income, poverty and food insecurity, etc. Hollaender, 2010, finds that agriculture productivity, food security and poverty; are all directly linked to climate change. Above and beyond knowing all the scenarios, we cannot ignore the farmers' income, as at the national level, they are getting INR 10218 per month

(NSSO report of the year 2018-19) However, the average monthly income of an agricultural household in Punjab was comparatively higher with INR 23133, which is not efficient to meet daily amenities required by farmers. The findings provide credence to the claim that the future climate scenario is not very welcoming as nothing uninformed about the constraints of crisis and climate justice is adhered to. The results indicated that the climate-smart packages must be incorporated into the agricultural development agenda at the policy level. These practices can only be implemented by improving farmers' access to agricultural information. Another area where we must focus is linking farmers with financial institutions to boost their capacity to adapt climate-smart technologies and practices. Finally, agromet advisories must be improved so that they are delivered to farmers in a timely manner, allowing them to make decisions ahead of a calamity.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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