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Impact of climate change on wheat productivity in mixed cropping system of Punjab

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Abstract

The climate change has important and measurable effects in Pakistan. The objective of this paper was to measure these effects on wheat productivity in mixed zone of Punjab province. A time series data from 1980-81 to 2008-09 was used to achieve the desired objective. The impact of climate change on wheat productivity was analyzed along with some economic incentives. The results of the analysis have shown that one degree centigrade increase in mean minimum temperature at sowing stage will increase wheat productivity by 146.57 kg ha^{-1}. At vegetation stage the increase in mean maximum temperature will reduce productivity, although non significant, by speeding up vegetative growth and reducing grain development period. At maturity stage, the productivity gain will be 136.63 kg ha^{-1} as result of one degree centigrade increase in mean maximum temperature. The adequate amount of rainfall increases wheat productivity by 275.77 kg ha^{-1}. The productivity response to economic variables was relatively flat and constant, 94.43 kg ha^{-1}. It was thus concluded that the climate change is the major determinant of wheat productivity at each stage of wheat growth.

Keywords: Temperature, rainfall, Ordinary Least Square (OLS), Faisalabad

Introduction

Pakistan is known as an agricultural economy because of the vital role it plays. It has strong linkages with other sectors ranging from supplier of raw material to the large market for industrial products like tractors, combine harvesters and fertilizer. Wheat is the main *Rabi* crop grown in Pakistan and being the staple diet of people occupies a central position in agricultural policies. It accounts for 38% of the cropped area and contributes 13.1 percent to the value added in agriculture. Wheat alone accounted for 2.8% of GDP growth in 2008-09. Pakistan ranks 6th in terms of wheat production, 8th in terms of area but 59th in terms of yield. Pakistan has an average wheat yield of 2504.58 kg ha^{-1} as noted by FAO (2010).

The major challenges for the agriculture sector include climate change, declining water availability and low productivity. While the voices about climatic change are getting more and more pronounced, it is becoming extremely important to foresee the likely impact it will leave on our main livelihood source i.e., agriculture. Climate change could have significant impact on agriculture but the first step in assessing potential costs and adaptation strategies is to determine the size and nature of these impacts on crop productivity. Climate is one of the major determinants of agricultural production all over the world. The key effects of climate change include increasing average temperatures, changing length of the seasons and changing patterns of rainfall, floods and droughts. Due to importance of wheat as food security crop, measuring its response to climate change was the need of the time, which was done in this study.

The climatic variables affect wheat crop at different stages of production including germination, vegetation and maturity. Temperature is an important variable to consider. It affects the wheat crop in all the stages of production. Rainfall also has important positive effect if it occurs in proper amount and at critical stages of growth. Thus the estimation of the effect of climate change on wheat productivity can provide important insights for adapting to it.

The climate change is a global phenomenon. The average global temperature will increase by 1.4-5.8°C because of projected increases in the concentrations of greenhouse gases by the end of the 21st century (Houghton *et al.*, 2001).

Different studies have assessed impacts of climate change on wheat productivity. Knight *et al*. (1978) analyzed the potential for wheat production in various regions of Alaska on the basis of air temperature. They believed production would be favored in regions where the mean maximum air temperature during July was at least 22°C (east-central Alaska) and would be poor in regions where the maximum July air temperature was less than 19°C (coastal and northern Alaska). Intergovernmental Panel on

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Climate Change (IPCC) (2001) reported that the average air temperature would rise by 1.4 to 5.8 celsius degrees over the period 1990 to 2100. The rise in temperature will shorten the growth period due to early flowering and fruit bearing, and decrease the nourishment sent to the seed due to increased respiration, and seeds might not be fully developed. Graciela *et al*. (2003) studied that the potential wheat yield had been declining at increasing rates since 1930 mainly due to minimum temperature increases. Further increases in temperature will lead to potential wheat yield reductions of 7.5% for each 1°C of temperature rise. Zhu (2004) studied that higher temperatures generally decreased yields by speeding up a plant's development so that it matured sooner, thus reduced the period available to produce yields. Higher temperatures often exacerbated stress on water resources that are essential for crop growth, and warmer and wetter conditions also tended to affect the prevalence of pests, diseases and weeds. Winter wheat yields were likely to decrease by about 14 per cent by 2080. You *et al*. (2005) concluded that a 1% increase in wheat growing season temperature reduced wheat yields by about 0.3%. Wajid *et al*. (2007) concluded that drought considerably reduces wheat productivity levels.

All the above-mentioned studies measured the impact of climatic changes in different parts of the world. The effects were favorable in some regions while unfavorable in the other. Therefore, the present study estimates the impact of such climatic changes and other traditional inputs on the wheat crop in mixed cropping zone of Pakistani Punjab.

Materials and Methods

The mixed cropping zone of Punjab was selected for the purpose of analyzing the impact of climate change on wheat productivity. Currently Punjab's share in total wheat production and area is approximately 76.64% in Pakistan. The share of mixed zone in wheat acreage (production) in Punjab is 21% (21.5%). Faisalabad district was selected from the mixed zone and it covers 4.15 percent of the total wheat area; larger than all districts from Punjab. After selecting the appropriate sample area, the next step was identifying key independent variables which had an effect on the dependent variable.

Data and Variables

The base dependent variable for the analysis was wheat productivity in kg ha^{-1}. Productivity data was collected from AMIS (Agriculture Marketing Information Service). The explanatory variables included climatic variables and economic variables in order to capture the impact of climate change. The economic variables were incorporated in order to avoid specification bias due to exclusion of important variables.

The proxy variable used for capturing the impact of economic conditions was change in input use. The change in input use (*Input Change*) was determined by equating the marginal value product $P_{crop} * (\Delta y / \Delta Q_{input})$ to the input price (P_{input}) (as determined by Cabas *et al.* (2009)).

In order to capture the effect of climatic variables the crop growing season was divided into three distinct growth stages, namely sowing, vegetation and maturity stage. The sowing period is November-December, vegetation period is January-February and maturity period is March-April. The climatic variables used in the analysis were mean maximum temperature, mean minimum temperature and mean rainfall, each taken in the three growth stages of wheat as well as for the entire crop season.

Ordinary Least Square (OLS) technique was used to estimate different models for climate change effects assessment. After analyzing various possibilities for combining the climatic and economic variables the following model was considered to be most appropriate for measuring the impact of climate change on wheat productivity.

$$Y_t = \beta_o + \beta_1\ temp\_min\_sowing + \beta_2 temp\_max\_vegetation + \beta_3\ temp\_max\_maturity + \beta_4\ total\_rainfall\_dummy + \beta_5\ input\_change + \beta_6\ input\_change\_square + \mu_t$$

Where,

Y_t= Wheat productivity (yield) in kg ha^{-1} and t= time period

temp_min_sowing = Mean minimum temperature for November and December

temp_max_vegetation = Mean maximum temperature for January and February

temp_max_maturity = Mean maximum temperature for March and April

total_rainfall_dummy = Binary variable (1 if total rainfall for wheat growing season is more than 70 mm, 0 otherwise)

$$Input\_change = \frac{P_{crop,t-1}(y_{crop,t} - y_{crop,t-1})}{P_{input,t}}$$

input_change_square = Square of input change variable
μ_t = Random error term

Results and Discussion

OLS estimation of the above model gives the following results of the impact of climate change and economic variables on wheat productivity.

It is apparent from Table 1 that the overall model is highly significant, at 1% level of significance. The adjusted R square value was calculated as 0.547 which means that 54.7 percent of the variation in the wheat productivity was explained by the climatic and economic variables considered in this model. However, only the overall fitness of the model did not guarantee appropriateness of the model because significance of individual variables is also very important. For this task following table was developed.

Table 1: ANOVA of impact of climate change on wheat productivity

ANOVA					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	4813510.19	6	802251.69	6.625	.000
Residual	2664013.34	22	121091.51		
Total	7477523.53	28			

The temperature is an important climatic variable which affects wheat productivity differently at different stages of its growth and for this reason the effect of temperature was divided into sowing, vegetation and maturity stages. The explanation of the above variables (Table 2) is as following:

Table 2: Results of the estimated model

Coefficients				
Model	**B**	**Std. Error**	**t-value**	**Sig.**
(Constant)	-3240.22	1661.38	-1.950	0.064
Temp_min_sowing	146.57	77.78	1.884	0.073
Temp_max_vegetation	-50.19	63.58	-.789	0.438
Temp_max_maturity	136.63	41.09	3.324	0.003
Total_rainfall_dummy	275.77	134.52	2.050	0.052
Input_change	94.43	41.08	2.298	0.031
Input_change_square	20.77	15.90	1.306	0.205
Dependent Variable: Yield (kg ha^{-1})				

As expected, the climatic variables have major effects on wheat productivity while economic variables have minor effect. At sowing time mean minimum temperature is very critical because germination of wheat seed is highly dependent on it. The coefficient of mean minimum temperature at sowing time was positive and significant at 10 percent level of significance. The positive sign was consistent with the situation in the selected sample. The maximum time for wheat sowing is till November 15, and after that delay in sowing results in 1% productivity loss per day. There will be 8, 16, 32 and 50% reduction in wheat grain yield for each fortnightly delay after 10th November (PARC, 2010), the reason being the fall in minimum temperature which results in lower germination of the seed, shorter growth period and heat stress at grain filling period. Wheat sowing continues till early December mainly due to delayed harvesting of *kharif* crops like cotton, sugarcane and rice, and consequent late planting of wheat which reduce wheat productivity. Thus the positive sign of the coefficient means that if minimum temperature at the time of sowing increases, it will increase the wheat productivity by improving the germination of the seeds. The magnitude of the variable shows that with each one degree Celsius increase in mean minimum temperature, the productivity will increase by 146.57 kg ha^{-1}. The optimal temperature for germination is from 12°C to 25°C (Spilde, 1989), while the mean minimum sowing temperature for the sample was 11.75°C. Thus an increase in minimum sowing temperature will increase wheat productivity in the selected zone.

At vegetation stage, mean maximum temperature is of prime importance because it determines the length of vegetation period (Cabas *et al.,* 2009). The mean maximum temperature at vegetation stage had negative sign and was in line with theory. This indicates that an increase in maximum temperature speeds up developmental cycle and reduces duration of the grain-filling period. Mitchell *et al.* (1993) also obtained similar signs of lower yields for many important grain crops such as corn, wheat and oat when temperature increased at plant development stage. The wheat productivity in mixed zone responds negatively to the increase in mean maximum temperature at vegetation stage but this effect was not significant. A significant increase in temperature at this stage may result in lower productivity but at this point of time a marginal increase in temperature is not going to reduce wheat productivity considerably.

At maturity stage, mean maximum temperature was of main concern. The coefficient was positive and was highly significant. With each one degree Celsius increase in temperature at maturity stage, the wheat productivity will increase by 136.63 kg ha^{-1}. This was because higher temperature at the maturity stage helps the grain filling process and the crop to mature and be harvested with less field losses. Similar results were obtained by Weber and Hauer (2003), Mendelsohn and Reinsborough (2007) and Knight *et al.* (1978).

Rainfall was the most important climatic variable in determining the wheat productivity and it responds positively to the appropriate amount of the rainfall. The binary rainfall variable taken here was positive and significant. This means that wheat productivity was 275.77 kg ha^{-1} higher if there was required amount of rainfall than the time when there was less rainfall. The higher size of coefficient was also due to shortage of canal water in mixed zone of Punjab. Khan *et al.* (2003) also found that 1 percent increase in water availability increases the wheat production by 0.68 percent. The effect of water supply on wheat growth was also found positive by Ashraf (2006). This impact is very important in the wake of growing shortage of water and less rainfall years.

The change in input use had a statistically significant positive effect on wheat productivity. With one unit increase in *input change,* the wheat yield increased by 94.43 kg ha^{-1}. Similar positive correlations were also found by other researchers, for example the positive correlation between input use and corn yield was found by Kaufmann and Snell (1997) which suggested that changes in relative prices can influence productivity. Reidsma *et al.* (2007) also concluded that increasing the input intensity increases the crop yield. The impact of economic variables on wheat productivity was statistically significant but relatively small. This small effect was consistent with the results obtained by Pannell (2006). He found that the response function for many agricultural inputs was flat around the optimum. Cabas *et al.* (2009) established that 10% increase in input use increases the yield of wheat, corn and soy crops by 0.1%.

The last variable, the input change square, shows that the rate of change of yield in response to economic variables was constant. The change in input square use was positive and non-significant even at 10% significance level. This suggested the existence of constant marginal returns to inputs on wheat productivity. This also suggested that the wheat productivity may increase by increasing input use but this effect will not be significant. So, in order to enhance productivity, there is need to develop new and improved varities which respond more positively to climate change than to more intensive use of inputs.

Conclusion and Recommendations

The climate change is the major determinant of wheat productivity at each stage of wheat growth. At sowing stage each one degree celsius increase in mean minimum temperature increases productivity by 146.57 kg ha^{-1}. At vegetative growth stage an increase in the mean maximum temperature reduces wheat productivity but this effect was not significant. At maturity stage an increase in mean maximum temperature increases productivity by 136.63 kg ha^{-1}. Sufficient amount of rainfall in the wheat growing season has the highest effect among all climatic and economic variables. It had strong positive effect of 257.77 kg ha^{-1} if there was adequate rainfall. The analysis had shown that the response of wheat productivity towards economic variables was relatively flat, while climatic variables have significant effect on it. The economic incentives increase wheat productivity at constant rate.

As the climate change is becoming more and more significant with every passing year, the researchers need to take their responsibility with full devotion to evolve new verities which can adapt to the climate change. As wheat is the most important staple food in Pakistan which accounts for over 55% of total caloric consumption and this share is significantly higher for the poorest households (Jansen and Malik, 2010), the need is to devote more resources in the development of new policies that help in adapting to climate changes and can capture its positive effects.

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