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The Impact of Climate Change on Major Agricultural Crops: Evidence from Punjab, Pakistan

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1. INTRODUCTION

It is necessary for a country to make its agriculture sector efficient to enhance food security, quality of life and to promote rapid economic growth. The evidence from least developed countries (LDCs) indicates that agriculture sector accounts for a large share in their gross domestic product (GDP). Thus the development of the economy cannot be achieved without improving the agriculture sector. According to the Economic Survey of Pakistan (2011-12) its main natural resource is arable land and agriculture sector's contribution to the GDP is 21 percent. The agricultural sector absorbs 45 percent of labour force and its share in exports is 18 percent. Given the role of agricultural sector in economic growth and its sensitivity to change in temperature and precipitation it is important to study the impact of climate change on major crops in Pakistan.

There are two crops seasons in Pakistan namely, Rabi and Kharif. Rabi crops are grown normally in the months of November to April and Kharif crops are grown from May to October. These two seasons make Pakistan an agricultural economy and its performance depends on the climate during the whole year. Climate change generally affects agriculture through changes in temperature, precipitation.

Schlenker (2006) estimated the impact of climate change on crop yield for the agriculture sector of United States. This study found threshold levels of temperatures to be 29°C for corn and soybeans and 33°C for cotton. It concluded that the temperature above threshold would harm the crops. The hypothesis was tested by incorporating 3000 counties of US in the analysis. Though temperatures in all seasons, except in autumn, reduced the farm value but high precipitation increased the agriculture production of the US [Mendelsohn (1994)]. Therefore, for the United States global warming has very little impact on the agriculture sector. However, at the beginning climate change may have small effects for developed countries but in future negative effects will be very large and stronger. Countries with longer latitude, climate change may lead to net benefits but countries with low latitude are more vulnerable [Stern (2006)].

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In recent decades, high temperatures have been observed in Asia and the Pacific regions. In these regions agriculture sector is more vulnerable as 37 percent of the total world emissions from agriculture production are accumulating from Asia and the Pacific. Countries most vulnerable to climate change include Bhutan, Indonesia, Pakistan, Papua New Guinea, PRC, Sri Lanka, Thailand, Timor-Leste, Uzbekistan, and Vietnam [Asian Development Bank (2009)]. On the other hand, there is also a possibility that agriculture sector may harm the climate. This problem is identified by Paul, *et al.* (2009). It is observed that 14 percent of nitric oxide and methane is coming from the agriculture sector and 18 percent is due to deforestation for agriculture use.

Season and location really matters for the production in agriculture sector. African crops are more sensitive to marginal change in temperature as compare to change in precipitation. For African crops temperature rise has positive effects, while reduction in rainfall negatively affects net revenues. These observations were based on seven African field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean) of 300 districts in South Africa [Gbetibouo (2005)]. Study also suggested that one can shift the growing season of a crop according to temperature but there is a possibility that, this type of action may lead to complete elimination of some crops of some regions.

The agriculture sector in Pakistan plays a pivotal role as the income of more than 47 percent of the population is dependent on this sector. This sector is under threat from climate change. It is projected that temperatures will increase by 3°C by 2040 and 5°C to 6°C by the end of this century. Due to this scenario, Asia can lose 50 percent of its wheat production [MOE (2009)]. Moreover, agriculture sector of Pakistan is more vulnerable to climate change because of its geographical location [Janjua, *et al.* (2011)]. This study explains that due to anthropogenic activities, temperature of earth is rising and it may have negative effect on the production of wheat. Using Vector Auto Regressive (VAR) model on the annual data from 1960 to 2009, the study did not find significant negative impact of climate change on wheat production in Pakistan. However, on the other hand, Shakoor (2011) found significant negative impact of temperature-rise on agriculture production and also found the positive impact of rain fall on agriculture production. Analyses were based on the wheat crop and study concluded that the negative impact of temperature is greater than the positive impact of rainfall for Pakistan. The authors also estimated cost of arid regions due to 1 percent increase in temperature, which came to Rs 4180/- to the net revenue per annum.

1.1. Objectives of the Study

The objective of present study is to investigate the impact of climate (through changes in temperature and precipitation) on four major crops namely; Wheat, Rice, Cotton and Sugarcane in the Punjab Province of Pakistan. Estimations based on the time series data from 1980-2008. The study also makes projections regarding the effects of changes in temperature and precipitation on the crops production. This is the first study incorporating scientific information on the stages of development of each crop in order to assess the impact of climate change on each stage of the crops.

1.2. Organisation of the Study

Section 1 of this study includes definition of key terms, problem and objectives. Section 2 describes data description and methodology. Section 3 covers empirical estimations and results. Section 4 concludes the study with recommendations and finally Section 5 describes the limitation of the study.

2. DATA AND METHODOLOGY

2.1. Data Description

The analysis is carried out using the data of four major crops namely Wheat, Rice, Cotton and Sugarcane form the province of Punjab. The scientific information of production stages of these crops and its optimal temperature and precipitations were taken from the Pakistan Agricultural Research Council (PARC), Rice Research Institute, Kala Shah Kaku, Cotton Research Institute, Faisalabad, and Sugarcane Research Institute, Faisalabad respectively. For each of the crops analysis the station wise selection of the districts were made according to their productivity e.g. the districts were varied from crops to crops depending on their productivity size.

The wheat and rice production has been consists of three different stages of production and of three different optimal temperature and precipitations. The optimal temperature of the cotton production remain the same therefore, scientifically it has not been divided into different production stages. Similarly, the sugarcane production has been divided into four different production stages that of their optimal temperature and precipitations. The data on districts wise productivity of each crop were taken from statistical year book of Ministry of Agriculture, the data on temperature and precipitation were taken from the department of Metrology. We faced many problems in unbalance panel; therefore we use the balance panel design for the year 1980–2009.

2.2. Specification of the Model

Fixed Effect Model (FEM) is used on the base of the balanced data design, the dependent variable is Crops (Wheat, Rice, Cotton, Sugarcane) productivity and explanatory variables are first stage temperature (FT), second stage temperature (SST), third stage temperature (TST), fourth stage temperature (FST), first stage precipitations (FP), second stage precipitation (SSP), third stage precipitation (TSP), fourth stage precipitation (FSP). In order to capture the nonlinearity impact, we have included squared term for these variables

The general equation of this study is

$$Crops_{\,w,\,r,\,c,\,s} = f\,(FT, FT^2, SST, SST^2, TST, TST^2, FST, FST^2, FP, FP^2, SSP, SSP^2, TSP, TSP^2, FSP, FSP^2)$$

$$(Crops)_{it} = \alpha_i + \beta_1\,(FT)_{it} + \beta_2\,(FT^2)_{it} \text{ -------- } + \beta_n\,(Tem, Pre)_{it} + V_{it}$$

$$(i = 1, 2 \ldots N;\ t = 1, 2 \ldots T)$$

$$V_{it} = \mu_i + \sum W_{it}$$

V_{it} is composite error term, and μ_i is unobservable individual country specific effects and $\sum w_{it}$ is other disturbances.

3. ESTIMATION RESULTS

In this section, we put forward the estimation results of the four crops and discuss the results in detail. Section 3.1 discusses the results of wheat crop in the Punjab province. The results for rice crop are presented in Section 3.2. The impact of climate change on cotton crop is inspected in Section 3.3. Section 3.4 discusses the impact of climate change on sugarcane. The last section discusses the simulation results for various scenarios changes in temperature.

3.1. Wheat Production

This section discusses the estimation results of wheat crop in Punjab province. The cropping period for wheat is from December to April. Consequently, we have divided the cropping period in three stages due to different requirement of temperature and precipitation for each stage. The first stage covers the month of December whereas the second stage consists of the period from January to March. The third stage again consists of only one month, namely, April. The estimation results are presented in Table 1.

Table 1

Estimation Results for Wheat Production

Variable	Model 1	Model 2
Contant	749.56***	730.09***
First Stage Temperature	–43.11***	–46.95***
First Stage Temperature ^2	1.45***	1.66**
Second Stage Temperature	–4.58	
Second Stage Temperature^2	0.16	
Third Stage Temperature	0.09	
Third Stage Temperature^2	–0.0004	
First Stage Precipitation	0.44***	0.45***
First Stage Precipitation^2	–0.002**	–0.002*
Second Stage Precipitation	0.34***	0.39***
Second Stage Precipitation^2	–0.002**	–0.002***
Third Stage Precipitation	–0.006	–0.06
Third Stage Precipitation^2	–0.0002	0.0001
Bahawalpur	306.21***	302.72***
Faisalabad	338.69***	339.52***
Jhelum	–325.69***	–324.47***
Lahore	–324.13***	–325.37***
Mianwali	–108.92***	–108.37***
Multan	41.65***	42.17***
Sialkot	72.18***	73.80***
R^2	0.90	0.90
DW-Statistic	1.98	1.98
F-Statistic	58.22***	77.24***

Note: ***, ** and * represents significance at 1 percent, 5 percent and 10 percent level of significance respectively.

Table 1 shows the results of two models estimated for identifying the impact of temperature and precipitation on wheat crop. In the first model, both temperature and precipitation have been used along with their square terms, assuming a non-linear relationship between the variables. The results of this model show that temperature affect wheat crop non-linearly only in first stage of production. Surprisingly, this non-linear relationship is of U-shaped type. This means that after the temperature of 14.76°C, further increase in temperature will positively affect wheat crop. In the second and third stages of production, however, variations in temperature have insignificant effect on wheat production. On the other hand, the precipitation has significant non-linear relationship with wheat crop in the first two stages of production. The optimal precipitations for the first two stages are 111 mm and 84.50 mm respectively. That is, beyond these optimal limits, further precipitation will adversely affect growth of plant and it's fruiting. As was the case with temperature, in the third stage precipitation does not affect wheat crop.

The constant term (intercept) shows the average production of the seven districts included in the model due to district specific characteristics whereas the coefficients of district dummies show deviations from this mean production. The significance of coefficients of these dummies variables indicates that district specific characteristics do have significance in the production of wheat crop. These results shows that, Jhelum, Lahore and Mianwali respectively produce 325.69, 324.13 and 108.92 thousand tonnes less, whereas, Bahawalpur, Faisalabad, Multan and Sialkot respectively produce 306.21, 338.69, 41.65 and 72.18 thousand tonnes more than the average production (which is 749.56). The model performed well on represented by F-Stats, significance of the model.

In the second model, the insignificant terms of temperature for the second and third stage were dropped from estimation. The results confirm the robustness of coefficients in terms of both sign and significance. It is also evident from the table that values of coefficients are not volatile either. This model also confirms that the positive effect of temperature in the first stage starts from 14.14°C. Likewise, the optimal precipitations for the first two stages are 112 mm and 97 mm respectively. Similarly, the deviation of district dummies variables from the mean is not significant and the sign and significance of the coefficient of these dummies have not changed. The DW statistics confirms the absence of serial correlation problem and F-stats shows the overall significance of the model.

3.2. Rice Production

This section explores the impact of climate change on rice production in the seven districts of Punjab province. The crop period for rice in Punjab consists of four months, from August to November. There are three main stages of production for rice crop, namely, Germination, Flowering and Ripening. Accordingly, we have classified time period of rice crop production in three stages. The first stage consists of the month of August, while the September and October jointly constitute the second stage. Third stage reaches in the month of November. The estimation results for rice crop are presented in Table 2.

Table 2

Estimation Results for Rice Production

Variable	Model 1	Model 2
Contant	83.64***	96.00***
First Stage Temperature	2.70*	1.70*
First Stage Temperature ^2	–0.05*	–0.03**
Second Stage Temperature	–5.35***	–5.06***
Second Stage Temperature^2	0.10***	0.09***
Third Stage Temperature	0.12	0.65
Third Stage Temperature^2	0.02	–0.005
First Stage Precipitation	0.004	
First Stage Precipitation^2	–0.00001	
Second Stage Precipitation	0.0093	
Second Stage Precipitation^2	–0.0001	
Third Stage Precipitation	–0.032	
Third Stage Precipitation^2	0.0003	
Bahawalpur	–58.51***	–58.62***
Faisalabad	–45.56***	–47.19***
Jhelum	–60.18***	–61.40***
Lahore	–10.04***	–10.00***
Mianwali	–56.08***	–56.78***
Multan	–44.63***	–44.63***
Sialkot	275.03***	278.64***
R^2	0.96	0.95
DW-Statistic	2.09	2.00
F-Statistic	175.28***	193.90***

Note: ***, ** and * represents significance at 1 percent, 5 percent and 10 percent level of significance respectively.

Two models have been estimated to investigate the impact of climate change on rice production as shown in Table 2. In the first model, both temperature and precipitation have been used with their square terms to inspect the non-linear impact of these variables. The results of this model confirm the notion that temperature affect rice crop non-linearly in first two stages of production. Accordingly, a rise in temperature is beneficial for rice production initially, in the first stage. However, beyond a certain optimal temperature 27°C for the first stage, further increase in temperature becomes harmful for production. In the second stage, however, the non-linear relationship is of U-shaped. Initially, a rise in temperature is harmful for production, but beyond a certain temperature limit (which is 26.75°C) the effect becomes positive. This outcome may be a result of overlapping of different stages of growth of the plant due to our classification of these stages using monthly data, as both low and high temperatures are harmful for production [Chaudhary, *et al*. (2002)]. The third stage of production is not affect by increase in temperature. It means that, for Punjab, the temperature for the third stage remains in the optimal limits for the entire period of this stage. The average temperature for included districts of Punjab is 22 degree centigrade, whereas the optimal required temperature for this stage ranges from 20°C-25°C [Chaudhary, *et al*. (2002)].

An interesting result is the insignificance of precipitation for rice production in all the stages. This result is, however, justifiable on the grounds that the annual precipitation in Pakistan is less [only 20 mm] than the optimal required precipitation [which is 40mm on the lower bound] for rice production. This deficiency has been met by the artificial arrangements of irrigation water through canals and tube wells, thereby reducing the dependency on rainfall. For 75 days [which is almost the first two stages], the rice fields should have 6 mm of slow moving water. However, the water requirement gradually decreases during the maturity period of crop. This maturity period is the third stage of production, which is in the month of November in our case. The data shows that the average rainfall during this month is only 5 mm and, hence, may not be harmful for the crop. In a nutshell, we may say this climate variable is irrelevant for rice crop in the sense that both neither the lower nor the upper levels of precipitation are harmful. The lower precipitation is covered by irrigation methods and the upper level does not reach at all.

Lastly, the significance of district dummies confirms the fact the production of rice crop does respond to district specific characteristics. The intercept term in the model represents the mean rice production of these seven districts, whereas coefficients of district dummies show the deviation from this average production. It is evident from the results that, except for Sialkot, all other districts produce less rice than the average production. The R^2 and F-Stats validate the significance of the overall model.

In the second estimation, the insignificant variable precipitation has been dropped from the model from all stages of production. The results are robust as only first two stages of production are affected by change in temperature. In addition, all the district dummies are also significant. Hence, one may easily conclude that these results are robust in terms of values, signs and significance for all the parameters. The optimal temperature for the first stage is 28.33°C in the respective case. Whereas, the positive effect of temperature in the second stage starts beyond 28.11°C. The differences between these temperatures between the two models are 1.33°C and 1.36°C respectively for the two stages. However, these optimal temperatures in both the models for both stages are consistent with optimal required temperature determined scientifically in literature [see for example, Chaudhary, *et al*. (2002) for details][1]. Again, the R^2 and F-stats confirm the significance of the overall model.

3.3. Cotton Production

The underlying section deals empirically with the impact of climate change on cotton production. The period for cotton crop in Punjab is from May to September. Since the optimal temperature and precipitation requirement is same for the whole period of crop production. We have not made different stages of production for cotton. The maximum temperature and precipitation required for cotton crop during the production period is 32°C and 40mm respectively.[2] Since the data shows obvious deviation from the

[1]Chaudhary, *et al.* (2002) gives the optimal temperatures range from 20°C-35°C for the first stage, where as 25°C-31°C for the second stage. However, based on our results, we may say that the starting pint of the optimal temperature range varies between 26.75°C from 28°C in the second stage.

[2]Arshad and Anwar [undated] in their online article titled “Best Methods/ Practices to Increase per Acre Cotton Yield” on the website of Ministry of Textile Industry gives the maximum temperature range of 30°C-35°C. However, other online sources have consensus upon the maximum limit of 32°C.

maximum limits for both variables, we take the deviation from maximum limits for purpose of estimation. This is in contrast to what we have done for wheat and rice crops where the historical data appeared to lie in the optimal limits and no clear deviations from maximum limits of either variable were observable. In the following lines we discuss the estimation results for cotton production.

Table 3 represents the results of impact of climate change on cotton production in five districts of Punjab province. Two models have been estimated for this purpose. Model 1 is estimated for investigating the non-linear relationships between the cotton production and climate variables namely changes in temperature and precipitation. The results of model 1 show that square terms of both the variables are statistically insignificant, suggesting that the relationship is linear. For this purpose, the square terms of these variables are dropped in the second model and a linear relationship is estimated. It is evident from the table that the coefficients all the variables (including districts dummies) are robust both in terms of sign and significance. Moreover, the values of the coefficients are not volatile either. It is important to mention that these results are presented after correcting for the problems of autocorrelation and heteroscedasticity. The overall models, represented by F-tests, are statistically significant at the conventional level of significance.

Table 3

Estimation Results for Cotton Production

Variable	Model 1	Model 2
Constant	411.42***	403.52***
DFMT	–47.46**	–42.33**
DFMT^2	–2.60	
DFMP	–1.46*	–0.50*
DFMP^2	0.007	
Bahawalpur	720.36***	735.1092***
Faisalabad	–286.06***	–289.203***
Jhelum	–397.61***	–406.731***
Mianwali	–338.28***	–355.775***
Multan	301.60***	316.5995***
R^2	0.95	0.95
DW-Statistic	1.98	1.98
F-Statistic	208.74***	264.70***

Note: DFMT = Deviation from Maximum Temperature, DFMP = Deviation from Maximum Precipitation. ***, ** and * represents significance at 1 percent, 5 percent and 10 percent level of significance respectively.

As is mentioned in the above lines, the climate variables are taken in the form of deviation from standard maximum required levels. Therefore, one should be careful in interpreting these results. Since the second model is the best one in terms of explaining the true relationship, we interpret the results of this model. The results indicate that a one degree centigrade deviation of temperature from the maximum required level (which is 32C) during the whole period reduces the production of cotton by 42.33 thousands bales. Similarly, a one millimetre deviation of precipitation from the maximum required level (which 40 mm) reduces the production of cotton by 0.50 thousands bales. This is a significant loss in the production of cotton due to change in the climate variables. The reduction in production due to both the variables indicates the climate change has been harmful for cotton production in this region.

Before explain the district dummies, it is worthwhile to recall that constant term in the model shows the mean production of the five districts. Consequently, the coefficients of the district dummies should be interpreted as deviation from this mean. The results show the mean production of cotton (after controlling for districts specific characteristics) is 403.52. Thus, the Bahawalpur and Multan districts produce more cotton (735.10 and 316.60 thousands bales respectively) than the mean production. On the other hand, in Faisalabad, Jhelum and Mianwali districts cotton production is lower than the average production. These results should not be surprising as cotton production in these three districts is significantly lower than production in Bahawalpur and Multan districts. For example, the average production of cotton during period 1987-2008 in Bahawalpur and Multan was 992 and 800 thousand bales respectively. Whereas, for the same period, the average production for Faisalabad, Jhelum and Mianwali was 105.5, 0.35, and 13.76 thousand bales only. The significance of district dummies, however, indicates that the district specific characteristics do have important impact on cotton production.

3.4. Sugarcane Production

Finally, in this section we are computing the impact of climate and precipitation change on the sugarcane production in seven districts namely Bahawalpur, Faisalabad, Jhelum, Mianwali, Sialkot, Lahore and Multan which are the prone cultivated areas of sugarcane in Pakistan. In Pakistan the sugarcane harvesting consists of two seasons. The cultivation of sugarcane crop starts in Feb-December. The production time is about nine month. However, 30 percent harvesting of crop is in Sept-December with its total duration of 14 months. The mill owners prefer this crop due to the high quality of sugarcane production as compare to the 9 months crop but the farmers enduring 9 month crop so that the land can be ready for wheat crops otherwise they have to forgo the wheat production. Similarly, globally two methods are pertinent for its harvesting e.g. firstly, by germination and secondly, by sowing seeds. Our farmers are using the first method as the second method normally takes two years to germinate.

With the consultation of the Sugarcane Research Institute, Faisalabad we divided the sugarcane production into four stages of production. These are: Germination of duration 45 days, tillering of duration of 90 days, vegetative of duration 90 days and maturing normally 60-75 days.

First stage:	Optimum temperature for sowing	: 20-32^{0}C
	Optimum temperature for germination	: 32-28^{0}C
Second stage:	Maximum temperature decreasing tillering	: 30^{0}C
Third stage:	Optimum temperature for sugarcane	: 28-38^{0}C
Fourth stage:	Temperature for good sugar production	: 10^{0}C

For the 9 months duration 22 times irrigation are required for good sugarcane production. The optimum rainfall for sugarcane is: 1250-2500 mm.

The results of Table 4 show that the increase in temperature in the first three stages of production are highly insignificant. If temperature rises in the first stage up to 28^0C the temperature has positive impact on sugarcane production but beyond 28^0C up to 32^0C it becomes negative. In the second stage the temperature beyond 30^0C would cause decreasing the telliring the square of the temperature becomes positive but its magnitude is minimal. The most important and vulnerable stage is third or vegetative stage of sugarcane production, the coefficients of the estimation shows that initially the increase in temperature causes increase in productivity which may be possibly the optimal temperature ranged from 28-38^0C in this stage but the square of temperature results in negative productivity. Finally, the maturity is the fourth and last productivity stage of production. The sweetness starts in this stage of production, which requires minimum temperature.

Table 4

Estimation Results for Sugarcane Production

Variable	Results
Constant	–30892.39**
First Stage Temperature	165.41
First Stage Temperature ^2	–3.85
Second Stage Temperature	–1.92
Second Stage Temperature^2	0.079
Third Stage Temperature	133.58
Third Stage Temperature^2	–2.65
Fourth Stage Temperature	2491.88**
Fourth Stage Temperature^2	–54.35**
First Stage Precipitation	4.11
First Stage Precipitation^2	–0.026
Second Stage Precipitation	–5.28
Second Stage Precipitation^2	0.074
Third Stage Precipitation	2.00
Third Stage Precipitation^2	–0.0039
Fourth Stage Precipitation	–2.73
Fourth Stage Precipitation^2	0.013
Bahawalpur	–402.95**
Faisalabad	4656.8**
Jhelum	–960.94**
Lahore	–889.71**
Mianwali	–820.44**
Multan	–789.13**
Sialkot	–793.61**
R^2	0.98
DW-Statistic	1.80
F-Statistic	235.70***

Note: ***, ** and * represents significance at 1 percent, 5 percent and 10 percent level of significance respectively.

The increase in temperature in these months would reduce the sweetness and ultimately the yields. The optimal temperature required in this stage is 10^0C, in the first stage the increase in temperature has negative impact on sugarcane productivity/yield. The further increase e.g. the square of the temperature again has positive but minimal effect on productivity/yields. It is important to mention that these results are presented after correcting for the problems of autocorrelation and heteroscedasticity. The overall models, represented by F-tests, are statistically significant at the conventional level of significance.

3.5. Simulation Analysis

The results of the simulations analysis for these four major crops are annexed. The simulations analysis carried out from 2008 to 2030. It covers almost one-generation period. The simulations results for wheat production in (000) tonnes shows that the when the temperature increases by 1C the cumulative loss up to 2030 would be 0.02 percent and if the temperature increases by 2C the cumulative loss up to 2030 would be 0.75 percent that of 2008. Moreover, the results for simulation analysis of rice production in (000) tonnes shows that when temperature increases by 1C the respective gain to rice productivity up to 2030 would be 1.85 percent and if the temperature increases by 2C the rice productivity gain would by 3.95 percent.

The simulation results for cotton production (000) bales with increase of 1C and 2C shows that the loss to cumulative cotton production up to 2030 is 13.29 percent and 27.98 percent respectively. Finally, for the same increase of 1C and 2C the sugarcane (000) bales, cumulative loss up to 2030 are 13.56 percent and 40.09 percent respectively.

4. CONCLUSION

The study focuses on the impact of on changes in climate change indicators on production of four major crops in Punjab, Pakistan. The results show that in the short run the increase in temperature is expected to affect the wheat productivity but in long term the increase in temperature has positive affect on wheat productivity. Similarly, the increase in precipitation has negative impact in both short and long term. A rise in temperature is beneficial for rice production initially. However, beyond a certain optimal temperature, further increase in temperature becomes harmful for rice production. Interestingly, the increase in precipitation does not harm the rice productivity. It has been evident that the change in climate variables (temperature, precipitation) has a significant negative impact on production of cotton. Finally, the increase in temperature also harms the sugarcane productivity in long term.

The major conclusions of the study are:

First: The impact of changes in temperature and precipitation varies significantly with the timing and production stages of the crops.

Second: The impact varies from crop to crop.

Finally: The districts variations in crop productivity are significant.

5. LIMITATION OF THE STUDY

The limitations are:

(1) The analysis is limited to the province of Punjab; we are in the process of finalising the results for other provinces of Pakistan.

(2) The study considers two important climate change variables namely temperature and precipitation but other explanatory variables like humidity, soil fertility, and other inputs variables are not consider due to non-availability of districts wise data. A district level survey is required to include these variables in the analysis.

(3) The simulation analyses consider temperature increases by 1C and 2 C respectively, and the precipitations scenarios are kept constant. The simulation results for precipitation are in the process.

ANNEX

Simulation Results for Wheat Production (000 tonnes)

Years	Temperature 1C	Wheat Production	Year Wise Gain	Cumulative Gain	Temperature 2C	Wheat Production	Year Wise Gain	Cumulative Gain
2008		63.24209				63.24209		
2009		63.29225	0.050168	0.050168		63.34273	0.100643	0.100643
2010		63.34273	0.050475	0.100643		63.4446	0.101872	0.202515
2011		63.39351	0.050783	0.151426		63.5477	0.103101	0.305617
2012		63.4446	0.05109	0.202515		63.65203	0.104331	0.409948
2013		63.496	0.051397	0.253913		63.75759	0.10556	0.515507
2014		63.5477	0.051704	0.305617		63.86438	0.106789	0.622296
2015		63.59971	0.052012	0.357629		63.9724	0.108018	0.730315
2016		63.65203	0.052319	0.409948		64.08165	0.109247	0.839562
2017		63.70466	0.052626	0.462574		64.19212	0.110477	0.950039
2018		63.75759	0.052934	0.515507		64.30383	0.111706	1.061745
2019		63.81083	0.053241	0.568748		64.41677	0.112935	1.17468
2020		63.86438	0.053548	0.622296		64.53093	0.114164	1.288844
2021		63.91824	0.053855	0.676152		64.64632	0.115393	1.404237
2022		63.9724	0.054163	0.730315		64.76295	0.116623	1.52086
2023		64.02687	0.05447	0.784785		64.8808	0.117852	1.638712
2024		64.08165	0.054777	0.839562		64.99988	0.119081	1.757793
2025		64.13673	0.055085	0.894647		65.12019	0.12031	1.878103
2026		64.19212	0.055392	0.950039		65.24173	0.121539	1.999642
2027		64.24782	0.055699	1.005738		65.3645	0.122769	2.122411
2028		64.30383	0.056007	1.061745		65.48849	0.123998	2.246408
2029		64.36014	0.056314	1.118058		65.61372	0.125227	2.371635
2030		64.41677	0.056621	1.17468		65.74018	0.126456	2.498091
				% Gain				**% Gain**
				1.857433				**3.950046**

Simulation Results for Cotton Production (000 Bales)

Years	Temperature 1C	Cotton Production	Year Wise Loss	Cumulative Loss	Temperature 2C	Cotton Production	Year Wise Loss	Cumulative Loss
2008		371.9732				371.9732		
2009		369.8384	2.134754	2.134754		367.6929	4.280251	4.280251
2010		367.6929	2.145498	4.280251		363.3697	4.323226	8.603478
2011		365.5367	2.156241	6.436493		359.0035	4.366202	12.96968
2012		363.3697	2.166985	8.603478		354.5943	4.409177	17.37886
2013		361.192	2.177729	10.78121		350.1422	4.452152	21.83101
2014		359.0035	2.188473	12.96968		345.6471	4.495127	26.32614
2015		356.8043	2.199217	15.1689		341.109	4.538102	30.86424
2016		354.5943	2.20996	17.37886		336.5279	4.581078	35.44532
2017		352.3736	2.220704	19.59956		331.9038	4.624053	40.06937
2018		350.1422	2.231448	21.83101		327.2368	4.667028	44.7364
2019		347.9	2.242192	24.0732		322.5268	4.710003	49.4464
2020		345.6471	2.252936	26.32614		317.7738	4.752979	54.19938
2021		343.3834	2.263679	28.58981		312.9779	4.795954	58.99533
2022		341.109	2.274423	30.86424		308.1389	4.838929	63.83426
2023		338.8238	2.285167	33.1494		303.257	4.881904	68.71617
2024		336.5279	2.295911	35.44532		298.3322	4.924879	73.64104
2025		334.2212	2.306655	37.75197		293.3643	4.967855	78.6089
2026		331.9038	2.317398	40.06937		288.3535	5.01083	83.61973
2027		329.5757	2.328142	42.39751		283.2997	5.053805	88.67353
2028		327.2368	2.338886	44.7364		278.2029	5.09678	93.77031
2029		324.8872	2.34963	47.08603		273.0631	5.139755	98.91007
2030		322.5268	2.360374	49.4464		267.8804	5.182731	104.0928
				%Loss				**%Loss**
				13.293				**27.98385**

Simulation Results for Sugarcane Production (000 Tonnes)

Years	Temperature 1C	Sugarcane Production	Year Wise Loss	Cumulative Loss	Temperature 2C	Sugarcane Production	Year Wise Loss	Cumulative Loss
2008		936.464				936.464		
2009		933.3288	3.135187	3.135187		929.9425	6.521487	6.521487
2010		929.9425	3.3863	6.521487		922.4166	7.525939	14.04743
2011		926.3051	3.637413	10.1589		913.8862	8.530391	22.57782
2012		922.4166	3.888526	14.04743		904.3514	9.534843	32.11266
2013		918.277	4.139639	18.18707		893.8121	10.5393	42.65196
2014		913.8862	4.390752	22.57782		882.2683	11.54375	54.1957
2015		909.2443	4.641865	27.21968		869.7201	12.5482	66.7439
2016		904.3514	4.892978	32.11266		856.1675	13.55265	80.29656
2017		899.2073	5.144091	37.25675		841.6104	14.5571	94.85366
2018		893.8121	5.395204	42.65196		826.0488	15.56156	110.4152
2019		888.1658	5.646317	48.29827		809.4828	16.56601	126.9812
2020		882.2683	5.89743	54.1957		791.9123	17.57046	144.5517
2021		876.1198	6.148543	60.34425		773.3374	18.57491	163.1266
2022		869.7201	6.399656	66.7439		753.7581	19.57936	182.706
2023		863.0694	6.65077	73.39467		733.1742	20.58382	203.2898
2024		856.1675	6.901883	80.29656		711.586	21.58827	224.8781
2025		849.0145	7.152996	87.44955		688.9933	22.59272	247.4708
2026		841.6104	7.404109	94.85366		665.3961	23.59717	271.0679
2027		833.9551	7.655222	102.5089		640.7945	24.60163	295.6696
2028		826.0488	7.906335	110.4152		615.1884	25.60608	321.2756
2029		817.8914	8.157448	118.5727		588.5779	26.61053	347.8862
2030		809.4828	8.408561	126.9812		560.9629	27.61498	375.5012
				% Loss				**% Loss**
				13.56				**40.098**

Simulation Results for Rice Production (000 Tonnes)

Years	Temperature 1C	Rice Production	Year Wise Loss	Cumulative Loss	Temperature 2C	Rice Production	Year Wise Loss/ Gain	Cumulative Loss/ Gain
2008		407.1121				407.1121		
2009		407.0383	0.073766	0.073766		406.9713	–0.14085	–0.14085
2010		406.9713	0.067084	0.14085		406.8571	–0.11412	–0.25497
2011		406.9109	0.060401	0.201251		406.7697	–0.08739	–0.34236
2012		406.8571	0.053718	0.254969		406.7091	–0.06066	–0.40302
2013		406.8101	0.047036	0.302005		406.6752	–0.03393	–0.43695
2014		406.7697	0.040353	0.342358		406.668	–0.0072	–0.44415
2015		406.7361	0.033671	0.376029		406.6875	0.019531	–0.42461
2016		406.7091	0.026988	0.403018		406.7338	0.046261	–0.37835
2017		406.6888	0.020306	0.423323		406.8067	0.072991	–0.30536
2018		406.6752	0.013623	0.436947		406.9065	0.099721	–0.20564
2019		406.6682	0.006941	0.443888		407.0329	0.126451	–0.07919
2020		406.668	0.000258	0.444146		407.1861	0.153182	0.073992
2021		406.6744	–0.00642	0.437722		407.366	0.179912	0.253904
2022		406.6875	–0.01311	0.424615		407.5727	0.206642	0.460545
2023		406.7073	–0.01979	0.404826		407.806	0.233372	0.693917
2024		406.7338	–0.02647	0.378354		408.0661	0.260102	0.954019
2025		406.7669	–0.03315	0.345199		408.353	0.286832	1.240851
2026		406.8067	–0.03984	0.305362		408.6665	0.313562	1.554413
2027		406.8533	–0.04652	0.258843		409.0068	0.340292	1.894705
2028		406.9065	–0.0532	0.205641		409.3738	0.367022	2.261728
2029		406.9663	–0.05988	0.145757		409.7676	0.393752	2.65548
2030		407.0329	–0.06657	0.07919		410.1881	0.420483	3.075963
				% Loss				**% Gain**
				0.01945				**0.755557**

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