Analysing the Impact of Climate Change on Rice Productivity in Pakistan

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ABSTRACT

This study, applying Fixed Effect Model (FEM), analyses the impact of climate change on yield of fine and coarse rice in Pakistan using district-level panel data for the period of 1987-2010. The evidence suggests that climate change significantly affects yield of both types of rice crops. The impact varies across different phenological stages of the crop both in magnitude and direction. Precipitation forms a statistically significant non-linear relationship with yield for both types of rice. No evidence, however, was found for presence of non-linear temperature effects.

1. INTRODUCTION

As the largest sector of Pakistan's economy, agriculture contributes 21.4 percent to GDP provides employment to 45 percent of the labour force and earns significant revenue from exports. Agriculture sector is perceived to be highly vulnerable to climate change. Intergovernmental Panel on Climate Change (IPCC)[1] reports that crop production in South Asian region is expected to be badly affected by climate change. Global warming[2] and, consequently, the weather variability can be harmful to agriculture sector through its negative impact on plant growth and development [Islam, *et al.* (2011)]. Pakistan, in general, and its agriculture sector in particular bears no exception and faces higher vulnerability to climate change.[3]

The impact of climate change on agriculture production is an empirical issue, and the extant literature, in general, concludes that climatic change is affecting agricultural production negatively

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[1] Fourth Assessment report of the IPCC (2007).

[2] Caused by the emission of methane from rice paddies [Cicerone and Shetter (1981)] carbon dioxide and greenhouse gases (GHG) from large scale manufacturing [Rehan and Nehdi (2005)] and atmospheric brown clouds (ABC) due to sea salt and mineral dust [Ramanathan (2006)].

[3] Maplecroft ranked Pakistan 24th in the list of countries most vulnerable to climate change.

[Adams, *et al.* (1988); Cline (1996); Parry, *et al.* (2004); Lobell and Field (2007); and Cabas, *et al.* (2010)].

Of the main crops of Pakistan, rice is the second major staple food, accounting 25.2 percent to the agricultural value added, [Pakistan (2013)].[4] The literature analysing the impact of changing climatic conditions on rice, however, is scarce.[5] The rice crop, grown in mild temperature with standing water in paddy fields, is already under heat stress and further rise in temperature may affect the crop badly [Welch, *et al.* (2010)]. The impact of rising temperature on rice varies across the growth stages and it is reported that high temperature during flowering stage increases the floret sterility in rice exerting a negative impact on the yield [Yoshida (1981) and Matsushima, *et al.* (1982)]. The hot and dry weather conditions during ripening stage of Basmati varieties result in abdominal whiteness of the grains harming rice quality [Hussain (1964)]. The crop is also highly sensitive to water stress and a small reduction in water use may result in significant reduction in rice yield by changing the soils state from submergence to that exposed to greater aeration [Yoshida (1981)]. Depletion of underground water and consequently lower levels of water available for irrigation, renders the rice crop highly sensitive to precipitation level and patterns [Aggarwal and Sivakumar (2011); Tuong and Bouman (2003)]. The issue bears a special relevance for Pakistan as the country is expected to experience severe shortage of water by 2025 [IWMI (2000)].

Literature, evaluating the impact of changing climate on rice production in Pakistan, is scant. Recently, Siddiqui, *et al.* (2011) analysed the impact of climate change on production of major crops in Pakistan including rice. The study at hands differs from Siddiqui, *et al.* (2011) both in nature and scope. Firstly, this work undertakes a separate analysis for two types of rice cultivars namely Basmati and Coarse which are quite different from each other in terms of crop duration and phenological stages[6] implying a different production response function for each. Secondly, withstanding the standard definition of climate change, this study reads the climate change a long-term phenomenon as contrary to Siddiqui, *et al.* which uses only the current year values of climatic variables representing weather and not climate. Thirdly, the present study controls the impact for certain non-climatic variables also. Fourthly, our work captures the non-linear impacts of climate on rice yield.

On these accounts, the present study is an attempt to extend the scope of work both in nature and rigor generating reliable estimates of the impact of climate change on rice productivity in Pakistan. The remaining part of the paper is structured as follows: Section 2 details the data and estimation methodology. Results are discussed in Section 3, while Section 4 concludes.

2. DATA AND METHODOLOGY

2.1. Data and Variables

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[4] Pakistan is known for the production of fine varieties of rice (basmati) as well as coarse rice cultivars.

[5] These studies include Auffhammer, *et al.* (2006), Cheng and Chang (2002), Felkner, *et al.* (2009), Barnwal and Kotani (2010); and Welch, *et al.* (2010), Islam, *et al.* (2011) and Auffhammer, *et al.* (2012).

[6] The rice crop period considered in Siddiqui, *et al.* (2011) covered the months of August to November as against the reality of May to November.

This study estimates the rice yield functions by using data from selected districts of Punjab and Sindh for the period 1987 to 2010.[7] The data were collected from Federal Bureau of Statistics Pakistan (FBSP), Provincial Development Statistics and National Fertiliser Development Centre (NFDC), Islamabad.[8] The data on climatic variables were obtained from the Pakistan Meteorological Department (PMD), Islamabad.[9] The temperature and precipitation variables are constructed using three phenological stages of rice crop since the variations in climatic conditions during stages of crop growth have different effect on crop yield [Auffhammer, *et al.* (2012)]. The first stage covers nursery growing, transplanting and tillering, the second stage covers vegetative growth, flowering and milking and the third stage covers maturity and harvesting of the rice. For Basmati (Coarse rice) the first stage extends from June to July (May to June), the second stage extends from August to September (July to August), and the third stage extends from October to November (September to October).

Following Segerson and Dixon (1999) and Cabas, *et al.* (2010), [10] this study uses 20 years moving averages of temperature and total precipitation during different phenological stages in order to capture the long-run impacts of climate change. Additionally, the effects of shocks are captured by taking the deviation of temperature and precipitation from their corresponding long-run means as used by Cheng and Chang (2002). The results are controlled for non-climatic variables including fertiliser use, area under respective rice variety and technological change captured through time trend. Furthermore, the main Coarse rice growing districts are prone to floods and drought incidences so we use dummy variable(s) for the extreme events showing a flood/drought year or otherwise.[11]

2.2. The Model

The issue of evaluating the impact of climate change on agricultural output attracted special attention of researchers after the seminal work of Nordhaus (1977). Production function approach has been widely used to analyse the climate change-agriculture nexus. A good volume of literature use simulation models[12] to look into the future changes in climate and their impact on agriculture

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[7] The district level data for total output and area of rice is available since 1981. However, variety-wise information is available since 1987. For Basmati rice, we took Gujranwala, Gujrat, Okara, Shikhupura, Sahiwal, Sialkot, Lahore and Kasur districts while for coarse rice, Badin, Larkana, Shikarpur, Jacobabad, Nasirabad, and Thatta districts were selected.

[8] Fertiliser use for rice is calculated by multiplying the total fertiliser off-take with rice share (fertiliser*rice share) in each concerned districts. Where, the total fertiliser use is the sum of Nitrogen, Phosphorus and Potassium (NPK) nutrients measured in thousand tonnes.

[9] The observed Met data is not available for all districts. Therefore, the missing data has been generated through ECHAM5 GCM using Grid Analysis and Display System (GrADS) software to obtain the mean temperature data at desired locations (latitude, longitude) [PMD (2013)]. However, the precipitation data generated through this system was not reliable as it differed widely from the actual observations. Therefore, the observed precipitation data of the adjacent district was used for those districts where the Met stations' data was not available.

[10] Segerson and Dixon (1997) used cross-sectional sample of 975 counties of United State for the year 1978, 1982 and 1987. They analysed climate impact on corn, soybean and wheat production. While, Cabas et al. (2010) used 8 counties data of Canada from 1981-2006 and analysed the impact of climate variables on corn, soybean and winter wheat yields.

[11] During the rice growing season (*Kharif*) there were droughts in the study area during years, 2000-01 and floods in 1992-93, 2003-04, 2006-07 and 2009-10.

[12] CCSR, AOGCM, PCM, CCCma, CERES, and APSIM-Wheat.

[Tubiello, *et al.* (2002); Luo, *et al.* (2003); Luo, *et al.* (2005); Lobell, *et al.* (2005); Magrin, *et al.* (2005); Lobell and Field (2007); Ludwig, *et al.* (2009); and Lea, *et al.* (2012)].[13] Incapacity of above mentioned models to accommodate crops substitutions and adaptations to climate led the formulation of Ricardian approach pioneered by Mendelsohn, *et al.* (1994) wherein the impact of climate change is analysed using value of farmland or net rent as dependent variable.[14] The major advantage of this technique is that it allows crop substitutions and farm-level adaptations—making it most attractive in evaluating the impact of climate change on agriculture. However, the major drawbacks of this approach include unavailability of reliable data for agricultural farm values and the existence of imperfect land markets in developing countries [Gbetibouo and Hassan (2005); and Guiteras (2009)]. This approach has also been criticised on the grounds of its implicit assumptions of constant prices and zero adjustment cost making the welfare calculations biased [Cline (1996)], providing lower-bound estimates of the costs of climate change [Quiggn and Horowitz (1999)].

Following Segerson and Dixon (1999), Cheng and Chang (2002) and Cabas, *et al.* (2010), the above deficiencies can be avoided using modified production function approach.[15] These studies introduced 20 to 30 years moving averages of temperature and precipitation in the production to capture the influence of climate change on crop yields more effectively. The impacts of weather shocks can be introduced in the same function by taking the deviations of current weather variables from their respective long-term means. Some studies including Adams, *et al.* (2003) and Felkner, *et al.* (2009)[16] introduced quadratic terms of climatic variables to examine whether the impact of climate change on crop production is non-monotonic or not. In order to account for the joint impact of temperature and precipitation Hansen (1991), Ludwig and Asseng (2006), Weersink, *et al.* (2010) and Cabas, *et al.* (2010) further extended the production function by introducing the interaction terms. The present study uses the modified production function to assess the impact of climate change on rice yield in Pakistan.

The general form of the production function can be written as:

$$Y = f(Cl, NCl) \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where, Y is rice production per-hectare (yield), Cl is the vector of climatic variables including temperature and precipitation while NCI is the vector of non-climatic variables such as fertiliser area under rice and technological change. Following Ahmad and Ahmad (1998), the Cobb-Douglas functional form can be written as:

$$Y_{it} = e^{\beta_0 + \beta_T (Tem_{it}) + \beta_P (\mathrm{P}recip_{it}) + \beta_{VT} DTem_{it}) + \beta_{VP} (D\mathrm{P}recip_{it})}$$

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[13] 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).

[14] Important applications of this approach include Mendelsohn and Dinar (1999), Reinsborough (2003), Weber and Hauer (2003), Gbetibouo and Hassan (2005), Schlenker, *et al.* (2006), and Deshenes and Greenstone (2011).

[15] The traditional production function studies have been criticised on the grounds that they estimate only the short-run impacts, while the climate change is a long-run phenomenon which takes years to impact on crop production [IPCC (2007)].

[16] See also Cabas, *et al.* (2010); Seo (2010) and Weersink, *et al.* (2010).

$$(Fert_{it})^{\beta_f} (RArea_{it})^{\beta_{Ar}} e^{\beta_g T} e^{\varepsilon_{it}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Where, Y_{it} is yield per hectare in district *i* and time *t. Tem*, and *Precip* are 20 year average of monthly mean temperature and precipitation (mm), *DTem,* and *DPrecip* are deviations of temperature and precipitation from respective long-run means, *Fert* is total amount of fertilisers used for rice, *RArea* is area under rice and *T* is a trend variable captured technological change. All β*s* are unknown parameters to be estimated. By taking the natural logarithm on both sides of the Equation 2 the function can be rewritten in the linear form as:

$$\begin{aligned} \ln(Y_{it}) &= \beta_0 + \beta_T Tem_{it} + \beta_P \Pr ecip_{it} + \beta_{VT} DTem_{it} + \beta_{VP} D\Pr ecip_{it}) \\ &+ \beta_f \ln(Fert_{it} + \beta_{Ar} \ln(RArea_{it}) + \beta_g T + \varepsilon_{it} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3) \end{aligned}$$

Where, "ln" denotes the natural logarithm. The quadratic and interaction terms of climatic variables are also introduced in the specification to capture the non-linearity and joint impacts of the climatic variables. Floods and drought conditions have been very common in districts which are growing coarse rice, and to control the results for natural disasters, a dummy variable (DF) is introduced in the model.[17] Eq (3), dropping subscript '*it*' for convenience, can be written as:

$$\begin{aligned} \ln(Y) &= \beta_0 + \beta_{TS} Tem_S + \beta_{TV} Tem_V + \beta_{TM} Tem_M + \beta_{PS} \Pr ecip_S \\ &+ \beta_{PV} \Pr ecip_V + \beta_{PM} \Pr ecip_M + \beta_{TS2}(Tem_S)^2 + \beta_{TV2}(Tem_V)^2 \\ &+ \beta_{TM2}(Tem_M)^2 + \beta_{PS2}(\Pr ecip_S)^2 + \beta_{PV2}(\Pr ecip_V)^2 + \beta_{DTS} DTem_S \\ &+ \beta_{DTV} DTem_V + \beta_{DTM} DTem_M + \beta_{DPS} D\Pr ecip_S + \beta_{DPV} D\Pr ecip_V \\ &+ \beta_{DPM} D\Pr ecip_M + \beta_{PM2}(\Pr ecip_M)^2 + \beta_{TPS}(Tem_S * \Pr ecip_S) \\ &+ \beta_{TPV}(Tem_V * \Pr ecip_V) + \beta_{TPM}(Tem_M * \Pr ecip_M) + \beta_f \ln(Fert) \\ &+ \beta_{Ar} \ln(RArea) + \beta_g T + \beta_{Df} DF + \varepsilon \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4) \end{aligned}$$

Where, *S, V, and M* (in subscript to βs) respectively represent first stage (sowing to tillering), second stage (vegetative growth to flowering/milking) and the third stage (maturity to harvesting).

Application of OLS to pooled/panel data provides inconsistent results as it requires the random and/or fixed effect models [Baltagi (2005); Asteriou and Stephen (2007); and Wooldridge (2009)]. This study uses the fixed effect method due to the presence of correlation between unobserved time invariants and regressors [Stock and Watson (2003); Baltagi (2005); Wooldridge (2009); and Sarker (2012)]. Furthermore, it also accounts the district specific effects that is preferred over pooled least square and random effect methods [McCarl, *et al.* (2008); Kim and Pang (2009); Barnwal and Kotani (2010); Cabas, *et al.* (2010); Sarker (2012)].

3. RESULTS AND DISCUSSION

3.1. Basmati Rice

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[17] DF is dummy variable having value equal to 1 in the case of a flood year and zero otherwise. This variable shall be considered only in coarse rice model in Sindh.

Fixed effect estimates for Basmati rice are reported in Table 1. General-to-specific (G2S) approach, widely argued [Hoover and Perez (2004); Hendry and Krolzig (2004)] and used in empirical literature [Ahmad and Battese (1997); Ahmad and Bravo-Ureta (1995a); Ahmad and Bravo-Ureta (1995b)] is followed in this study. Based on specification test, Model B, selected as final model, suggests a non-linear impact of temperature and precipitation on Basmati rice yield.[18] It is evident from the results that temperature and precipitation normals make a significant joint impact on Basmati rice yield across various stages of the crop growth which is indicative of the fact that the impact of temperature and precipitation is not separable.[19] Based on the joint Wald test (as reported in Table 2), squared terms of temperature normals, were not included in the Model B.

Table 1

Fixed Effect Model Estimates (Basmati Rice)

		Model A		Model B	
Variables	Parameter	Coefficient	SE	Coefficient	SE
Constant	β_0	1.036	0.138	4.279	0.698
Temperature (June-July)	β_{TS}	0.291	0.198	-0.047**	0.025
Temperature (Aug.-Sep.)	β_{TV}	-0.167	0.315	-0.089***	0.029
Temperature (Oct.-Nov.)	β_{TM}	-0.178	0.135	0.024*	0.013
Precipitation (June- July)	β_{PS}	0.008	0.009	-0.007	0.006
Precipitation (Aug.-Sep.)	β_{PV}	-0.039***	0.008	-0.033***	0.006
Precipitation (Oct.-Nov.)	β_{PM}	0.071***	0.024	0.092***	0.022
D Temperature (June- July)	β_{DTS}	0.002	0.002	0.001	0.002
D Temperature (Aug.-Sep.)	β_{DTV}	-0.005**	0.003	-0.005**	0.003
D Temperature (Oct.-Nov.)	β_{DTM}	0.005***	0.002	0.005***	0.002
D Precipitation (June- July)	β_{DPS}	0.001***	0.00004	0.0002***	0.0005
D Precipitation (Aug.-Sep.)	β_{DPV}	-0.00009**	0.00004	-0.00009**	0.0004
D Precipitation (Oct.-Nov.)	β_{DPM}	0.001***	0.001	0.0007***	0.001
Temperature (June- July)^2	β_{TS2}	-0.005*	0.003	–	–
Temperature (Aug.-Sep.)^2	β_{TV2}	0.002	0.005	–	–
Temperature (Oct.-Nov.)^2	β_{TM2}	0.005	0.004	–	–
Precipitation (June- July)^2	β_{PS2}	-0.0008	0.00007	-0.00003	0.000
Precipitation (Aug.-Sep.)^2	β_{PV2}	0.0005***	0.00006	0.00005***	0.0006
Precipitation (Oct.-Nov.)^2	β_{PM2}	-0.001	0.001	-0.0003	0.001
Temperature x Precipitation (June- July)	β_{TPS}	-0.0002	0.001	0.0004***	0.001
Temperature x Precipitation (Aug.-Sep.)	β_{TPV}	0.001***	0.001	0.0006***	0.0001
Temperature x Precipitation (Oct.-Nov.)	β_{TPM}	-0.003***	0.001	-0.004***	0.0001
Natural logarithm of Fertiliser	β_f	0.052***	0.014	0.047***	0.014
Natural logarithm of Rice Area	β_{Ar}	-0.014	0.014	-0.020*	0.013
Time Trend	β_g	0.029***	0.001	0.029***	0.001
Adjusted R-Square		0.77		0.77	

Note: ***, **,* indicate the 1 percent, 5 percent and 10 percent level of significance, respectively.

Table 2

Specification Tests for Alternative Basmati Yield Models

Models	Null Hypothesis	Variables	F-value (Prob.)	χ^2-value (Prob.)	Result
Model A	$\beta_{TPS} = \beta_{TPY} = \beta_{TPM} = 0$	Interaction Terms	5.77 (0.006)	17.29 (0.006)	Rejected
	$\beta_{TS2} = \beta_{TV2} = \beta_{TM2} = 0$	Temperature Normal Square	1.62 (0.19)	4.68 (0.19)	Not Rejected

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[18] For brevity, the results of Model B are discussed. See Table 2 for specification test supporting that Model B fits the data best.

[19] These results are in concurrence with Yoshida (1981), Hansen (1991), Ludwig and Asseng (2006) and Cabas, *et al.* (2010).

Model B	$\beta_{PS2} = \beta_{PV2} = \beta_{PM2} = 0$	Precipitation Normal Square	57.38 (0.000)	172.14 (0.00)	Rejected
	$\beta_{DTS} = \beta_{DTV} = \beta_{DTM} = 0$	Temperature Variations	3.19 (0.02)	9.58 (0.02)	Rejected
	$\beta_{PS2} = \beta_{PV2} = \beta_{PM2} = 0$	Precipitation Variations	9.67 (0.00)	29.00 (0.00)	Rejected
	$\beta_{TS} = \beta_{TV} = \beta_{TM} = 0$	Temperature Normal	12.52 (0.00)	37.56 (0.00)	Rejected
	$\beta_{PS} = \beta_{PV} = \beta_{PM} = 0$	Precipitation Normal	21.27 (0.00)	63.79 (0.00)	Rejected

The results of Model B further suggest that increase in mean temperature normal during the first and second stage of crop growth reduces the basmati rice yield. The temperature normals interact with precipitation normals and form a significant influence on rice productivity implying that higher temperature with greater precipitation during June-July (first stage of crop growth) is beneficial for Basmati rice. The marginal impact of increase in temperature during June-July on Basmati yield is 0.0075 [20] which implies that any increase in temperature assuming that the precipitation occurs at the historic mean would prove beneficial for the crop productivity. The net impacts of rising temperature during August-September (the second stage) and in October November (the third stage) were found to be –0.0069 and –0.0179 respectively suggesting that the rise in temperature during phonological stage covering flowering, milking, and maturity stages is harmful for productivity of Basmati rice.

Increase in precipitation normal during first two growth stages (covering nursery growing, transplanting, tillering, vegetative growth, flowering, and milking) significantly reduces the yield of Basmati rice. The squared terms of precipitation normals influence the yield significantly. The marginal impacts, assessed at the mean of temperature normal, are –0.0014 and –0.0012 for the first and second stages of crop growth, respectively. The plausible explanation of the result could be increased erratic rains which may cause submergence of newly transplanted rice and overflow of fertiliser nutrients which are crucial for vegetative growth. Also increase precipitation results in high humidity that can cause high pests and disease infestation of the crop and ineffectiveness of weed control measures. The marginal impact of precipitation normal during the maturity stage, evaluated at the mean levels of precipitation and temperature normal, turned out to be positive (0.0006) implying that better precipitation helps the crop productivity if the temperature stays at the historical mean.

Deviations of temperature and precipitation from their respective long-run means (variations) are incorporated to gauge the impact of weather shocks on rice yield. Temperature variation at first stage enters statistically insignificant showing that heat waves during June-July had not significantly affected the yield in case of Basmati rice. Statistically significant coefficients for the deviations of temperature from historic mean during the second and third stages imply that the temperature variations from their respective normals would influence yield

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[20] Marginal impacts can be computed by taking the partial derivative of the estimated version of Equation 4 with respect to the targeted variable, and then be evaluated at the mean of the other variable(s) involved.

adversely when the crop is in vegetative growth, flowering, and milking stages and positively during the maturity and harvesting stages.[21]

Deviation of precipitation from its long-run mean during June-July yields statistically significant positive effect indicating that a cool wave or positive precipitation shock would affect rice yield positively. According to Tuong and Bouman (2003) and Islam, *et al.* (2011), rice paddy requires standing water at initial stage which is evident from the sign and significance of the precipitation term at first stage. The precipitation shocks may decrease rice yield which is evident from the floods and drought prevailed in Pakistan. During the third stage (maturing/ripening and harvesting) precipitation variation is found affecting Basmati yield positively and significantly.

Fertiliser use has significant positive impact on Basmati rice yield. The response coefficient for fertiliser is low—may be due to unbalanced use of fertiliser. The coefficient of area under Basmati rice is negative and statistically significant supporting the evidence of decreasing returns to scale. The plausible explanation of decreasing return may be that major proportions of the farm-lands are under rice cultivation during Kharif season in rice growing districts of Pakistan with little opportunity for fallowing the land and/or crop rotation. Allocation of additional farm area to rice production thus amounts to intensification of monocropping agriculture that in turn results in land degradation and pest/insect build-up reducing productivity.[22] The tech-nological improvement, captured through time trend, contributes positively to yield of Basmati rice.

3.2. Coarse Rice Yield

The results of alternative models estimated for Coarse rice using fixed effects are reported in Table 3. The application of G2S criteria and Wald tests statistics (see Table 4) lead us to choose the Model E for further discussion. Against the temperature normals no evidence non-linear relationship between rice yields and warming is found. However, the evidence suggests that non-linear relationship between precipitation and rice yield exists. Further no significant joint impact of climate normals is found. The impacts of weather shocks (temperature as well as precipitation) were also found statistically insignificant.

The results reported in Table 3 (Model E) show that the temperature normal during the first phonological stage (May-June) contributed to the yield of coarse rice positively while the rise in temperature normals during second stage (July-August) and third stage (September-October) influences coarse rice productivity negatively. However, the impact are not statistically significant.[23] In order to assess the impact of precipitation normals (linear as well as squared terms) on rice yield, the response coefficients were evaluated at the mean precipitation levels for May-June and July-August periods covering the first and the second crop growth stages of rice. The magnitudes of these response coefficients are 0.0372 for May-June and 0.002 for July-August—implying that the precipitation during the

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[21] Similar results are reported by [Hussain (1964)].

[22] see Cassman and Pingali (1993); Pingali, *et al.* (1997); Ahmad, *et al.* (1998); and Ahmad (2003).

[23] The results are in line with Cramer (2006).

first and second phenological stages of coarse rice enhances crop yield. The precipitation normal during the third stage (maturity) also exhibits non-linear relationship with rice yield.

The frequency and intensity of floods has increased during the past couple of decades. The impacts of these extreme events are captured by introducing a dummy variable in the model. The sign of the coefficient indicate negative influence on rice yield in Sindh; however, the impact is statistically non-significant.[24]

Among the non-climatic variables, the sign of fertiliser variable is unexpectedly negative. However, it is statistically insignificant. The main reason for fertiliser having no impact on yield of rice at the margin could be the unbalanced use of nitrogen, potassium and phosphorus (macro nutrients). The coefficient value of area under rice is 0.0865 indicating increasing returns to scale; however, it is also statistically non-significant. The time trend—proxy for technological change shows that the rice yields have been declining over the time. The results of RRA conducted in various districts of Sindh highlighted the poor support of technological backup in terms of new verities and agronomic methods, particularly under the fast changing climatic indicators [Ahmad, *et al.* (2013)].

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[24] The floods of 2004, 2007 and 2010 are prominent. In 2007, rice production decreased by 2 percent as compared to the last year and 4.5 percent from target level. In 2010, there was 2.7 percent reduction in rice sown and also 1.0 percent less than the target level.

Table 3

Fixed Effect Model Estimates for Course Rice (Dependent Variable: Natural Logarithm of Yield)

		Model A		Model B		Model C		Model D		Model E	
Variables	Parameter	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	β_0	3.264	43.165	5.1912	41.898	2.4031	2.1265	2.0891	2.0320	2.4536	2.0026
Temperature (May-June)	β_{TS}	5.019	3.358	4.8380	3.005	0.3200**	0.1584	0.3300**	0.1531	0.3245**	0.1517
Temperature (July-Aug.)	β_{TV}	-4.976**	2.573	-4.5516*	2.457	-0.2319	0.1800	-0.2371	0.1707	-0.2612	0.1679
Temperature (Sep.-Oct.)	β_{TM}	-0.558	2.275	-0.8974	2.018	-0.2097	0.1400	-0.2054	0.1362	-0.1815	0.1341
Precipitation (May-June)	β_{PS}	-0.294	0.418	0.0710*	0.040	0.0718*	0.0400	0.0700*	0.0395	0.0629*	0.0386
Precipitation (July-Aug.)	β_{PV}	0.033	0.054	0.0333***	0.008	0.0325***	0.0086	0.0328***	0.0084	0.0320*	0.0081
Precipitation (Sep.-Oct.)	β_{PM}	0.125	0.207	-0.0563*	0.031	-0.0465	0.0308	-0.0456	0.0302	-0.0434	0.0283
*D*Temperature (May-June)	β_{DTS}	0.014	0.019	0.0121	0.018	0.0107	0.0177	–	–	–	–
*D*Temperature (July-Aug.)	β_{DTV}	-0.002	0.017	-0.0008	0.017	0.0031	0.0169	–	–	–	–
*D*Temperature (Sep.-Oct.)	β_{DTM}	-0.005	0.016	-0.0041	0.016	-0.0051	0.0160	–	–	–	–
DPrecipitation (May-June)	β_{DPS}	-0.001	0.001	-0.0013	0.002	-0.0012	0.0014	-0.0014	0.0013	–	–
*D*Precipitation (July-Aug.)	β_{DPV}	0.0001	0.0004	0.0003	0.0004	0.0003	0.0004	0.0003	0.0004	–	–
*D*Precipitation (Sep.-Oct.)	β_{DPM}	-0.001	0.001	-0.0010	0.0011	-0.0010	0.0011	-0.0009	0.0010	–	–
Temperature (May-June) ^{2}	β_{TS2}	-0.066	0.047	-0.0630	0.0423	–	–	–	–	–	–
Temperature (July-Aug.) ^{2}	β_{TV2}	0.070*	0.037	0.0620*	0.0352	–	–	–	–	–	–
Temperature (Sep.-Oct.) ^{2}	β_{TM2}	0.007	0.038	0.0129	0.0342	–	–	–	–	–	–
Precipitation (May-June) ^{2}	β_{PS2}	-0.003	0.002	-0.0033	0.0019	-0.0035*	0.0019	-0.0034*	0.0018	-0.0031*	0.0018
Precipitation (July-Aug.) ^{2}	β_{PV2}	0.002***	0.002	-0.0003***	0.0001	-0.0003***	0.0001	-0.0003***	0.0001	-0.0003***	0.0001
Precipitation (Sep.-Oct.) ^{2}	β_{PM2}	0.003**	0.001	0.0034***	0.0013	0.0032***	0.0012	0.0032***	0.0012	0.0029***	0.0012
Temp x Precip (May-June)	β_{TPS}	0.011	0.012	–	–	–	–	–	–	–	–
Temp x Precip (July-Aug.)	β_{TPV}	0.000	0.001	–	–	–	–	–	–	–	–
Temp x Precip (Sep.-Oct)	β_{TPM}	-0.006	0.007	–	–	–	–	–	–	–	–
Natural logarithm of fertiliser	β_f	-0.033	0.028	-0.0358	0.0276	-0.0347	0.0272	-0.0337	0.0264	-0.0327	0.0263
Natural logarithm of rice area	β_{Ar}	0.075	0.089	0.1349*	0.0645	0.0931*	0.0574	0.0910*	0.0564	0.0865	0.0556
Time Trend	β_g	-0.017***	0.007	-0.0170**	0.0059	-0.0155***	0.0058	-0.015***	0.0057	-0.0149***	0.0056
DF (Extreme Events)	β_{Df}	-0.040	0.053	-0.0343	0.0523	-0.0352	0.0524	-0.0333	0.0515	-0.0439	0.0494
Adjusted R-Square		0.68		0.68		0.68		0.679		0.683	

Note: ***, **,* indicate the 1 percent, 5 percent and 10 percent level of significance, respectively.

Table 4

Specification tests for Alternative Coarse Rice Yield Models

Models	Null Hypothesis		F-value (Prob.)	χ^2 value (Prob.)	Result
Model A	$\beta_{TPS} = \beta_{TPV} = \beta_{TPM} = 0$	Interaction Terms	0.636	1.907	Not rejected
			(0.593)	(0.593)	
Model B	$\beta_{TS2} = \beta_{TV2} = \beta_{TM2} = 0$	Temperature Square	1.176	3.529	Not rejected
			(0.321)	(0.317)	
Model C	$\beta_{PS2} = \beta_{PV2} = \beta_{PM2} = 0$	Precipitation Square	10.91	32.31	Rejected
			(0.000)	(0.000)	
	$\beta_{DTS} = \beta_{DTV} = \beta_{DTM} = 0$	Temperature Variations	0.222	0.666	Not rejected
			(0.880)	(0.881)	
Model D	$\beta_{DPS} = \beta_{DPV} = \beta_{DPM} = 0$	Precipitation Variations	0.625	1.874	Not rejected
			(0.601)	(0.599)	
Model E	$\beta_{TS} = \beta_{TV} = \beta_{TM} = 0$	Temperature normal	3.668	11.001	Rejected
			(0.015)	(0.012)	
	$\beta_{PS} = \beta_{PV} = \beta_{PM} = 0$	Precipitation normal	8.865	26.59	Rejected
			(0.00)	(0.00)	

4. CONCLUSION AND POLICY IMPLICATION

The findings of this suggest that temperature has significant impact on yield of Basmati as well as coarse rice. The impact, however, varies in magnitude and direction across the growth stages. The precipitation normal plays a significant role in enhancing rice yield. The extreme events (shocks) of temperature as well as precipitation during second stage (covering phonological stages of vegetative growth, flowering, and milking) reduce yield of Basmati rice but during other two stages, these shocks exert a positive effect on Basmati yield. The extreme weather conditions (temperature and precipitation shocks) had no significant impact on yield of coarse rice in Pakistan during the period under study.

We find the evidence for the existence of hill-shaped relationship between precipitation normal and rice productivity. However, the specification tests indicate non-existence of hill shaped relationship between temperature normal and rice productivity. The combined effect of climatic variables was found significant in Basmati rice yield model. In spite of that, sensitivity analysis checks the robustness of the coefficients for both types of rice with the application of general to specific criteria.

There is a need to identify, test, and scale up the adaptation strategies in order to reduce the adverse impact of climate change. Some special measures should also be undertaken to enhance the adaptive capacities of farmers through developing innovations/ technologies that can withstand the adverse impact of climate change which may include the following:

- Enhancing physical availability and economic access to promising technologies.
- Improving knowledge of farmers.
- Remodelling of the required support services.

The development of high yielding verities (HVYs) tolerant of biotic and abiotic stresses as well as adapting crop production practices to climate change (especially sowing dates, sowing methods, and irrigation practices) are crucial to improve rice yields in Pakistan. Therefore, reprioritising of the agricultural research agenda is required giving higher attention to address the issues of climate change. Promotion of balanced use of NPK (macro nutrients) and application of micro nutrients in rice fields can be effective for rice yields in Pakistan.

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