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Impact of Climate Change on Wheat Productivity in Pakistan: A District Level Analysis

Munir Ahmad
Hasan Siftain
Muhammad Iqbal

Pakistan Institute of Development Economics
Spirit of Free Inquiry
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Islamabad

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Munir Ahmad
Pakistan Institute of Development Economics, Islamabad

Hasan Siftain
Pakistan Institute of Development Economics, Islamabad

and

Muhammad Iqbal
Pakistan Institute of Development Economics, Islamabad

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Pakistan Institute of Development Economics
Islamabad, Pakistan

E-mail:
Website: http://www.pide.org.pk
Fax: +92-51-9248065

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ABSTRACT

This study analyses the impact of climate change on wheat productivity in Pakistan by employing production function approach using districts level data for the period of 1981-2010.The Fixed Effect (FE) estimations support the evidence that an increase of 1^{0}C in the mean temperature during sowing time would reduce crop yield by 7.4 percent. The same rise in mean temperature in January and February enhances wheat productivity to the tune of 6.2 percent. However, no significant impact of rise in temperature normals during the maturity stage (March-April) was observed on wheat productivity. The deviations of mean temperature from historic (long run) mean—weather shocks are found posing no threat to wheat productivity during the period under study. Precipitation normals—during vegetative and maturity stages and their deviations from historic mean (positive) exert a positive impact on the wheat yield but the magnitude of the impact of incremental rains came out to be very low.

Keywords: Agriculture, Wheat Yield, Climate Change, Growth Stages, and District Level Panel Data

1. INTRODUCTION

The ecology of Pakistan is suitable for growing a large variety of crops. Wheat, a staple food, is one of the most important crops from national food security point of view and is grown during the winter season (*rabi*) at more than $2/3^{rd}$ of the farms and accounts for about $1/3^{rd}$ of the total cultivated area in the country. Thus, not only food security of millions of farmers and landless rural inhabitants is dependent on wheat output levels but also it is a major source of their livelihood.

Studies show that wheat crop is under climate change stress and the Green Revolution technology potential has already been exploited in Pakistan—yield growth rates declined from over 7.2 percent per annum in early 1970s to around 2 percent in recent years. Sivakumar and Stefanski (2011) reported that an increase of 1^{0}C in temperature would reduce wheat yield by 5. 7 percent in Pakistan, while Leads (2009) foresees over 40 percent decline in wheat yield by 2035.

Although, the impact analysis of climate change on agriculture attracted attention of the scientific community very

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Munir Ahmad <munir@pide.org.pk> is Joint Director, Hasan Siftain <hasan.sfn@gmail.com> was Junior Researcher when this paper was written, Muhammad Iqbal is Chief of Research at the Pakistan Institute of Development Economics (PIDE), Islamabad, Pakistan.

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recently in Pakistan, fairly good number of empirical studies are available in the literature which explore the relationship between climate change and agricultural productivity in various regions and countries. However, results of most of the studies are in disagreement. Various empirical studies found that climate change is adversely affecting agricultural productivity and projected very alarming situation during the days to come [Tubiello, *et al.* (1995), Mendelsohn and Dinar (1999), Chang (2002), Tubiello, *et al.* (2002), Luo, *et al.* (2003), Ludwig and Asseng (2006), Lobell, *et al.* (2007), and You, *et al*. (2009)]. On the other hand, studies like Magrin, *et al.* (1998), Gbetibouo and Hassan (2005), Magrin, *et al.* (2005), and Lobell, *et al.* (2005) found that climate change is rather beneficial for agricultural yields. A strand of literature on the issue indicated that the climate change is not uniformly affecting agricultural productivity in different countries and regions and that the impact varies within a country [e.g. Kurukulasuriya and Ajwad (2004); Schlenker, *et al*. (2005); and NDRC (2007)].

The empirical studies conducted by using data from Pakistan are in no way more conclusive than those undertaken elsewhere in the world. Shakoor, *et al.* (2011) reported that rise in temperature affects agriculture adversely. Hanif, *et al.* (2009) concluded that the impact of climate change is not uniform across seasons (*Rabi and Kharif*) in Punjab. Janjua, *et al*. (2011) found no evidence of a significant impact of climate change on wheat production in Pakistan whereas Ashfaq, *et al*. (2011) concluded that climatic variables play more dominant role in explaining the variations in wheat productivity than the non-climatic variables. Similarly, Siddiqui, *et al.* (2012) supported non-negative impact of climate change on wheat production in Punjab. In another study regarding 13 Asian countries including Pakistan, Lea, *et al.* (2012) found that higher temperature and precipitation during summer increases agricultural production in tropical Asian countries, while warming up of fall season reduces production—the net effect however is negative in Asia.

Some of these studies used either annual climate data [Shakoor, *et al*. (2011)] or average of the growing season [Janjua, *et al*. (2011); and Hanif, *et al.* (2009)]. Most of these studies missed non-climate variables—like agricultural inputs and technology, considered only selected districts of Punjab, applied linear models—may not be suitable for agricultural data, and used only the current values of climatic variables—capturing only the weather variations/shocks, for estimating the impact of climate change on agriculture. We believe that these studies may have either overestimated or underestimated the climate impacts on agriculture.

Against this backdrop, the major objective of this study is to estimate the impact of climate change on productivity of wheat in Pakistan. This study covers all the major wheat producing districts existing as independent administrative units in 1980-81 and for which the original meteorological data were available since early 1960s. Nonetheless, these districts represent all cropping systems prevailing in the country fairly well. This research also incorporates climate as well as non-climatic explanatory variables and differentiates between the effects of climate change and weather shocks on wheat productivity. More importantly, we have also tried to corroborate the results obtained from quantitative analyses using district-level time-series data through field observations, opinions, and information gathered by a comprehensively conducted Rapid Rural Appraisal in selected agro-ecologies/ cropping systems of Pakistan. On these accounts, it can safely be said that the present study contributes to the existing literature by enlarging the scope of work and the nature of analysis.

The rest of the paper is organised in the following manner. The Introduction is followed by Section 2 that deals with the data and empirical model. The results are discussed in Section 3, and Section 4 concludes the paper.

2. THE DATA AND THE EMPIRICAL MODEL

2.1. The Data

This study uses data for 19 major wheat producing districts of Pakistan over the period 1981-2010.[i] The selection of district was based on three considerations namely; (a) presence of meteorological observatory since early 1960s; (b) contribution of the district to wheat production; and (c) the year of creation of the district[ii] (in 1980-81 or earlier). Out of these selected districts, 13 are from Punjab, 3 from Sindh, 2 from Khyber Pakhtunkhwa (KP) and 1 district is from Baluchistan. The district level data regarding crop yield, area and production were taken from Government of Pakistan, Statistics Division, Federal Bureau of Statistics Pakistan (Economic Wing). District level off take of fertiliser (NPK nutrients) was taken from various issues of Provincial Development Statistics and shares of fertiliser used for wheat crop were obtained from National Fertiliser Development Centre (NFDC), Islamabad. The data on climatic variables were obtained from the Pakistan Meteorological Department (PMD), Islamabad.

2.2. The Empirical Model

The previous empirical work that estimated impact of climate change on agriculture can be divided into three categories based on the methodologies used—production function analysis; Ricardian approach; and simulation models. Production function analysis used by Callaway (1982), Decker, *et al.* (1986), and Adams, *et al.*

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[i] The list of these districts include Rawalpindi, Jhelum, Sargodha, Mianwali, Faisalabad, Sialkot, Lahore, Multan, Muzaffargarh, D. G. Khan, Rajanpur, Bahawalpur, Bahawalnagar, Sukker, Nawabshah, Hyderabad, Nasirabad, Peshawar and Mardan.

[ii] Several new districts were created in Pakistan during the period 1981-2010, the statistics regarding these districts for the years prior to their creation were never worked out by the concerned quarters and therefore are not reported. This left us with no choice but to merge the available data in parent districts. In addition, this action also helped in balancing the panel.

(1988) relied on experimental data/production to predict the impact of climate change on agricultural crops. This approach takes an underlying production function and estimates impacts by varying one or more input variables such as precipitation, temperature and carbon dioxide levels. More recently, some studies have[iii] used simulation models like CCSR, AOGCM, PCM, CCCma, CERES, and APSIM-Wheat.[iv] These studies predicted impact of climate change by assuming certain scenarios for temperature, precipitation and CO_2 changes in coming years. The crop simulation approach is an important technique to look into the future changes in climate and their impacts on agriculture. However, it is costly and difficult to implement in developing countries as argued by Kurukulasuriya and Ajwad (2004). The negative impact of climate change predicted using these methods is often exaggerated—since these approaches do not accommodate the crops substitutions and adaptations to climate changes.

Employing icardian Approach (RA) can avoid these biases as it allows crop substitutions and farm-level adaptations [Mendelsohn, *et al*. (1994)]. This method analyses the impact of climate change on value of farmland or net rent instead of yield or total production as is done in traditional approach. Various studies used this approach including Mendelsohn, *et al*. (1994), Mendelsohn and Dinar (1999), Gbetibouo and Hassan (2005), Deressa and Hassan (2009) and Shakoor, *et al.* (2011). Thus the RA appeared to be the most suitable technique to evaluate the impact of climate change on agriculture. However, this approach is also not without fundamental flaws, and has been criticised on various grounds. The major shortcomings of its applications in

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[iii]For details see Tubiello, *et al.* (2002), Luo, *et al*. (2003), Luo, *et al*. (2005), Lobell, *et al.* (2005), Magrin, *et al.* (2005), Lobell, *et al*. (2007), Ludwig, *et al.* (2009), and Lea, *et al.* (2012).

[iv]The Center for Climate Systems Research (CCSR), Atmosphere-Ocean General Circulation Model *(*AOGCM*), Parallel* Climate Model (PCM), Canadian Centre for Climate Modelling and Analysis (CCCma),Crop Estimation through Resource and Environment Synthesis (CERES), Agricultural Production Systems IMulator (APSIM).

developing countries are the absence of proper documentation of agricultural farm values and the existence of imperfect land markets [Gbetibouo and Hassan (2005); and Guiteras (2009)]. Other critics include: Cline (1996)—constant price assumption in RA biases the welfare calculations; Quiggn and Horowitz (1999)—implicitly assuming zero adjustment cost yields lower-bound estimates of the costs of climate change; Darwin (1999)—RA does not take into account the water supply and its availability; and Gbetibouo and Hassan (2005)—RA ignores the costs of adaptation.

In the light of above discussion, this study employs production function approach. General form of the production function can be written as

$$Y_{it} = f(C_{norm}, C_{var}, C_{sqr}, Ar, Fr, Tr) \tag{1}$$

Where, Y_{it} is wheat output per acre (yield) in district i in the year t and C_{norm}, C_{var}, and C_{sqr} are respectively vectors of climatic normals, variations of climatic variables form normals, and squares of climatic normals. The variables Ar, Fr, and Tt respectively denote area under wheat crop, fertiliser use per hectare, and time trend (to control the impact of technological change overtime). All explanatory variables are also observed at time t for district i. However, for simplicity we avoided the subscripts. The Cobb Douglas functional form for the general wheat yield function given in Equation 1 can be rewritten as

$$Y_{it} = e^{\beta 0 + \beta_n C_{norm} + \beta_v C_{var} + \beta_s C_{sqr}} * (Ar)^{\beta a} * (Fr)^{\beta f} * e^{\beta g Tt} * e^{\mu it} \tag{2}$$

Where, β_0 is constant and β_n, β_v, and β_s are vectors of unknown parameters to be estimated that respectively relate to climatic normals, variations of climatic variables from normals, and square terms (climatic variables). The parameters β_a, β_f, and β_g are unknown coefficients associated with area under wheat, fertiliser use and the time trend respectively. The μ_{it} is usual error term with zero mean and σ^2 variance. After taking the natural logarithm *(ln)* on both sides, the Equation 2 can be rewritten in following linear form

$$lnY_{it} = \beta_0 + \beta_n C_{norm} + \beta_v C_{var} + \beta_s C_{sqr} + \beta_a \ \ln(Ar) + \beta_f \ln(Fr) + \beta_g T_t + \mu_{it} \qquad (3)$$

Wheat growing season in Pakistan normally extends from November to end of April covering various crop growth stages (germination/tillering, vegetative growth/flowering, and grain formation/maturing—hereafter referred as stage-1, stage-2, and stage-3). Mostly, wheat crop passes through these growth stages respectively during the periods November-December (ND), January-February (JF), and March-April (MA). We used data for climatic variables (temperature and precipitation) for these three time periods and estimated the following full version of Equation 3 written as:

$$\begin{aligned}\ln Y_{it} = \beta_0 &+ \beta_{TND} (TEMP_{ND}) + \beta_{TJF} (TEMP_{JF}) \\ &+ \beta_{TMA} (TEMP_{MA}) + \beta_{PND}(PRECP_{ND}) \\ &+ \beta_{PJF} (PRECP_{JF}) + \beta_{PMA}(PRECP_{MA}) \\ &+ \beta_{VTND} (VTEMP_{ND}) + \beta_{VTJF}(VTEMP_{JF}) \\ &+ \beta_{VTMA} (VTEMP_{MA}) + \beta_{VPND}(VPRECP_{ND}) \\ &+ \beta_{VPJF} (VPRECP_{JF}) + \beta_{VPMA}(VPRECP_{MA}) \\ &+ \beta_{TND2} (TEMP_{ND})^2 + \beta_{TMA2}(TEMP_{MA})^2 \\ &+ \beta_{PND2} (PRECP_{ND})^2 + \beta_{PJF2}(PRECP_{JF})^2 \\ &+ \beta_{PMA2} (PRECP_{MA})^2 + \beta_{ar} \ln Ar + \beta_f \ln Fr \\ &+\beta_g Tt + \beta_i \Sigma_i D_i + u_{it} \qquad (4)\end{aligned}$$

Where, *TEMP*, *PRECP*, *VTEMP*, and *VPRECP* represent temperature normal, precipitation normal, temperature variation, and precipitation variation respectively and the subscripts of these variables denote the time period representing various growth stages as defined above. D_i represents the dummy variable for *i*th district. The climate normal is defined as the average of about 30 years of weather indicators [Kurukulasuriya and Ajwad (2004) and Gbetibouo and Hassan (2005)]. However, Chang (2002) used 20 years moving average in the analysis. Deschenes and Kolstad

(2011) used five years moving average. Because of non-availability of long enough climatic variables data, we use 20 years moving average to represent climate normals. Different specifications for the climatic variation variables are found in the literature. For example, Mendelsohn, *et al*. (1999) took the difference between highest and lowest monthly precipitation and temperature whereas Chang (2002) used the deviations of seasonal average temperature and precipitation from their corresponding sample means. Following Chang (2002), we took the difference between the average monthly temperature and precipitation from their corresponding historic long-term means.[v] Square of normal temperatures and precipitations are also included in the equation to capture non-linearity of the impact of climate [Mendelsohn and Dinar (1999), Chang (2002), Kurukulasuriya and Ajwad (2004), and Gbetibouo and Hassan (2005)].

3. RESULTS AND DISCUSSION

It is believed that the temperature has increased the world over and precipitation has generally declined and became more erratic. In order to have an idea about how these climatic variables behaved over time during wheat growing season in selected districts of Pakistan, we regressed 20 years moving average of precipitation and temperature on time trend. The overall trends of temperature and precipitation normals are obtained using fixed effects technique. The estimates of trends are presented in Table 1.The results indicate that temperature has generally increased overtime during the November-December (stage-1) with the exception of Sukkur and Mardan where it witnessed declining trend. In most of the districts an increase in the mean temperature (or insignificant change) was observed during the months of January-February (stage-2) however a declining trend of mean temperature during the same months was observed in Mardan,

[v] Studies including Schlenker, *et al*. (2005), Schlenker, *et al*. (2007), Deschenes and Kolstad (2011) used degree days.

D.G. Khan, and Sukkur districts. The mean temperature at wheat growth stage-3 (March-April) witnessed a slightly declining trend in majority of the districts in southern and northern parts of the country whereas an increasing trend in temperature prevailed in central districts of the Punjab during the same months. It can be concluded, in terms of mean temperature during wheat crop season, that the districts of Sargodha, Faisalabad, Multan, Sialkot, Lahore, and Bahawalnagar became warmer and districts of Mardan and Sukkur became cooler during the study period.

Table 1

Trends of Temperature and Precipitation Normals (Slope Coefficient of Time)

		Temperature Normals			Precipitation Normals		
Province	District	Nov-Dec (Sowing)	Jan-Feb (Vegetative)	March-Apr (Maturity)	Nov-Dec (Sowing)	Jan-Feb (Vegetative)	March-Apr (Maturity)
	Northern Punjab						
	Jhelum	0.0227	0.0313	-0.0104 ^{NS}	0.2479	-0.0081^{NS}	0.1275 ^{NS}
	Rawalpindi	0.0281	0.0132	-0.0424	0.2487	-0.0091 ^{NS}	0.1316 ^{NS}
	Central Punjab						
	Sargodha	0.0290	0.0227	0.0218	0.0777	0.2456	-0.1053 ^{NS}
	Mianwali	0.0233	0.0093	-0.0006 ^{NS}	0.1536	0.4982	1.1778
	Faisalabad	0.0828	0.0174	0.0397	-0.0491	0.1108	0.0254 ^{NS}
	Sialkot	0.0229	0.0197	0.0020	0.1094	-0.0646	-0.0707^{NS}
Punjab	Lahore	0.0501	0.0411	0.0309	-0.0821	-0.0864 ^{NS}	-0.3029
	Southern Districts						
	Rajanpur	0.0220	-0.0049 ^{NS}	-0.0294	0.0481	0.3314	0.1411
	Multan	0.0303	0.0257	0.0256	-0.0820	0.0872	-0.1128
	DG Khan	0.0141	-0.0059	-0.0323	-0.0809	0.0867	-0.1179
	Bahawalpur	0.0536	0.00451 ^{NS}	-0.0073 ^{NS}	-0.0426	0.0375	0.0364 ^{NS}
	M Garh	0.0137	-0.0030 ^{NS}	-0.0310	-0.0820	0.0865	-0.1137
	Bahawalnagar	0.0714	0.0779	0.1252	0.0474	0.3283	0.1391
	Sukkur	-0.0280	-0.0083	-0.0347	-0.0629	-0.0813	0.0192
Sindh	Nawabshah	0.0276	0.0233	0.0062 ^{NS}	-0.0617	0.0597	0.0272
	Hyderabad	0.0127	0.0071	-0.0119	-0.0295	0.0950	0.0126
Baluchistan	Nasirabad	0.0311	-0.00324 ^{NS}	-0.0168	0.0354 ^{NS}	0.0458	0.0261 ^{NS}
	Peshawar Valley Districts						
KP	Peshawar	0.0113	0.0245	-0.0230	-0.0138 ^{NS}	0.6301	0.0673 ^{NS}
	Mardan	-0.0338	-0.0340	-0.0609	-0.3214	0.3659	-0.2383
Min growth		-0.0338	-0.0340	-0.0609	-0.3214	-0.0813	-0.3029
Max growth		0.0828	0.0779	0.1252	0.2487	0.6301	1.1778
Average growth		0.0255	0.0136	-0.0026^{ns}	0.0081^{ns}	0.1452	0.0457
Proportion of +tive deviations		0.64	0.58	0.58	0.31	0.47	0.41

^{NS}Statistically non-significant temperature/precipitation growth rates.

Overall, there was no significant change in occurrence of precipitation during the wheat sowing period in selected districts. However, a declining trend in precipitation was found in districts of Sindh and southern district of Punjab whereas incidence of precipitation increased during Nov-Dec in the central and northern district of Punjab. The precipitation during the stage-2 (Jan-Feb) increased almost in all districts except in Sialkot and Sukkur districts. The incidence of precipitation during stage-3 (March-April) kept an increasing trend in Sindh and in northern districts of Punjab while it declined in other districts of Punjab except Mianwali, Ranjanpur and Bahawalnagar. The last row in Table 1 shows that the overall proportions of hotter months (above the historic mean) during three stages of growth are higher as compared to the cooler months (below the historic mean), while the proportions of precipitation deviations that are above the historic mean are lower than the negative deviations (below the historic mean).

In order to investigate the impacts of climatic and non-climatic variables on wheat productivity, fixed effects (FE) model was estimated—incorporating the district-specific dummy variables considering the rain-fed districts (Rawalpindi and Jhelum) as base category. The estimation results of Equation 4 in full (Model 1) and three variant of the same (Model 2 through Model 4) are presented in Table 3. The results show that about 79 percent of the variation in the dependent variable, i.e. yield of wheat, is explained by the independent variables included in Model 1. The Wald tests were applied to choose the model that best suits the data and the test results are presented in Table 2.

Table 2

Results of Specification Tests for Alternative Models

	Null Hypothesis	F-test	F-Crit	Decision
1	$\beta_{VTND} = \beta_{VTJF} = \beta_{VTMA} = 0$	0.35	2.60	not rejected
2	$\beta_{PND2} = \beta_{PJF2} = \beta_{PMA2} = 0$	2.74	2.60	Rejected
3	$\beta_{TMA} = \beta_{TMA2} = 0$	0.02	3.00	not rejected
4	$\beta_{PND} = \beta_{PND2} = 0$	0.18	3.00	not rejected

The first hypothesis we tested is that H$_0$: $\beta_{\mathrm{VTND}} = \beta_{\mathrm{VTJF}} = \beta_{\mathrm{VTMA}} = 0$ which specifies that the wheat productivity is not affected by the temperature shocks which we fail to reject. Given the outcome of this test, the second hypothesis that we tested was that H$_0$: $\beta_{\mathrm{PND2}} = \beta_{\mathrm{PJF2}} = \beta_{\mathrm{PMA2}} = 0$ which indicates that the coefficients of square terms of precipitation normals are equal to zero. This null hypothesis was rejected, which implies that jointly the non-linear terms of precipitation normals significantly influence wheat productivity. Nonetheless, the coefficients of linear and square terms of November-December precipitation normals, and of linear and square terms of March-April temperature normals are all statistically non-significant. To test joint impact of the latter two variables, the null hypothesis of H$_0$: $\beta_{\mathrm{TMA}} = \beta_{\mathrm{TMA2}} = 0$ was tested which implies that March-April temperature does not impact wheat productivity. This hypothesis was not rejected. Given the outcome of this hypothesis, the last test we performed relates the null hypothesis of H$_0$: $\beta_{\mathrm{PND}} = \beta_{\mathrm{PND2}} = 0$ implying that precipitation normal during the months of November-December and its square term do not impact yield. This hypothesis was again not rejected. The results of specification tests reported in Table 2 lead to the conclusion that Model 4 (Table 3) best suites our data and same are discussed in the following.

The results of Model 4 demonstrate that all estimated coefficients of districts-specific dummy variables are statistically significant and carry positive signs indicating higher productivity in irrigated areas relative to the rain-fed districts—Rawalpindi and Jhelum. The parameter estimates of non-climatic variables including area under wheat, fertiliser and technology represented by time trend are all statistically significant and carry positive signs. Two important conclusions emerge from these results: First is that growing of wheat crop faces increasing returns to scale—that could mainly be due to government interventions in wheat economy both in inputs and output markets which induces greater specialisation in wheat production on the part of farmers; and the second is that improvement in production technologies has played a significant role in enhancing wheat yield in Pakistan.

The impact of temperature on wheat production depends strictly on location—higher temperatures could have positive effect in the cooler and wetter regions, while it influences the produce negatively in hotter and tropical regions [Ludwig and Asseng (2006)]. In general higher temperature tends to have negative effect on wheat crop because wheat is grown in the cold winter season. It germinates, matures and sets seed at low temperatures. Rise in temperature during early stages may result in poor seed emergence, less tillering, and thus low productivity etc. Since we were very much constrained by the data and had to pool information from 19 districts of Pakistan for which climatic related information were available for the study period, therefore, could not run regressions separately for various regions/cropping systems.

The coefficient of the average temperature during the stage-1—November and December, is statistically significant and carries a positive sign, while the coefficient of its square term is negative and statistically significant. The impact coefficient of average temperature during the months of November-December on wheat yield was evaluated at the mean temperature that came out to be -0.0741—implying that 1^0C increase in average temperature during the sowing stage would reduce the yield by 7.4 percent. The estimated increase in temperature normal during the study period for the months of November-December is projected to be 0.765^0C. [vi] Therefore, the overall potential wheat yields got depressed by 5.67[vii] percent. This estimate is in close agreement with Sivakumar and Stefanski (2011). They reported that an increase of 1^0C in mean temperature would reduce the overall wheat yield by 5-7 percent in Pakistan.

[vi] Considering growth rate of 0.0255^0C for November-December every year, the overall increase over the last 30 years period for the same month would be 0.765^0C.

[vii] This is a simple calculation. If with 1^0C increase in temperature reduces yield by 7.4 percent, then with 0.765^0C rise in temperature would reduce yield of wheat by 5.67 percent (= 7.4*0.765).

The results of a Rapid Rural Appraisal (RRA) conducted in Punjab, Sindh and KP provinces highlighted the facts that the farmers do perceive the long-term changes in climate and their resulting adverse impacts on agriculture. This realisation induced the wheat growers to ignore the recommendations of agricultural extension department that is of completing the sowing of crop before 20th of November. The wheat sowing has generally been delayed 2-3 weeks throughout the country to avoid higher temperature level (above the normal) from mid-October to early-November [Ahmad, *et al.* (2013)]. Had this adaptation strategy of shifting the sowing time of wheat not been adopted, the wheat yield losses in various areas of the country could have been much higher.

The coefficient of linear and square terms of temperature normal for January-February period—the stage-2, are highly significant and carry negative and positive signs respectively. The coefficient at the mean temperature is calculated to be 0.0621 which implies that 1^0C increase in average temperature during vegetative growth period would encourage wheat yield by 6.4 percent. The temperature during this stage has however shown an increase of 0.408^0C which helped raise wheat yield by an amount of 2.53 percent during the study period. armers perceptions survey has highlighted the fact that the temperature has generally increased and frost incidence has declined in most areas of Pakistan during the vegetative growth stage (January-February). However, the rise and fall in temperature have become very uncertain over time—in certain areas frost may occurs in late winter months, i.e. February, impacting the wheat yield adversely [Ahmad, *et al.* (2013)]. Therefore, warming weather during the vegetative growth helped enhance wheat yield in cold areas.

We found no significant impact of temperature normal during the stage-3 (March-April). The growth in average temperature normal during this stage was observed to be negative and was statistically non-significant with a wide variation from district to district. On the whole, the non-significance of the impact of temperature could have been mainly due to the non-rising temperature trend—that might have actually helped sustain the duration of crop stand in the field and avoided yield losses. Conversely, if the temperature during March-April had been on the rise as witnessed during the sowing stage (November-December)—that persuaded the farmers to delay wheat sowing time as strategy, would have had shorten the growing season considerably causing a further loss of 6-11 percent in yield [Ali (2011)].

Impact of higher precipitation on wheat production also depends strictly on geographical area. In general, higher precipitation in arid and semi-arid regions affects wheat production positively. However, in regions with already high rainfall, more precipitation can reduce wheat production by nutrient leaching and water logging [Ludwig and Asseng (2006)]. Further, prolonged wet conditions during vegetative growth period increase the risk of yellow rust incidence in wheat crop [ICARDA (2011)]. Our results have shown that the parameter estimates of linear and squared terms of November-December precipitation were statistically non-significant—so has been the rate of growth in precipitation for the same months. The response coefficients at mean levels of rainfall for the remaining two stages of growth are computed as 0.00004 and 0.00673 implying that 10mm increase in precipitation normals during the vegetative growth and maturity stages would increase wheat yield by 0.004 and 0.67 percent, respectively. The parameter estimate for the maturity stage precipitation was found to be 0.0067 indicating 0.067 percent increase in yield with 10mm greater precipitation. Variations on temperature and precipitation from the long term trend have also been used to examine the impacts of climatic shocks. As mentioned before, the collective impact of temperature variations on yield turned out to be statistically non-significant. The precipitation variation variables (relating stage-1 through stage-3) were included in the model. The results show that the coefficients of deviations from the long-term mean precipitation during the first and second stages of wheat growth are statistically significant and carry positive signs implying that the weather shocks have influenced wheat productivity positively—the positive impacts may be due to the fact that most of the deviations from the historic mean precipitation are positive (see Table 1). However, the variations variable relating to the wheat growth stage-3 shows statistically non-significant impact on wheat yield.

4. CONCLUSION AND POLICY IMPLICATION

The study shows that climate change is affecting the wheat productivity significantly in Pakistan and that the impact varies across growth stages of the crop. The increase in long-run mean temperature during germination and tillering stage effects wheat yields adversely. The results show that an increase of 1^0C in the mean temperature during this stage would reduce crop yield by 7.4 percent. The results of the RRA conducted by the authors highlighted the fact that the farmers do perceive the long-term changes in climate and its adverse impacts on agriculture. This realisation led the farmers to delay wheat sowing 2-3 weeks throughout the country to avoid higher temperature level (above the normal) from mid-October to early-November. Had this adaptation strategy of shifting the sowing time of wheat not been adopted, the wheat yield losses in various areas of the country could have been much higher.

Such an increase in temperature during vegetative growth stage enhances wheat productivity especially in cold regions of the country whereas no evidence of any significant effect on crop yield was found for the increase in temperature during maturity stage. The 1^0C rise in mean temperature during vegetative growth enhances wheat productivity to the tune of 6.4 percent. Due to changing climate pattern, the rise and fall in temperature have become very uncertain over time. The frost occurs even in February in certain areas impacting the wheat yield adversely. Therefore, warming weather during the vegetative growth helped enhance wheat yield in cold areas. No significant impact of rise in temperature normals during wheat maturity stage was observed on wheat productivity. The non-significance of the impact of temperature could have been mainly due to the non-rising temperature trend during this period—that might have actually helped sustain the duration of crop stand in the field and avoided yield losses. The deviations of mean temperature from historic (long run) mean—weather shocks, had also posed no threat to wheat productivity during the period under study.

Precipitation normals—during vegetative and maturity stages and their deviations from historic mean (positive) have impacted the wheat yield positively—but the magnitude of the impact of incremental rains came out to be very low.

The results of this study have certain important policy implications. First, the effect of climate change (normal and variations) on wheat yield should be given due consideration in policymaking in order to make Pakistan s food production systems more resilient to climate change. Second, there should be sufficient expenditure on agriculture research and development for improving varieties of wheat crop which should be resilient to climate change i.e. high yielding, tolerant to heat and water stresses, and less prone to viral attack. Third, since climate change is not uniformly affecting all parts of Pakistan so there is need to have more localised adaptation policy in order to tackle climate change instead of one common national level policy framework.

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This series of papers is an outcome of a joint research project of PIDE and IDRC. Transnational financing of developmental projects by donor agencies has emerged to be a notable phenomenon around the globe. Amongst others, International Development and Research Centre (IDRC) Canada remains one of the leading agencies providing funds for multifaceted developmental projects being implemented in developing countries. The project ***"Climate Change Agriculture and Food Security in Pakistan: Adaptation Options and Strategies"*** is one such an endeavor of PIDE and IDRC. Broadly speaking, the project aims at exploring responses of crop yields to changing climate and analyzing the adaptation efforts undertaken by farmers. The issue of climate change bears a special importance for Pakistan's economy being heavily dependent on agriculture sector both in terms of its contribution to GDP and employment. This project involves two strands of empirical undertakings: i) studies based on districts-level panel; and ii) studies based on Rapid Rural Appraisal (RRA) and household level survey data. The outcomes of the studies based on panel and cross-sectional data are being reported in working paper series of the project whereas findings of RRA have been published as a policy brief. However, for information of readers, the salient upshots of RRA are summarized in the following.

The evidence from RRA is suggestive that the farming communities in various regions of Pakistan widely perceive that climate is changing and is adapting accordingly through undertaking a wide range of adaptation strategies. Some of the adaptations in rainfed areas include use of deep tillage for rainwater harvesting and preserving moisture, building of small check dams, shifting away from shallow rooted to deep rooted crops, and delayed sowing of wheat and mustard by 15-30 days etc. While adaptations in irrigated agriculture include, in major, increased installation of tube-wells, increased area under low-delta/low-input requiring crops like canola and mustard as alternative to wheat in water scarce areas and substitution of other crop (guar seed and cotton crops being replaced with mungbean in low intensity zone), delayed wheat sowing by 15-21 days, and sowing of cotton on ridges to manage water scarcity etc.

Surprisingly, however, notwithstanding the changing climate, the research institutions and extension department still keep recommending completion of wheat sowing by 20th of November irrespective of regional climate variations. The sowing of rice nursery before 20th of May is prohibited according to the Punjab Agricultural Pest Ordinance, 1959 in order to control multiplication of harmful pests on early sown rice nurseries. Further, canal closure schedules do not match with the adaptation needs of farmers confronting climate changes (especially wheat in Punjab and rice in Sindh. The farmers have an urgent need of support from agricultural research and extension as well as other government departments to enhance their adaptive capacities.

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