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Impact of Climate Change on Crops' Productivity across Selected Agro-ecological Zones in Pakistan

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This study estimates the impact of major climate variables (temperature and rainfall) on crops' productivity across four agro-ecological zones of Pakistan. The crops selected were rice, wheat, maize, cotton and sugarcane. The study used panel data from 1991 to 2010 and applied panel least square techniques. The results revealed that the effect of climatic variables on crops yield varied across agro climatic zone due to differences in their climate conditions. Temperature and rainfall were the important determinants affecting crops productivity across agro climatic zones of Pakistan. Wheat productivity has been impacted more in Northern Irrigated Plain-a by average temperature and in Northern Dry Mountains by rainfall than the other zones. Rice productivity has been impacted more in Dry Mountains by average temperature and in the Indus Delta by rainfall than other zones. Sugarcane productivity has been impacted more by average temperature and rainfall in Indus Delta than zone IV. Maize productivity has been impacted more by average temperature and rainfall in Northern Dry Mountains than other zones. Finally the study recommends proper mitigative and adaptative strategies to enhance the positive and lessen the adverse impact of climate change on crops productivity across agro climatic zones of Pakistan.

JEL Classifications: Q15, Q54, Q57
Keywords: Climate Change, Agro-ecological Zones, Rainfall, Temperature, Productivity

INTRODUCTION

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity [IPCC (2007)]. Climate change defines changes in the variability or average state of the atmosphere over time scales ranging from a decade to millions of years or "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" [UNFCCC (1992)].

In the South Asian Regions climate change is a serious challenge for human societies and economies due to their ecological and geographical variations. Countries with large population are living along river deltas and coastal lines are more prone to the adverse impact of the climate change. There are certain clear evidences of climate changes in these countries like, recession of Himalayan glaciers, changes in marine ecosystems and rainfall variability [Mustafa (2011)].

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Like in other developing countries, climate change in Pakistan is a serious concern with its tremendous environmental, social and economic impacts. Pakistan has a diverse climate ranges from mild winters and hot, dry summers in the north to semi-arid and arid zones in the west and the south. Annual rainfall in the country varies from 50mm in arid and semi-arid areas to 2000mm in moist forests. The temperature varies by altitude to below freezing in northern mountains during winter to 35–50°C in central and southern plains during summer [Ahmad, *et al*. (2007)]. The country's mean annual temperature and precipitation increased by 0.6°C and 25 percent during the previous century (1901-2000) respectively [Sheikh, *et al*. (2009)]. IPCC Fourth Assessment Report (2007) revealed that in the northern region of Pakistan rains would increase. So due to changes in climatic parameters (rainfall and temperature), the country is exposed to natural threats like droughts, floods, intense rains and cyclones. When these hazards combine with the vulnerabilities in the form of exclusion, poverty and incongruous political decisions and actions, then it makes people more vulnerable to the impacts of the climate change [Mustafa (2011)]. Pakistan is at 28th place among the countries which are highly vulnerable to the adverse impact of climate change. Pakistan is also included in World Bank's list of 12 highly exposed countries to climate change [Shakoor, *et al.* (2011)]. Such high degree of vulnerability of the country to climate change is due to resource, technological and institutional constraints.

Climate Change and Agriculture Sector of Pakistan

Global climate change affect all economic sectors to some degree, but agricultural sector is the most sensitive and vulnerable to the adverse effect of the climate change as world agriculture, whether in developing or developed countries, remains very dependent on climatic resources. Agriculture productivity is associated with various factors of climate change including temperature hike, changes in rainfall pattern, changes in sowing and harvesting dates, evapo-transpiration, water availability, high concentration of CO_2 and land suitability [Alexandrov, *et al.* (2000)]. In poor parts of the world agriculture sector is more vulnerable to the effects of climate change because crops production in these parts of the world is low technology based, current information about agriculture is poor and the domestic economies are heavily depends on the agriculture for their livelihoods. The impact of climate change on agricultural sector varies from region to region. Countries which are lying in the temperate regions would take advantages of the climatic changes, while tropical and sub-tropical regions would face opposing results [Janjua, *et al*. (2011)].

Pakistan's status as a developing country is dependent mainly on the agriculture sector. Agriculture contributes 21 percent to the GDP and employs 44 percent of workforce. More than two-third (62 percent) of the country's population lives in rural areas and their livelihood depends on agricultural and agro-based activities [Government of Pakistan (2010)]. Two types of crops are grown in a year in Pakistan i.e. Rabi crops (Oct-April) which includes wheat, barley, Gram and Oil seeds and Khraif crops (May-Oct) include Rice, Maize, Sorghum, Millets, cotton, sugarcane. As the country is lying in an arid and semi-arid region and is heavily dependent on irrigated agriculture and is facing the adverse impact of climate change with higher glacial melt, prolonged droughts, hot winters and early summers. The effects of climate change are relatively more pronounced in Pakistan due to its over-reliance on the environment for basic survival, high population growth rate and density, low capacity to mitigate the negative impacts of climate change, and poverty. These long term impacts of climate change are expected to threaten our biodiversity (loss of species and their habitats), water availability, food security, human health and overall well-being. In spite of such a high degree of vulnerability of agriculture to climate change in developing countries, little research work has been done and very limited in case of Pakistan.

In the past some researchers worked on the impact of climate change on farm revenue such as Shakoor, *et al.* (2011) and Tunde, *et al.* (2011) while some worked on the impact of climate change on the agricultural production in Pakistan such as Lee, *et al.* (2012), Ayinde, *et al.* (2010) and Chaga (2002). Many studies also focused on the impact of climate change on the specific crop productivity in various countries such as Sarker, *et al. (*2012); Siddiqui, *et al.* (2012), Janjua, *et al.* (2011), Ashfaq, *et al.* (2011), Prakash, *et al.* (2011), Nwajiuba and Onyeneke (2010), Chaudhari, *et al.* (2009), Kalra, *et al.* (2008), Tao, *et al.* (2008), Kaul (2007), Hussain and Mudasser (2006), Binbol, *et al.* (2006), Peng, *et al.* (2004), Gbetibouo and Hassan (2004), Torvanger, *et al.* (2004), Ozkan and Akcaoz (2002) and Alexandrov, *et al.* (2002). Some of the researchers such as Li, *et al.* (2015), Asseng, *et al.* (2015) and Burke, Hsiang and Miguel (2015) found that climatic variability affects crops yield.

It is also a fact that the climatic effects cannot be bound to specific districts and these effects are also not drastically different within same district/locality. Their effects vary, mainly across ecological zones of the region. Looking at this perspective, this study answers whether the climate variables i.e. rainfall and temperature affect productivity of major agricultural crops (wheat, rice, maize, sugarcane and cotton) across the agro climatic zones in Pakistan.

Theoretical Background

In the past researchers used various approaches to estimate the relationship between crop productivity and climate change. Ricardian approach was used by Mendelsohn and Dinar (1999), Seo and Mendelsohn (2008). Agronomic crop simulation model was used by Reddy, *et al*. (2002). The production function approach was proposed by many researchers such as Mundlak, (1978), Mundlak, *et al.* (1999), Cabas, *et al.* (2010). The production function approach is easy to apply [Haim, Shechter, and Berliner (2008)] and also minimise the chance of endogeniety [Holst, Yu, and Grun (2010)], therefore, in present study this approach is followed.

This model basically predicts two phenomenon production (Q_i) and inputs (K_i). On the basis of previous research [Rosenzweg and Iglesias (1994)] yield per hectare of each crop is a function of climate, soils and other inputs which can be written as,

$$Q = Q_i\,(K_i, E) + u_i$$

Where $i = 1,., n$ and

Q = a vector of production

K_i = a vector of all inputs in the production of good i.

E = a vector of exogenous environmental inputs like precipitation, temperature and soil condition.

u_i= an error term.

Different studies have estimated the production function approach by including environmental variables such as temperature and rainfall. On the basis of estimated production function, change in production due to climate variables was analysed [Alexandrov and Hoogenboom (2000); Olsen (2000)]. The estimated change in production due to climate variables either aggregated to capture the overall national impact or integrated into an economic model to estimate the welfare impacts climate change on yield [Olsen, Jensen, and Petersen (2000); Chang (2002)].

Total factor productivity (TFP) and Partial factor productivity (PFP) are the important concepts of production function. TFP accounts for the effects in total output which is not caused by the traditionally measured inputs like labor, land or capital. TFP growth measures the increase in production due to technological and institutional changes rather than increased by the use of inputs. PFP refers to the average productivity of a single factor which can be measured by the output divided by the quantity of that applied factor. The current study uses the PFP of crops across selected zones where the crop productivity is obtained by dividing the total production by the area which is covered by that crop. The current study used yield as a dependent variable to measure the potential impacts of climatic variables (temperature and rainfall) on crops productivity. This study used the historical data of crop yields and climatic variables while the other inputs are not included in the model due to non-availability of data across districts in agro climatic zones of Pakistan.

The study includes separately maximum temperature, minimum temperature, average temperature and precipitation. As minimum temperature refers to the lowest night-time temperature while maximum temperature represents the day time highest temperature [Rasul, *et al.* (2012)]. Mean air temperature is widely used to evaluate the effects of global warming on grain yield. But the use of only mean air temperature assumes no difference in the impact of day versus night temperature. So the inclusion of maximum and minimum temperatures will capture differential effects of day and night temperature [Peng, *et al.* (2004)].

MATERIALS AND METHODS

Nature of Data and its Sources

To assess the impact of climate change (rainfall and temperature) on yield of crops in the selected agro-ecological zones of Pakistan, balanced panel data has been used, covering time period ranging from 1990-91 to 2009- 10. Major variables which are used in the study are crops yield, three different temperature ranges (minimum, maximum temperatures and average temperature) and precipitation. Yield of major crops such as wheat, rice, maize, cotton and sugarcane measured in kilograms per hectare (kgs/hect) is considered for the study. In the Indus Delta (Zone I) the crops yield data is used from 1990-91 to 2008-09 on the basis of its availability. In case of Lahore, cotton is excluded due to its low production in the region. District wise yield data of each crop is taken from Federal Bureau of Statistics (1982–2009), Khyber Pakhtunkhwa Development Statistics (2010), Punjab Development Statistics (2011) and Statistical Pocket Book of the Punjab (2011). District level climate data is taken from Pakistan Meteorological Department, Islamabad.

Description of Selected Agro-ecological Zones

In Pakistan, variations exist in climate, altitude, geography, soil, season and culture. The country has ten agro-ecological zones/regions divided on the basis of variations in physiographic, soil composition, climate, agriculture land use and many other factors that affect agriculture [PARC (1980); Muhammad (1986)]. These main agro-ecological zones of Pakistan are Indus Delta, Southern Irrigated Plain, Sandy Desert, Northern irrigated Plain, Barani (rainfall), Wet Mountains, Northern dry mountains, Western Dry Mountains, Dry western Plateau and Suleiman Piedmont.

This study is confined to four agro climatic zones of Pakistan namely, Indus Delta, Northern irrigated plains (a) and (b), Wet Mountains and Northern Dry Mountains. The selection of the region is subject to the availability of the data.

To evaluate the impact of climate change on crops productivity the following four agro-ecological zones of Pakistan are selected for the study namely,

(i) Indus Delta (Zone I).
(ii) Northern irrigated plains (a) and (b) (Zone IV).
(iii) Wet Mountains (Zone VI) and
(iv) Northern Dry Mountains (Zone VII).

Northern irrigated plains (a) and (b) (Zone IV) have been selected as these are the major crops growing zones. As far as Wet Mountains (Zone VI) and Northern Dry Mountains (Zone VII) regions are concerned, these regions are more prone to small changes in climatic variables (rainfall and temperature) due to their fragile nature, steep gradient, topography and diversity of environment [Hussain, *et al.* (2005)]. As a rise in temperature in such regions leads to glacial run off and melts permafrost that accelerates soil erosion, landslides and floods etc. The Indus Delta (Zone I) is a large area of fertile land feeding a large proportion of population and already facing the impacts of climate change in the form of prolonged heat waves, high frequency of torrential rains, persistent drought and flooding [Rasul, *et al*. (2012)]. The melting of glaciers in the North also results in raising of sea level that leads to intrusion of saline sea water that can affect the fertile agricultural land of Indus Delta.

The production of major crops varies across zones because of the differences in their climate conditions as well as crops cultivation pattern. Major crops from each region are selected on the basis of percentage share of area covered by each crop and production in the region. Only those regions are selected from each zone where the meteorological observatory stations (climate stations) are available. In Indus Delta (Zone I) two regions i.e. Badin and Hyderabad are selected on the basis of the availability of climate observatory stations. Three main crops namely, wheat, rice and sugarcane are chosen from Indus Delta (Zone I) because these are the major crops on the basis of production (sugarcane 85.1 percent, rice 8.7 percent and wheat 3.4 percent) and area (rice 47.8 percent, sugarcane 27.5 percent and wheat 18.2 percent) covered by the crops. The selected crops, their percent share with respect to area and production and the selected regions from each zone are detailed in Table 1. For robust analysis, the average crop water requirements of major crops along with the required temperature are also given in Table 2. Deviation from the required level of water and temperature will adversely affect

Table 1

Selection of Study Area, Crops and Its Share

Zone	Crops included	Selected Regions	% Share of Crops with Respect to Area	% Share of Crops with Respect to Production
Indus Delta (Zone I)	Wheat, Rice, Sugarcane	Badin, Hyderabad	Rice 47.8 Sugarcane 27.5 Wheat 18.2	Sugarcane 85.1 Rice 8.7 Wheat 3.4
Northern Irrigated Plains (a)(Zone IV)	Wheat, Rice, Maize, Cotton, Sugarcane	Multan, Lahore, Bahawalnagar, Faisalabad	Wheat 51.1 Cotton 20.2 Rice 17.8 Maize 5.9 Sugarcane 4.3	Sugarcane 42.2 wheat 29.7 Cotton 14 Rice 7.3 Maize 6.9
Northern Irrigated Plains(b)	Wheat, Maize, Sugarcane	Peshawar, Nowshera	Wheat 40.7 Maize 29.1 Sugarcane 22.4	Sugarcane 81.5 Wheat 8.7 Maize 7.7
Wet Mountains (Zone VI)	Wheat, Maize	Abbottabad, Mansehra	Maize 56.9 Wheat 41.6	Wheat 46.7 Maize 51.7
Northern Dry Mountains (Zone VII)	Wheat, Maize, Rice	Chitral, Swat	Wheat 65.1 Maize 29.2 Rice 5.5	Wheat 62.8 Maize 28.5 Rice 8.6

Table 2

Temperature Thresholds and Average Crop Water Requirements

Crop	Temperature/Water Requirements		
Wheat	Temperature	Minimum	3-4 °C
		Optimum	25°C
		Maximum	30-34°C
	Crop Water requirement		480 mm
Rice	Temperature	Minimum	10-12°C
		Optimum	30-32°C
		Maximum	36-38°C
	Crop Water requirement		1500 mm
Cotton	Temperature	Minimum	20 °C
		Optimum	27-35°C
		Maximum	42-45°C
	Crop Water requirement		620 mm
Maize	Temperature	Minimum	16.7 - 23.3 °C
		Optimum	20- 22.7 °C
		Maximum	22 – 32 °C
	Crop Water requirement		550 mm

Source: Riaz (2001); Siddiqui, *et al*. (2011).

crops productivity. Sugarcane Research Institute Faisalabad divided the sugarcane production into four stages of production. Each stage requires specific temperature level during the development.

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

Comment [T1]: tilling

The optimum rainfall for sugarcane is 1250-2500 mm.

Analytical Techniques

Panel Least Square Estimation Techniques

Fixed effect and random effect models are generally used for a panel data analysis [Baltagi (2008)]. This study is based on the balanced panel data and therefore, used Fixed Effect Model (FEM) and Random Effect Model (REM) detailed as under:

Fixed Effect Model (FEM)

Fixed Effect Model (FEM) using dummy variables is also known as the least square dummy variable model. FEM have constant slopes but different intercept according to time. In FEM the intercept is a group specific which means that the model allows for different intercepts for each group. The variation in the intercept may be due to unobserved factors. These unobserved factors vary across entities but are constant over time [Stock and Watson (2003)]. The time invariant characteristics (like gender, race, culture etc.) of the cross sections are perfectly collinear with other cross sections dummies. The FEM model controls all the time invariant differences between the individuals, therefore due to omitted time invariant factors the estimated coefficients of FEM cannot be biased. Basically fixed effect model are design to study the causes of changes within entities. As the time invariant factor is constant for each entity so it cannot cause such a change. The applied form of FEM for the study taken the form:

$$Y_{it}=\alpha_i+\beta_1(RF)_{it}+\beta_2(Tem)_{it}+u_{it}$$

Where

α_{i} = Constant term
Y_{it} = Yield per hectare in i_{th} district for time period t (yield in kgs/hect).
RF_{it} = Average Rabi (October-March) and Khraif (April-September) precipitation in i_{th} district for time period t. The total monthly rainfall data is grouped into crops seasonal average on the basis of their sowing and harvesting periods. Both the Kharif and Rabi seasons rainfall is measured in millimetre (mm).
$Temp_{it}$= Average Rabi (October-March), Khraif (April-September) temperatures and the average of maximum and minimum Rabi and Khraif temperatures in the i_{th} district for the time period t. Monthly temperatures data is also converted into crops seasonal average on basis of growing and harvesting period of crops. Average temperature, mean of maximum and minimum

temperatures for both the Kharif and Rabi seasons are measured in degree Celsius (^{0}C).

Random Effect Model (REM)

The basic logic of random effect model is that the variation across entities is supposed to be random and not correlated with those independent or predictor variables which are included in the model. It assumes that the entity's error term is uncorrelated with the explanatory variables which allows for time invariant variables to act as explanatory variables. The basic advantage of REM is that it includes time invariant variables while FEM absorbed these variables by the intercept. In REM there is a need to specify those individual features that may or may not affect the predicator variables. Some variables may be available or not therefore it leads to the problem of omitted variable bias in the model.

For the study the applied form of REM is,

$$Y_{it}=\alpha_i+ \beta_1(RF)_{it}+ \beta_2(Tem)_{it} +\varepsilon_{it}$$

While $\varepsilon_{it} = \lambda_i+ u_{it}\lambda_i$ is now part of error term

As u_{it} is between entity error and ε_{it} is within entity error term.

α_i = Constant term

Y_{it} = Yield per hectare in i_{th} district for time period t (yield in kgs/hect).

RF_{it} =Average Rabi (October-March) and Khraif (April-September) precipitation in i_{th} district for time period t (in mm).

$Temp_{it}$= Average Rabi and Khraif temperature and the average of maximum and minimum Rabi and Khraif temperatures in the i_{th} district for the time period t (in Degree Celsius = ° C).

To select the appropriate model out of FEM and REM, Hausman test is used. The basic assumption of this test is that the preferred model is random effects over the fixed effects [Green (2008)]. It basically tests whether the error term (u_i)are correlated with the regressors or not. The null hypothesis for this test is that the Random Effects model coefficients are consistent and efficient. The Hausman test statistics is:

$$H = (ß^{\wedge FE} - ß^{\wedge RE}) [var (ß^{\wedge FE}) - var (ß^{\wedge RE})]^{-1}(ß^{\wedge FE} - ß^{\wedge RE}) \sim \chi^2 k$$

H = Hausman test

$ß^{\wedge FE}$ = Coefficient of determination of the fixed effect

$ß^{\wedge RE}$= Coefficient of determination of the random effect

χ^2= Chi square statistic

k = degree of freedom.

The above models applied separately for each crop i.e. wheat, rice, maize, cotton and sugarcane. However, the appropriate model was selected on the basis of Hausman test results. In this study different panels based on each agro climatic zones have been made. The inclusion of the districts in each panel is subject to availability of data in that particular zone. It is important to mention that REM is applied only for Northern irrigated plain a (Zone IV) because this zone included four cross sections and the estimation of random effects model requires that number of cross section should be greater than the number of coefficients for between estimators for estimate of RE innovation variance.

The results of Housman test suggested that REM is the appropriate model only for rice and maize crops and FEM is the suitable model for wheat, cotton and sugarcane crops in Northern irrigated plain a (Zone IV). For Indus Delta (Zone I), Northern Irrigated plain b (Zone IV), Wet Mountains (Zone VI) and Northern Dry Mountains (Zone VII) only FEM is applied because each zone includes only two regions.

RESULTS AND DISCUSSION

Climate–Yield Relationship in Indus Delta (Zone I)

The results in Table 3 show that seasonal mean minimum temperature (Tn) is positively related to rice, wheat and sugarcane yield. As Tn increases, rice and wheat yield also increases. More specifically one degree (1°C) rise in Tn increases rice and wheat yield by 76.25 kgs/hect and 143.7 kg/hect respectively. The relationship is also in line with the study of Tao, *et al*. (2008). Similarly 1°C increase in minimum temperature increases sugarcane yield by 1207.9 kgs/hect. For rice, wheat and sugarcane, the minimum temperature is statistically significant.

Table 3

Regression Results of the Impact of Temperature and Rainfall on Crops Productivity in Indus Delta (Zone I)

	Coefficients with Average Minimum Temperature and Rainfall			Coefficients with Average Maximum Temperature and Rainfall			Coefficients with Average Temperature and Rainfall		
Variables	Rice	Sugarcane	Wheat	Rice	Sugarcane	Wheat	Rice	Sugarcane	Wheat
Constant	–11.002	–11.942	–5.208	3.190	38.145	–2.067	–3.134	12.668	–4.965
Temperature	76.258***	1207.932***	143.745***	51.282***	1452.006***	75.019***	61.719***	1719.998***	98.786***
Rainfall	5.212***	68.614**	– 12.385	5.589***	77.387**	–9.570	5.433***	73.657**	–10.752
Diagnostics									
R-squared	0.889	0.958	0.863	0.884	0.954	0.855	0.886	0.956	0.859
Adj- Rsq	0.888	0.956	0.858	0.877	0.953	0.849	0.879	0.954	0.853
F-statistic	134.402	545.176	151.502	127.931	508.006	142.069	133.549	524.638	146.854
Prob(F-stat)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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

The coefficient of rainfall shows that there is a positive and significant relationship between rice, sugarcane yield and rainfall. As rainfall increases the productivity of these two mention crops also increases. More specifically 1mm (millimetre) increase in rainfall increases rice and sugarcane yield by 5.21 kgs/hect and 68.61 kgs/hect respectively. The results further reveal that wheat productivity responds negatively to the increase in rainfall but its coefficient is statistically insignificant. A significant increase in rainfall may result in lower wheat productivity but at this point of time a marginal increase in rainfall is not going to affect the productivity of wheat considerably. Similar findings were also derived by Tao, *et al.* (2008) while analysing the impact of seasonal precipitation on wheat yield.

Furthermore, mean Maximum Temperature (Tm) is positively related to the yield of major food crops i.e. wheat, rice and sugarcane. More specifically, 1^oC increase in maximum temperature increases wheat yield by 75.01 kgs/hect. The positive result for wheat yield and Tm is quite consistent with the findings of Prakash, *et al*. (2011). Similarly 1^oC increase in Tm increases rice and sugarcane yield by the amount of 51.28

kgs/hect and 1452 kgs/hect respectively which is in line with the study of Sarker, *et al.* (2012). For these three major crops (rice, wheat, sugarcane) maximum temperature is statistically significant. The recommended maximum temperature limit for wheat and rice is 30–34°C and 36–38°C respectively [Siddiqui, *et al.* (2012)]. In the study area the average maximum temperature for wheat and rice ranges from 29.3 to 31.4 °C and 35.5–38.7 °C respectively. So average maximum temperature data from 1991–2010 is in line with the recommended ranges, therefore increase in Tm during the study period is not affecting crops productivity adversely.

The results in Table 3 show that the coefficient of rainfall has a positive impact on the yield of rice and sugarcane. More specifically 1 mm (millimeter) increase in rainfall increases rice and sugarcane yields by 5.58 kgs/hect and 77.3 kgs/hect respectively. The positive response of rice yield to increase in Tm and rainfall is in line with the findings of Sarker, *et al.* (2012) and Prakash, *et al.* (2011). The coefficient of rainfall is statistically significant for sugarcane and rice yield. The results also reveal that rainfall is negatively related to wheat yield but its coefficient is statistically insignificant.

Besides, Table 3 show that there is a positive and significant relationship between average temperature and yield of the three crops i.e. rice, sugarcane and wheat, as average temperature increase yield of the respective crops also increases. More specifically, 1°C increase in average temperature increase wheat yield by 98.78 kg/ hect which is similar to the findings of Janjua, *et al*. (2011). They found a positive response of wheat yield to increase in average temperature in Pakistan. Similarly 1°C increase in average temperature increases the rice and sugarcane yield by 61.71 kg/hect, and 1719.9 kg/hect respectively. This effect is statistically significant for these three crops. The recommended optimum temperature for wheat and rice are 25°C and 30–32°C respectively [Siddiqui, *et al.* (2012)]. In the study area the average temperature during wheat and rice growing seasons in the last 20 years ranged from 22 to 23.8 °C and 30–32.3 °C respectively. So the metrological data for last 20 years lies within the optimum temperature limits, therefore it effects crops yield positively.

The sign of rainfall coefficient shows that it has positive effect on rice and sugarcane yield. As rainfall increases yield of these two crops increases. For rice and sugarcane, the rainfall coefficient is statistically significant. The results show that seasonal rainfall has negative impact on wheat yield followed by statistically insignificant coefficient. The diagnostics derived also favour the model estimated.

In case of all three different temperature ranges (minimum, maximum and average) in Indus Delta, increase in summer rainfall favors both rice and sugarcane crops because both are water demanding crops and need more water. The recommended water requirements of rice and sugarcane is 1500 mm and 1800 mm respectively [Riaz (2001)] which is very high while climate of the region is arid where summer mean monthly rainfall is about 75 mm. Therefore, increase in summer rainfall is beneficial for the productivity of aforementioned crops. There is negative relationship between wheat yield and Rabi rainfall. It may be due to the fact that in these regions a strong and supplementary irrigation system is available which can meet the water requirement of wheat crop. Therefore increase in Rabi rainfall may not have favoured wheat productivity in Indus Delta during the last 20 years.

As Indus Delta is located in climatically arid zone of extreme heat and highly variable rainfall therefore vulnerable to the problems related to climate change like droughts and floods, saline water intrusion, increased crop water requirements [Rasul, *et al.* (2012)]. Being nearer to the sea all the phenomenal changes due to global warming over the sea and land can affect it in future. The results of the study showed that during last twenty years (1990-91 to 2009-10) there is no negative impact of the increased temperature on crops yield in Indus Delta. In order to enhance the positive impact of climate change on crops productivity in the future in such warmer areas proper adaptation techniques must be considered like developing new heat and drought resistant crop varieties, shifting in sowing and harvesting dates to avoid intense heat.

Climate Yield Relationship in Northern Irrigated Plain a (Zone IV)

The results in Table 4 indicates that mean minimum temperature (Tn) has a positive and statistically significant impact on major crops such as rice, Sugarcane, Cotton and Wheat while affects maize yield negatively, in the Northern Irrigated plain regions of Punjab. More specifically, 1 ^{0}C increase in Tn increases yield of rice, Sugarcane, Cotton, and Wheat by 58.6 kgs/hect, 1719.25 kgs/hect, 19.94 kgs/hect and 208.73 kgs/hect respectively. Some crops like sugarcane, cotton and rice are tropical crops that require a warm and humid climate for different stages of growth and development. Wheat crop requires optimal temperature for germination and it take place between 4-37^{0}C, optimal temperature starts from 12–25 ^{0}C [Spilde (1989)]. In the study area the average minimum temperature during rabi season ranges from 8.3- 13.6 ^{0}C in last 20 years. Therefore increase in Tn during last 20 years (1991-2010) is not effecting aforementioned crops yield adversely. The result further explores that increase in Tn affects maize yield adversely. More specifically, 1 ^{0}C increase in Tn reduces maize yield by 98.25 kgs/hect. The optimal night temperature for maize plant ranges from 16.7 to 23.3^{o}C [Khaliq (2008)] while the average minimum temperature of the study area during maize growing season ranges from 24.2- 27.2 ^{o}C in 1991-2010. This show divergence from the critical limit therefore reduces maize yield.

The sign of rainfall coefficient show that it has a positive effect on rice, sugarcane, cotton, maize and wheat yield. As rainfall increases yield of these aforementioned crops also increases. More specifically, 1 mm increase in rainfall increases maize yield by 0.69 kgs/hec which is in line with the study of Tunde, *et al.* (2011). The results also show that 1 mm increase in rainfall, increases wheat yield by 6.37 kgs/hec. Prakash, *et al.* (2011) also obtained similar positive impact of winter rain and minimum temperature on wheat yield. Ashfaq, *et al.* (2011) also concluded that the adequate amount of rainfall increased wheat productivity by 275.77 kg ha-1 in Punjab. Similarly 1 mm increase in rainfall increases rice, sugarcane and cotton yields by 0.92 kgs/hect, 6.0kgs/hect and 0.73 kgs/hect respectively. The positive impact of Tn and rainfall on rice crop is in line with the results of Sarker, *et al.* (2012). For cotton, maize and wheat rainfall is statistically significant while for rice and sugarcane crops the rainfall coefficient is insignificant. The diagnostics derived also favoured the model estimated.

Table 4

Regression Results of the Impact of Average Minimum Temperature and Rainfall on Crops Yield in Northern Irrigated Plain a (Zone IV)

	Coefficient of				
Variables	Rice	Sugarcane	Maize	Cotton	Wheat
Constant	6.182	14.618	–186.760	0.146	84.264*
Minimum temperature	58.652***	1719.254***	–98.251*	19.942***	208.760***
Rainfall	0.926	6.087	0.699*	0.734*	6.379***
Diagnostics					
R-squared	0.963	0.966514	0.945921	0.91179	0.976684
Adj- Rsq	0.963	0.979581	0.944766	0.90978	0.976186
F-statistic	1659.195	1812.366	819.1808	473.731	1961.799
Prob(F-stat)	0.000	0.00000	0.00000	0.00000	0.00000
Chi sq.stat 0.46849		Chi sq stat 24.173	Chi sq stat 0.846	Chi.sq.stat 16.661	Chi sq.stat. 48.565
Prob. 0.7912		Prob. 0.000	Prob 0.654	Prob.0.000	Prob.0.000

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

The results reported in Table 5 indicate that maximum temperature (Tm) has a positive effect on major crops (Rice, Sugarcane, cotton, and Wheat), as Tm increase yield of these major crops increases as well. More specifically, 1^0C increase in Tm increases rice, sugarcane, cotton and wheat yield by 38.35 kgs/hect, 1152.59 kgs/hect, 1.64 kgs/hect and 92.1 kgs/hect respectively. Hanif, *et al.* (2010) also found that increase in Rabi mean maximum temperature increased wheat yield in Punjab because wheat crop need heat for maturation. The results further show that maize yield is negatively related to Tm i.e. 1^0C increase in Tm decreases maize yield by 87.23 kgs/hect. The adverse impact of Tm on maize yield is in line with the findings of Prakash, *et al*. (2011). The negative relationship can be justified on the grounds that maize crop requires optimal day temperature from 22 to 32^0C [Khaliq (2008)] while the average maximum temperature (day temperature) of the study area during maize growing season ranges from 36.6 to 39.9 ^{0}C in last twenty years which shows larger deviation from the recommended threshold level. Temperature falls to 5^0C or above 32^0C can affect yield of maize adversely. Maize crop growth enhanced at the temperature from 22–32^0C because at this temperature, rate of photosynthesis is higher than losses due to respiration. So Tm above 32^0C may affect maize crop yield negatively in these plain areas of Punjab. As increase in temperature affected maize productivity adversely in the last 20 years so there is a need to introduce high temperature tolerant maize cultivars.

The required maximum temperature for wheat, rice and cotton are in ranges from 30-34^0C, 36-38°C, and 42-45^0C respectively [Siddiqui, *et al.* (2012)]. The average maximum temperature of the study area during Rabi and Kharif growing seasons in last 20 years are ranges from 24.1-27.5 ^{0}C and 35.9-40.6^0C respectively which show that the data is within the recommended threshold. Therefore not effecting wheat, rice, cotton and sugarcane crops yield adversely. For these aforementioned crops the coefficient of Tm is also statistically significant. The sign of rainfall coefficients show that the productivity of major crops (rice, cotton, sugarcane, maize and wheat) responds positively to changes in rainfall. For wheat, maize and cotton the rainfall coefficient is statistically significant while for rice and sugarcane crops its coefficient is statistically insignificant. The diagnostics derived also favour the model estimated.

Table 5

Regression Results of the Impact of Average Maximum Temperature and Rainfall on Crops Yield in Northern Irrigated Plain a (Zone IV)

	Coefficients of				
Variables	Rice	Sugarcane	Maize	Cotton	Wheat
Constant	13.339	4.658	–143.897	444.216	7.911
Maximum Temperature	38.351***	1152.596***	–87.238**	1.648***	92.107***
Rainfall	1.281	5.166	0.331	0.887**	0.923**
Diagnostics					
R-squared	0.960	0.968	0.946	0.984	0.987
Adj- Rsq	0.959	0.967	0.945	0.983	0.986
F-statistic	1510.670	1896.222	827.940	9.346	3511.725
Prob(F-stat)	0.000	0.000	0.000	0.000	0.000
Chi sq. stat 0.447 Prob. 0.799	Chi sq. stat 2.756 Prob. 0.252	Chi sq. stat 0.203 Prob. 0.903	Chi sq. stat 26.023 Prob. 0.000	Chi sq. stat 21.174 Prob. 0.000	

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

The results reported in Table 6 indicate that average temperature has a positive influence on the yield of major crops (Rice, Sugarcane, Cotton and Wheat) in Northern Irrigated plain areas of Punjab. As average temperature increases, yield of these major crops increases as well. More specifically, 1°C increase in average temperature increases rice, sugarcane, cotton and wheat yield by 46.5 kgs/hect, 1381.3 kgs/hect, 15.9 kgs/hect and 133.6 kgs/hect respectively. The result revealed that an increase in average temperature effects maize yield negatively and reduces it by 109.46 kgs/hect. According to Wiatrak, *et al.* (2006) the optimal average temperatures for maize growth ranges from 20 to 22.7 °C while the average temperature of the study area in last 20 years ranges from 30 to 34.2 °C which shows clear deviation from the recommended limit. As this zone includes plain area from Punjab where irrigation water is already in stress condition and increase in temperature above 32°C is harmful for maize yield especially during tasseling, silking and grain filing stages. Therefore increase in average temperature affected maize yield adversely.

Table 6

Regression Results of the Impact of Average Temperature and Rainfall on Crops Yields in Northern Irrigated Plain a (Zone IV)

	Coefficients of				
Variables	Rice	Sugarcane	Maize	Cotton	Wheat
Constant	9.246	1.179	–154.237	–0.042	–7.393
Average Temperature	46.577***	1381.392***	–109.469**	15.901***	133.674***
Rainfall	1.136	0.359	0.140*	0.805**	1.424**
Diagnostics					
R-squared	0.961	0.980	0.946	0.955	0.975
Adj- Rsq	0.960	0.979	0.945	0.953	0.974
F-statistic	1575.248	2444.429	826.795	476.191	1867.659
Prob(F-stat)	0.000	0.000	0.000	0.000	0.000
Chi Sq. stat 0.563 Prob.0.754	Chi Sq. stat 19.800 Prob 0.000	Chi Sq. stat 0.354 Prob. 0.837	Chi Sq. stat 17.685 Prob. 0.000	Chi Sq. stat 6.961 Prob 0.0308	

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

The sign of rainfall coefficient show that it is positively related to wheat, rice, sugarcane, cotton yield and maize yield. More specifically, 1mm increase in rainfall increases rice, sugarcane, cotton, wheat and maize yield by 1.1 kgs/hect, 0.35 kgs/hect, 0.80 kgs/hect, 1.42kgs/hect and 0.14kgs/hect respectively. The results for wheat and average rainfall is in line with the finding of Janjua, *et al.* (2011) also found a significant positive impact of average temperature and rainfall on wheat productivity in Pakistan. For wheat, maize and cotton crops the rainfall variable is statistically significant while for sugarcane and rice its coefficient is insignificant.

Thus in case of three different temperatures ranges (minimum, maximum and average) the impact of rainfall on rice and sugarcane yield is positive but statistically insignificant. As both rice and sugarcane are water intensive crops and require sufficient amount of rainfall during growing season. These crops can be grown in the regions where annual rainfall is more than 40 inches while in Pakistan annual average rainfall is less than 20 inches [Siddiqui, *et al*. (2010)] which is insufficient. Cotton requires about 620 mm [Riaz (2001)] while maize requires up to 700 mm [Rasul (2010)] of water during the whole growing period which is high. In plain areas of Punjab annual rainfall ranges from 300-500 mm in the south west and 200-300 mm in the east [PARC (1980); Muhammad (1986)] which is very low as compared to the actual water requirements of major crops. Therefore the area which has little or no rainfall during the growing period, irrigation is crucial for agricultural crops. Therefore the deficiency of rainfall can be met by means of artificial irrigation arrangements like tube wells and canals. So increase in rainfall favors crops productivity in such areas.

As Northern irrigated plain a (Zone IV) which are included regions from Punjab having arid to semi-arid type of climate with the highest summer temperature (40-43 ^{0}C). Therefore there is need to cultivate high yielding crop varieties to cope with the expected increase in temperature in future.

Comment [T2]:

Climate—Yield Relationship in Northern Irrigated Plain b (Zone IV)

The results given in Table 7 show that minimum temperature (Tn) is positively related to wheat, maize and sugarcane yields. As Tn increases yield of these three major crops also increases. More specifically 1°C rise in Tn increases wheat, sugarcane and maize yield by 234.26 kgs/hec, 1247 kgs/hec and 74 kg/hect respectively. The positive relationship for wheat and maize yield is also in line with the study of Tao, *et al.* (2008). The coefficient of Tn is also statistically significant for these three crops. The required minimum temperature for wheat and maize ranges from 3-4°C and 16-23.3°C respectively [Siddiqui, *et al.* (2012)]. The temperature data in last twenty years shows that the average minimum temperatures of the study area during Rabi and Kharif seasons ranges from 5.8-10.8 °C and 21.8 –24.5 °C respectively which show very little deviation from the recommended limits. It is due to the semi-arid and continental type climate of the regions, therefore slight increase in Tn is not affecting the crops productivity adversely. As for as sugarcane is concerned, which is a tropical crop, requires warm climate during the entire growth period. So temperature below 15°C and 40 °C are harmful the crop. The average minimum temperature of the study area is 21.8–24.5 °C during sugarcane growing season therefore Tn is not affecting cane productivity adversely.

Table 7

Regression Results of the Impact of Temperature and Rainfall on Crops Yields in Northern Irrigated Plain b (Zone IV)

	Coefficients with Average Minimum Temperature and Rainfall			Coefficients with Average Maximum Temperature and Rainfall			Coefficients with Average Temperature and Rainfall		
Variables	Wheat	Sugarcane	Maize	Wheat	Sugarcane	Maize	Wheat	Sugarcane	Maize
Constant	26.829	30.229	2.592	–1.471	29.728	–0.379	119.000*	12.340	0.171
Temperature	234.261***	1247.252***	74.042***	81.901***	1373.842***	47.917***	116.474***	1679.553***	58.320***
Rainfall	0.327	18.7630***	3.314***	1.462	9.327*	2.782***	0.334	11.786**	2.948***
Diagnostics									
R-squared	0.942	0.998	0.968	0.966	0.967	0.972	0.841	0.998	0.971
Adj- Rsq	0.939	0.997	0.966	0.964	0.966	0.971	0.834	0.997	0.970
F-statistic	390.510	12416.87	760.740	677.079	9399.528	893.525	126.941	15590.71	853.194
Prob(F-stat)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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

The sign of rainfall coefficients show that there is a positive relationship between rainfall and yield of maize and sugarcane crops. One mm (millimetre) increase in rainfall increases maize and sugarcane yield by 3.31 kg/hec and 18.76307 kg/hec respectively. The results further reveal that rainfall is positively related to wheat yield but its coefficient is statistically insignificant. Torvanger, *et al*. (2004) also obtained similar positive and insignificant results for wheat yield and rainfall. For maize and sugarcane rainfall coefficient is statistically significant.

The results reported in Table 7 further show that maximum temperature (Tm) is positively related to wheat, maize and sugarcane yield. As Tm increases yields of all these three crops increases. More specifically, 1°C increase in Tm increases wheat, maize and sugarcane yield by 81.9 kg/hect, 47.9 kg/hect and 1373.842 kg/hect respectively. The coefficient of maximum temperature is statistically significant for wheat, maize and sugarcane. The average maximum temperature of the study area during Rabi and Kharif growing seasons ranges from 21.6–24.6 °C and 34.7–37.5°C respectively. These ranges are consistent with the required maximum temperature level of aforementioned crops therefore increase in Tm during the year 1991-2010 is not affecting the productivity of crops negatively. To enhance the positive impact of climate change on crops productivity, technology adoption and modification to farm management are also important aspects to reduce the losses due to climate change in such warmer areas.

The coefficient of rainfall shows that it is positively related with the yield of maize, sugarcane and wheat as rainfall increases yield of these three crops also increases. More specifically, 1 mm increase in rainfall increases maize and sugarcane yield by 2.78 kgs/hect and 9.32 kgs/hect respectively. Tunde, *et al.* (2011) also obtained similar positive results for rainfall and Tm on maize yield. For maize and sugarcane yield rainfall coefficient is statistically significant while it is insignificant for wheat yield.

Furthermore, average temperature is positively related to wheat, maize and sugarcane yield. As average temperature increases yield of these three aforementioned crops also increases. More specifically, 1°C increase in average temperature increases wheat, sugarcane and maize yield by 116.47 kgs/hect, 1679.55 kgs/hect and 58.32 kgs/hect respectively. The coefficient of average temperature is statistically significant for these three major crops (Table 7).

The coefficient of precipitation shows that it is positively related to the yield of these three major crops as precipitation increases yield of these crops increases as well.

More specifically, 1 mm increase in rainfall increases maize and sugarcane yield by 2.9 kgs/hect and 11.7 kgs/hect respectively. For maize and sugarcane rainfall, coefficient is statistically significant while for wheat it is insignificant. For maize yield the positive and statistically significant effect of temperature and rainfall is in line with the study of Nwajiuba and Onyeneke (2010).

Thus in case of the three different temperatures ranges (maximum, minimum and average) the impact of rainfall is positive and significant on maize and sugarcane yield. Maize is the crop that requires moderate amount of water therefore it can be grown in the areas with moderate rainfall even without irrigation [Sánchez-Cortés and Chavero (2011)]. As climate of the regions like Peshawar and Nowshera is semi-arid subtropical continental type where the monthly rainfall ranges from 20-32 mm both in winter and summer [PARC (1980); Muhammad (1986)], therefore increase in rainfall favours crops yield.

Climate–Yield Relationship in Wet Mountains (Zone VI)

The results reported in Table 8 show that the mean minimum temperature (Tn) is positively related with wheat and maize yield. As Tn increases yield of these two crops in these regions also increases and vice versa. One degree ($^{\circ}$C) rise in Tn increases wheat and maize yield by181.75 kgs/hect and 116.59 kgs/ hect respectively. These results are in line with the findings of Tao *et al* (2008).The relationship between Tn and yield of these two crops is statistically significant. As these are the mountains regions with mild summer and cold winter so slight increase in Tn is beneficial for the growth of wheat and maize crops. The increase in crops yield is due the fact that the average minimum temperature of the study area is laying within the require temperatures limits for both the crops. The recommended minimum temperature for wheat crop is about 3-4°C [Siddiqui, *et al.* (2012)] which is in line with the metrological data for these last 20 years which show that in Rabi season the average minimum temperature of the study area ranges from 3.9- 6.7 $^{\circ}$C. The optimal night temperature (Tn) for maize plant ranges from 16.7 to 23.3°C [Khaliq (2008)] and average minimum temperature of the study area during maize growing season ranges from 15.7 to 18.7°C. Any change in recommended minimum temperature below threshold level may affect the productivity of wheat and maize adversely.

Table 8

Regression Results of the Impact of Temperature and Rainfall on Crops Yields in Wet Mountains (Zone VI)

	Coefficients with Average Minimum Temperature and Rainfall		Coefficients with Average Maximum Temperature and Rainfall		Coefficients with Average Temperature and Rainfall	
Variables	Wheat	Maize	Wheat	Maize	Wheat	Maize
Constant	17.054	–0.310	0.512	–1.316	–1.323	–1.887
Temperature	181.752***	116.598***	53.921***	67.875***	87.955***	86.516***
Rainfall	7.020***	–3.139***	6.220***	–3.123***	5.650***	–3.227***
Diagnostics						
R-squared	0.896	0.949	0.906	0.946	0.909	0.949
Adj- Rsq	0.892	0.946	0.902	0.944	0.905	0.946
F-statistic	208.760	469.864	232.312	447.927	241.843	470.206
Prob(F-stat)	0.000	0.000	0.000	0.000	0.000	0.000

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

Furthermore, there is a positive and significant relationship between wheat yield and rainfall. One mm increase in rainfall increases wheat yield by 7.0kgs/hect. Janjua, *et al.* (2010) also obtained similar positive results for wheat production and average precipitation in Pakistan while analysing the impact of climate change on wheat productivity. The results also show that precipitation is negatively related to maize yield in Abbottabad and Mansehra and its coefficient is also statistically significant. More specifically, 1 mm increase in rainfall decreases maize yield by 3.139kgs/hect. This is in line with the findings of Prakash, *et al.* (2011) who found that increase in summer rain adversely affected the yield of maize.

The results derived in Table 8 show that maximum temperature (Tm) is positively related to wheat and maize yield. As Tm increases yield of both the crops also increases and vice versa. More specifically, one degree rise in Tm increases wheat yield by 53.92 kgs/hect and maize yield by 67.87 kgs/hect which is in line with the study of Tunde, *et al.* (2011). The coefficients of maximum temperature for these two crops are also statistically significant. Hussain, *et al*. (2005) also concluded that there is an increase in maximum temperature in the mountainous regions of Pakistan. This increase in Tm may have some positive influences on area and yield of different crops in such areas. Rise in Tm during winter season is significant for winter crops like wheat as increase in Tm lead to earlier maturity of such crops and raises the overall productivity. The required maximum temperature (day temperature) for maize crop ranges from 22 to 32 °C [Khaliq (2008)] which is laying within the range of last 20 years data which show that during maize growing season the average maximum temperature of the area ranges from 27.6 – 31.6°C, so increase in Tm is not affecting maize yield adversely.

The sign of rainfall coefficient shows that there is a positive relationship between wheat yield and rainfall while the relationship for maize is negative. More specifically, 1 mm increase in rainfall increases wheat yield by 6.22 kgs/hect. This type of relationship is also found by Tao, *et al.* (2008). Similarly 1 mm increase in rainfall decreases maize yield by 3.1 kgs/hect. The coefficients of maximum temperature and rainfall are also statistically significant for both maize and wheat crops. The results given in Table 8 show positive relationship between average temperature and yield of maize and wheat crops. More specifically, 1^0C increase in average temperature increases wheat yield by 87.95 kgs/hect. The results further show that 1^0C increase in average temperature increases maize yield by 86.51 kgs/hect. According to Ozkan and Akcaoz (2002) maize is a crop that requires hot environment to grow and the difference between day and night should be low. So this increase in average temperature is favorable for the crops production from mid to high altitude regions. The positive impact of average temperature on maize yield is in line with the results of Nwajiuba and Onyeneke (2010). The coefficient of the average temperature is statistically significant for these two crops. The coefficient of rainfall shows that it has a positive impact on wheat yield and a negative impact on maize yield. More specifically, one mm increase in rainfall increases wheat yield by 5.65 kgs/hect and decreases maize yield by 3.2kgs/hect. The coefficient of rainfall is statistically significant for these two major crops. Similar positive and significant impact of rainfall and average temperature on wheat yield in Pakistan is shown by Janjua, *et al.* (2010).

In case of all three different temperature ranges (minimum, maximum and average), the impact of rainfall is negative on maize yield. This is also consistent with the actual status of the mountains regions that receive higher rainfall throughout the year especially in the summer. These are summer rain dominated regions receive about 235 mm monthly rainfall in summer season while the actual water requirements of maize crop is 550 mm [Riaz (2001)]. The growing season for maize is highly vulnerable to any change in rainfall pattern. So excessive rain in summer is harmful for the land fertility as it can lead to reduce water recharge by accelerating runoff and causes floods that may lead to the reduction of maize yield in the zone. It may also affect the initial stages of crop development that lead to yield reduction. It is necessary to cultivate such crop varieties which are resistant to drought and heavy spell of rain in such regions. The results further show a positive relationship between wheat yield and rainfall. As wheat requires 480 mm water [Riaz (2001)] for growth and development during the whole period while the average rainfall in the study area during the year 1991-2010 ranges from 38–147 mm, which is not sufficient. Therefore increase in rainfall favours wheat yield in these regions.

Planting of early maturing crop varieties such as wheat in mountains regions is another step to reduce yield losses due to climate change. In this way the crops can reach to their full maturity before the frost kill them during the initial stages of development in such cold regions.

Climate–Yield Relationship in Northern Dry Mountains (Zone VII)

The results reported in Table 9 show that mean minimum temperature (Tn) is positively related to wheat, rice and maize yield. As Tn increases, yield of these three major crops also increases and vice versa. 1°C rise in Tn increases wheat, rice and maize yield by 150.86 ksg/hect, 146.32 kgs/ hect and 168.9 kgs/hect respectively. These results are in line with the findings of Tao *et al* (2008). The relationship between Tn and yield of these three major crops is statistically significant. Cheema, *et al.* (2011) also analysed that there is a considerable increase in the night temperature (Tn) in the Northern Areas of Pakistan during 1991 to 2009. So increase in Tn in hilly areas may be is useful for the growth of all crops particularly for winter season crops like wheat. In these areas night temperature is mostly low sometime below freezing point especially in winter season which can damage the crop in the initial stages of development. Therefore increase in winter temperatures may reduce the risk of crops damages and raise the overall productivity. The recommended minimum temperature for wheat and rice ranges from 3-4 °C and 10-12°C respectively [Siddiqui, *et al.* (2012). Although the average minimum temperature of last 20 years data of the study area is showing deviation from the recommended minimum temperature ranges specially in case of rice (13.6–18.8 °C) but not to a greater extent, therefore increase in Tn is not effecting productivity adversely.

Precipitation is positively related to wheat and rice yield while it has significant negative relationship with maize yield in these two regions. One mm increase in rainfall increases wheat and rice yields by 13.16 kgs/hect and 2.65 kgs/ hect respectively. Khan, *et al.* (2003) also found that 1 percent increase in water availability increases the wheat production by 0.68 percent. Similarly maize yield decreased by the amount of 11.5 kgs/hect with a unit increases in precipitation which is in line with the findings of

Prakash, *et al*. (2011). The value of F-statistic favors the overall significance of the explanatory variables. For wheat and maize the effect is statistically significant while for rice the effect is insignificant**.**

The results which are given in Table 9 shows that maximum temperature (Tm) is positively related to the yield of major food crops i.e. wheat, rice and maize and their coefficients are also statistically significant. 1°C increase in maximum temperature increases rice, maize and wheat yield by 66.49 kgs/hect, 76.76 kgs/hect and 70.78 kgs/hect respectively. In the mountainous regions increase in Tm is beneficial for the growth of major crops by limiting the number of days with extreme cold. Secondly it speeds up the process of photosynthesis as well as increases the amount of arable land by melting of ice and glaciers so provides favourable conditions for yield of the crops. The maximum temperature data for the last 20 years is not showing too much deviation from the recommended maximum temperature for these crops. For these three aforementioned major crops maximum temperature is statistically significant.

The coefficients of rainfall indicate that it is positively related to wheat and rice yield. More specifically, 1mm (millimetre) increase in rainfall increases rice and wheat yield by 1.15 kgs/hect and 4.34 kgs/hect respectively. The effect of increase in Tm and rainfall on rice yield is in line with the findings of Sarker, *et al.* (2012). Prakash, *et al*. (2011) also obtained similar results for wheat yield in case of increase in rainfall and Tm. Maize yield shows negative relationship with rainfall which is in line with the results of Tao, *et al.* (2008). The coefficient of rainfall is statistically significant for wheat and maize yield while it is insignificant for rice yield.

Table 9

Regression Results of the Impact of Average Minimum Temperature and Rainfall on Crops Productivity in Northern Dry Mountains (Zone VII)

	Coefficients with Average Minimum Temperature and Rainfall			Coefficients with Average Maximum Temperature and Rainfall			Coefficients with Average Temperature and Rainfall		
Variables	Wheat	Rice	Maize	Wheat	Rice	Maize	Wheat	Rice	Maize
Constant	144.759**	14.587	30.398	11.814	1.911	2.492	27.169	4.186	13.037
Temperature	150.869***	146.320***	168.977***	70.784***	66.490***	76.766***	114.213***	91.844***	107.373***
Rainfall	13.166***	2.653	–11.533***	4.345**	1.156	–6.734***	4.528**	0.130	–8.928***
Diagnostics									
R-squared	0.743	0.961	0.898	0.889	0.975	0.943	0.868	0.972	0.924
Adj- Rsq	0.732	0.960	0.894	0.884	0.973	0.942	0.863	0.971	0.921
F-statistic	69.396	635.020	223.411	193.138	986.785	425.780	0.863	887.634	309.441
Prob(F-stat)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

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

The results given in Table 9 shows that there is a positive relationship between yield of maize, wheat, rice crops and average temperature. More specifically, 1°C increase in average temperature increases wheat, rice and maize yield by 114.21 kgs/hect, 91.84 kgs/hect and 107.37 kgs/hect respectively. Their coefficients are also statistically significant for these three crops. Malla (2008) also concluded that the yield of wheat, rice and maize crops are supposed to increase with the rise of temperature in the hill and mountains regions. So rising temperatures may have a positive effect on crops productivity in the mountain areas, like shortening of the growing season length for the winter season crops. The shrinking of the growing season period in the high mountains regions due to increase in temperature might be beneficial in such areas as it would help the winter crops to reach its maturity level within the optimal time period and also positively influencing the overall crop yield. This zone included (Chitral, Swat, Malakand, and Dir), the northern mountains regions of Pakistan where temperature is already low. So most of the winter crops like wheat do not reach to maturity due to low temperature and harvested premature as fodder. But this increase in temperature is not productive in southern parts of the country where high temperature increases the crop water requirement due to which most of crops are suffering adversely. Hussain and Mudasser (2004) also concluded from the past temperature trends that there is an increase in the temperature in the high mountains regions, (Swat and Chitral) where it has already reduced the length of the growing season. This increase in temperature is helpful for wheat yield and area in such regions like in district Chitral. The coefficient of rainfall shows that it has a positive impact on wheat and rice yields while shows negative impact on maize yield. The coefficient of rainfall is statistically significant for wheat and maize yield while for rice rainfall is statistically insignificant. In case of all these three different temperatures (minimum, maximum and average) in the dry mountains regions the effect of rainfall on rice is statistically insignificant. It might be due its less dependency on rainfall because it is a water intensive crop requires about 1500 mm [Riaz (2001)] water for normal growth, while the average summer rainfall in the zone is about 10-20 mm which is insufficient. In these areas rice crop is cultivated in irrigated areas in order to meet the water requirement by means of artificial irrigation system. Similarly in case of minimum, maximum and average temperature ranges the effect of rainfall on wheat crop is positive and statistically significant for these dry mountainous regions. Wheat crop requires 480 mm [Riaz (2001)] water during growing season while in winter monthly rainfall in the study area is about 25-75 mm therefore increase in rainfall in winter effect wheat crop positively. The results show that there is a negative relationship between maize yield and rainfall. According to Sánchez-Cortés and Chavero (2011), maize is the crop that requires moderate water during entire growth period and can be grown in the regions with moderate rainfall without irrigation. As these are the hilly areas (Chitral, Swat) with abundant rainfall that may lead to excessive soil moisture. There is also a positive correlation between increased rainfall and cloud cover. Therefore increased rainfall means reduced radiation from the sun that leads to reduce the process of photosynthesis so decreases crop yield. So agricultural research need to develop such crop varieties that are appropriate for the mountain regions under the changing climate condition.

Comparison of the Impact of Climate Change on Crops Productivity across Agro Climatic Zones of Pakistan

The effect of climate change on crop productivity across agro-ecological zone is not uniform and the results show that the impact of average temperature is positive on wheat productivity across four selected agro climatic zones and this effect is more pronounced in Northern Irrigated Plain a (Zone IV) than the other zones. The effect of rainfall on wheat productivity is negative in Indus Delta (Zone I) and positive in the remaining zones. The effect of rainfall is high on wheat yield in Northern Dry Mountains (Zone VII). Similarly, the impact of average temperature and rainfall is positive on rice yield across Northern Irrigated Plain a (Zone IV), Indus Delta (Zone I) and Dry

Mountains (Zone VII). The results showed that the impact of average temperature on rice yield is high in Dry Mountains (Zone VII) while the effect of rainfall is high in Indus Delta (Zone I).There is positive impact of average temperature and rainfall on sugarcane yield in Indus Delta (Zone I) and Northern irrigated plain a and b (Zone IV). The effect of both temperature and rainfall on sugarcane yield is high in Indus Delta (Zone I) than Zone IV. The impact of average temperature is negative on maize yield in Northern irrigated plain a (Zone IV) while it is positive in plain b, Northern Dry Mountains (Zone VII) and Wet Mountains (VII). The effect of average temperature on maize yield is high in Northern Dry Mountains (Zone VII). The effect of rainfall on maize yield is negative in Northern Dry Mountains (Zone VII) and Wet Mountains (VII) and this effect is more prominent in Dry Mountains (Zone VII) while the positive impact of rainfall is high in Northern irrigated plain b (Zone IV). Similarly, cotton is the crop that only grown in Northern irrigated plain a (Zone IV) due to its major share. The impact of rainfall of average temperature is positive on cotton yield in that zone.

CONCLUSION AND POLICY IMPLICATION

To analyse the impact of climate change on agriculture crops this study basically focused on the impact of major climate variables (rainfall and temperature) on major crops yield i.e. wheat, maize, rice, sugarcane and cotton across four agro climatic zones of Pakistan. The empirical results of the study show that the two major climatic variables have significant impact on major crops yield in the selected regions. The study concluded that the increase in major climate variable i.e. temperature (maximum, minimum and average temperatures) has a positive impact on major crops yield in all four selected agro zones except for maize in Zone IV a. Any change in temperature beyond optimum or far below optimum level is disastrous for crops yield. Rainfall shows positive impact on all major crops in the selected zones of Pakistan expect for maize both in Wet Mountains (Zone VI) and Northern Dry Mountains (Zone VII) where an increase in rainfall effects maize yield adversely. Also the impact of rainfall is negative on wheat productivity in the Indus Delta (Zone I).The impact of climate change varies across agro climatic zones due to differences in their climatic conditions. So the impact of average temperature is positive on wheat productivity across four selected agro climatic zones and this effect is more pronounced in Northern Irrigated Plain a (Zone IV) than the other zones while the effect of rainfall on wheat yield is high in Northern Dry Mountains (Zone VII). The impact of average temperature on rice yield is high in Dry Mountains (Zone VII) and the effect of rainfall is high in Indus Delta (Zone I) than other zones. The effect of both temperature and rainfall on sugarcane yield is high in Indus Delta (Zone I) than zone IV. The effect of average temperature and rainfall on maize yield is high in Northern Dry Mountains (Zone VII) than other zones. This panel study confirms that climate change has significant impact on crops yield**.**

Based on the findings the study recommends adaptation options like cultivation of heat and drought resistant crop varieties and planting of early maturing crop varieties in such regions. Further, the agricultural research organisations should develop such crop varieties which are appropriate for the mountainous regions under changing climate conditions.

The main shortcoming of this study is that it only considers two climatic variables i.e. rainfall and temperature as explanatory variables while the other explanatory variables like fog, pesticides consumption, technology and water availability are not included due to non-availability of data at districts level. Crop wise consumption of fertilizer and labor force employed data is not available at districts level therefore not included in the study. The distribution of fog varies across regions so due lack of systematic data across study area the impact of fog is not included. The effect of geographic variables such as soil type and altitude are not included because panel data has the special features to absorb the effect of unobservable factors. Climate change may affect crops productivity at different stages which may affect yield because each and every stage requires specific temperature and rainfall. This study considers only the impact of average rainfall and temperature on average crops yield for the whole season and does not consider the impact of climate change on different stages of each crop. Over the time, cropping pattern also changed across agro climatic zone altering the sowing and harvesting period of crops. The present study does not capture these variations. The study considers the impact of climate change on crops productivity only in irrigated areas and does not consider the rain-fed areas which are more vulnerable to the impact of climate change due to their dependency on rain.

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