Research Article

Estimation of Wheat Yield Response under Different Agro-Climatic Conditions in Punjab

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Abstract | The knowledge of supply greatly helps planners and policy makers to allocate and achieve production targets and in longer term planning. A study was conducted during 2009-10 with an objective to estimate the wheat yield response function in two agro-ecological zones in Punjab. The method of ordinary least square was used. Time series data for different explanatory variable (economic, location and climatic) from 1979-2009 relating to wheat were used for Faisalabad and Bahawalpur. The results of analysis showed that the effect of climatic variables was found significantly higher than that of non-climatic variables. The largest impact on wheat yield was of mean maximum average temperature at the time of maturity, ceteris paribus with one °C increase in temperature the average wheat yield increased by 56.64 kg per hectare in the study area. It was deduced from the economic variable that the level of input used was less than optimum. The negative coefficient of the location variables revealed that increasing the area virtually decreased the yield. It was concluded from location variables that vertical expansion was solution of Pakistan's growing food security needs. Based on the results of the economic variables it is recommended that the optimal input use should be ensured to increase crop yield. Also because of the significant changes in the climatic conditions in the two zones there will be growing need of developing new wheat varieties which should be more adaptable to changing climatic conditions.

Editor | Tahir Sarwar, The University of Agriculture, Peshawar, Pakistan
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Citation | Zulfiqar, F., Ashfaq, M.,2014. Estimation of wheat yield response under different agro-climatic conditions in Punjab. *Sarhad Journal of Agriculture*, 30(4): 459-465.
Keywords | Climate change, Economic inputs, Structural stability

Introduction

Pakistan is predominantly an agricultural country. The importance of agriculture can be well recognized by the fact that it currently contributes 21.8% to national GDP and about 44.7% of the labor force is engaged in agriculture (Zulfiqar and Hussain, 2014). Within agriculture wheat is the most important crop that serves as staple food for 1/3rd of the world population (Government of Punjab, 2010). Pakistan contributes 3.5 percent to the overall world wheat production. Pakistan ranks 6th in terms of wheat production, 8th in terms of area but 59th in terms of yield (FAOSTAT, 2009). This is indicative of the vast potential which is missed and not realized. Harnessing this yield potential can go a long way in sustaining a much higher output of wheat. Despite all above Pakistan is listed by the United Nations as one of 40 countries most affected by the food crisis (Jansen and Malik, 2010). To avoid acute shortages of the staple food, wheat, the correct estimation of its availability is of utmost importance so that appropriate measures can be taken, such as taking decision about imports.

The knowledge of supply greatly helps planners and policy makers to allocate and achieve production targets and in longer term planning. It thus provides a framework for adjusting production to the optimum resource employment to promote economic development. These projections help the government to make policies with regard to relative price structure, production and consumption and also to establish trade contracts with other countries of the world (Iqbal et al., 2005).

Several studies have been carried out in Pakistan using ordinary least square approach and aggregate data. Niamatullah et al. (2010) measured the significant contribution of price factor and non-price factor towards rice production and wheat acreage responses in Khyber Pakhtunkhwa, Pakistan by employing Nerlovian adjustment model through ordinary least square estimation technique. Khan et al. (2003) studied the impact of Pakistan's support price policy on wheat production in the country. They used national level data for Pakistan, on all inputs, output and prices taken from secondary sources, over the period 1966-2001. Both ordinary least square and maximum likelihood estimation methods were used. Ikram (2000) have also shown that wheat growers in Pakistan respond positively to the price incentives.

The purpose of this study was to estimate wheat yield response under two different agro-ecological zones of Punjab. It was hypothesized that the wheat yield is affected by the economic, location and climatic variables. All of these variables were individually tested for their effect on wheat yield. The assumptions relating to ordinary least square method were considered.

Materials and Methods

Currently Punjab contributes approximately 77% to the total wheat production and area in Pakistan. In Punjab usually there are four cropping zones, which produce wheat. The share of cotton and mixed zone in wheat acreage and production in Punjab is 66 and 68.4 percent, respectively. Their large share is used as basis for their selection. Faisalabad and Bahawalpur Districts were selected from the two zones because they account for largest share in the total area of the Punjab in terms of wheat area. Faisalabad covers 4.15% while Bahawalpur covers 4.33 percent of the total wheat area; both are larger than all other districts from Punjab.

After selecting the two zones the first step of model specification was to check whether there is any structural difference in the regression of two districts, Faisalabad and Bahawalpur. If there exists some structural difference in the two districts separate model should be developed for estimating the wheat yield response function. But if there would be no difference in them we can pool the data and use it as a single entity.

Dummy Variable Test

Faisalabad and Bahawalpur were assumed to be representative of the two zones. But firstly it was necessary to find out whether yield responses in the two representative districts actually differ. The average wheat yield was 2207.6 kg/hectare in Faisalabad and 2132.8 kg/hectare for Bahawalpur. These numbers look different but whether they are statistically different from one another or not is an empirical question. Dummy variable approach was used for testing the above and for similarity of the functional form across these two districts. The following model was used.

$$Y_t = \alpha_o + \beta_o D + \beta_1 X_{1t} + \beta_2 X^2_{1t} + \beta_3 X_{2t} + \beta_4 X_{1t} X_{2t} + \beta_5 (D X_{1t}) + \beta_6 (D X^2_{1t}) + \beta_7 (D X_{2t}) + \beta_8 (D X_{1t} X_{2t}) + \mu_t$$

Where; Y= Yield, X_{1t}= Input change, X_{2t}= Area change, t= Time and

D= 1 for observations from Bahawalpur

= 0, otherwise (i.e., for observations from Faisalabad)

In the above equation β_o is the differential intercept and β_5, β_6, β_7 and β_8 are the differential slope coefficients (also called slope drifter), indicating by how much the slope coefficient of the Bahawalpur function (the category that receives the dummy value of 1) differs from that of the first period.

Dummy variable test was used for the analysis of pooling the data and in order to check any structural change in the supply response models of the two selected districts F-test was used. This test tells us, in the time series data, whether there is a structural change in the relationship between the dependent and independent variables. By structural change we mean that the values of the parameters of the model do not remain same in the two districts. This structural change may be due to economic factors of the region, different farming practices and access to input and output markets etc.

F-Test for Checking Structural Stability

F-test was used for checking the stability of the entire regression under the hypothesis that the regressions of Faisalabad and Bahawalpur are similar. And alter-

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nate hypothesis is that they are not.

Unrestricted Model:

$Y_t = \alpha_o + \beta_o D + \beta_1 X_{1t} + \beta_2 X^2_{1t} + \beta_3 X_{2t} + \beta_4 X_{1t} X_{2t} + \beta_5 (D X_{1t}) + \beta_6 (D X^2_{1t}) + \beta_7 (D X_{2t}) + \beta_8 (D X_{1t} X_{2t}) + \mu_{1t}$

Restricted Model:

$Y_t = \alpha_o + \beta_1 X_{1t} + \beta_2 X^2_{1t} + \beta_3 X_{2t} + \beta_4 X_{1t} X_{2t} + \mu_{2t}$

After estimating the restricted and unrestricted model the following F-test is employed to check the structural stability.

$F_{cal} = [(RSS_R - RSS_{UR})/k] \div [RSS_{UR}/ (n-2k)]$

The next step is identifying key independent variables which have an effect on the dependent variable.

Data and Variables

The base dependent variable for the analysis was yield in kg per hectare for wheat. Yield data were collected from AMIS (Agriculture Marketing Information Service) for the two selected districts of Punjab. The yield response model was found to have three major categories of explanatory/ independent variables: (1) economic variables, (2) location variables, and (3) climate variables.

Output to input price ratios were used as an economic variable to explain yield as used by Rickard and Fox (1999), Segerson and Dixon (1999), and Dixon et al. (1994). The change in input use (Input Change) can be determined by re-arranging the profit maximizing input level condition (as determined by Cabas et al. (2009)) which is where marginal value product i. e., $P_{crop} * (\Delta y / \Delta Q_{input})$ is equal to the input price (P_{input})

$$Input - chnage = \Delta Q_{input} = Q_{input,t} - Q_{input,t-1}$$

$$= \{ P_{crop,t-1} (y_{crop,t} - y_{crop,t-1}) \} / P_{input,t}$$

Where $Q_{input,t}$ the quantity of is purchased inputs per acre in period t, $P_{crop,t-1}$ is the price per unit of crop lagged one year, $P_{input,t}$ is the price index for input purchased in the current period, and $Y_{crop,t}$ is crop yield in the current period. Crop price is proxied by actual prices in the previous year and input prices are measured by the index of prices paid by farmers. For the creation of input price index only the most important inputs were included. The input prices taken into analysis were of urea, DAP, electricity and high speed diesel (HSD). Because only the trend of the input prices was of main concern the input price index was created by simply adding the input prices of these. Location characteristics were captured by the change in acres planted to a crop from one period to the next (Area Change). A time-trend variable (Time Trend) was also added to represent the effect of technological progress, such as new crop varieties and improved cropping practices. The effect of climatic variables was captured by using average temperature and rainfall in the two districts in the crop growing time period.

An ordinary least square technique was used here to estimate different regression equations for the wheat yield response function estimation in Punjab. Analyzing various possibilities for combining the economic, site and climatic variables in one model and then individual analysis of the independent variables as well as overall model significance following model was considered to be best representing the wheat yield response.

$Y_t = \beta_o + \beta_1 input\_change + \beta_2 input\_change\_square + \beta_3 area\_change + \beta_4 input\_change\_area\_change + \beta_5 time\_trend + \beta_6 temp\_max\_maturity + \beta_7 rainfall\_avg + \mu_t$

Results and Discussion

In the results firstly the possibility of data pooling was checked using dummy variable test and F-test and then the results of the estimated model are discussed.

Dummy Variable Test

The results given in table 1 were obtained from the dummy variable test using pooled data. As the regression results showed, both the differential intercept and differential slope coefficients were statistically insignificant, strongly suggesting that the yield response regressions for the two time periods are same for the two districts, Faisalabad and Bahawalpur, based on the selected variables.

F-Test for Checking Structural Stability

The results of the models are described in table 2 which are obtained by applying the F-test.

$F_{cal} = [(RSS_R - RSS_{UR})/k] \div [RSS_{UR}/ (n-2k)]$

Putting RSS_R = 10284946.69, RSS_{UR}= 9264192.10, n = 58 and k = 2

Table 1. *Results of dummy variable test*

Variables	Coefficients	t-value	P-value
(Constant)	2020.290	19.587	0.000
input_change	20.058	0.933	0.355
input_change_square	9.719	2.676	0.01
Area_change	4.844	0.335	0.739
input_change_area_change	5.663	1.747	0.087
Dummy	-105.468	-0.724	0.473
Dummy_input_change	11.638	0.383	0.703
Dummy_input_change_square	1.896	0.394	0.696
Dummy_area_change	.322	0.02	0.984
Dummy_input_change_area_change	-7.205	-1.861	0.069

Table 2. *Results of F-test*

Restricted Model					
Model	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**Sig.**
Regression	4347948.29	4	1086987.07	5.601	0.001
Residual	10284946.69	53	194055.59		
Total	14632894.98	57			
Unrestricted Model					
Model	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**Sig.**
Regression	5368702.87	9	596522.54	3.091	0.005
Residual	9264192.10	48	193004.00		
Total	14632894.98	57			

Table 3. *ANOVA of yield response model*

ANOVA					
Model	**Sum of Squares**	**DF**	**Mean Square**	**F-value**	**Sig.**
Regression	6934429.60	7	990632.80	6.434	.000
Residual	7698465.37	50	153969.30		
Total	14632894.98	57			
Predictors: (Constant), rainfall_avg, area_change, input_change, input_change_square, temp_max_maturity, input_change_area_change, time_trend					
Dependent Variable: Yield (Kg/hectare)					

$F_{cal} = 2.97$ and F_{tab} (α= 5%, n_1= 2 and n_2= 54) = 3.16

Because calculated F-value is less than F-tab the null hypothesis of similar regression is accepted. Thus there is no structural difference in the regressions of Faisalabad and Bahawalpur. So, the regressions lines for Faisalabad and Bahawalpur are coincident. Thus the data were pooled instead of estimating separate regressions.

Yield Response to Economic, Site and Climatic Variables

The next step is the estimation of wheat yield response to economic, site and climatic variables. The results of the estimated wheat yield response to economic, site and climatic variables are given in table 3 and table 4. It is evident from the data in table 3 that the overall model is highly significant, i.e., at 1% level of significance. The R square value was calculated as 47.4 per

Table 4. *Results of estimated yield response model*

Coefficients				
	B	**Std. Error**	**t-value**	**Sig.**
(Constant)	-396.715	899.775	-.441	.661
input_change	35.181	13.451	2.616	.012
input_change_square	7.438	2.090	3.559	.001
area_change	-3.095	5.810	-.533	.597
input_change_area_change	2.177	1.632	1.334	.188
time_trend	8.276	4.223	1.960	.056
temp_max_maturity	56.647	26.355	2.149	.036
rainfall_avg	17.114	9.419	1.817	.075
Dependent Variable: Yield (Kg/hectare)				

cent. Thus the overall model is appropriate.

The overall fitness of the model did not guarantee good results as well because individual variables' significance is also very important. For this task following table was developed. From data in table 4 it can be deduced that most of the variables are statistically significant. Their explanation is as following.

The change in input use determined from the profit-maximizing input level condition has a statistically significant positive effect on average yield. With one unit increase in input change the wheat yield increased by 35.18 kg per hectare. Similar positive correlations with input use and corn yield was also found by Kaufmann and Snell (1997) who suggested that changes in relative prices can influence productivity. Similarly, Reidsma et al. (2007) found that crop yield increases with input intensity. While the impact of economic variables was statistically significant, the impact on yield response was relatively small. The small effect is consistent with the finding by Pannell (2006) that the response function for many agricultural inputs is flat around the optimum. The elasticity of yield to input change was estimated and was low. With 10% increase in input change variable the increase in yield was found to be just 0.12%. This result is consistent with the results obtained by Cabas et al. (2009). They found that 10% increase in input use increases the yield of wheat, corn and soy crops by 0.1%. Krishna (1963) found that the short and long-run elasticities for economic variables were inelastic.

The rate of change of yield increases with increase in input change. The change in input square was positive and was significant at 1% significance level. The calculated elasticity from the estimated model showed that with 10% increase in input change square variable the yield increased by 0.63%. This suggested the existence of increasing marginal returns to inputs on crop yield. It means that the input use is not optimum in the selected districts. This also suggested that there was very obvious possibility of increasing wheat yield by increasing the level of input use. Another important point that can be made here was that either the farmers were unaware of the level of use or they lacked finance for the purchase of inputs. As wheat yield increased at increasing rate, using inputs more intensively to achieve food self-sufficiency and more importantly for food security is a good option.

An increase in area planted to a crop, especially wheat, decreases average yield because more marginal land is brought into production. This is because most productive lands are always under cultivation, especially in Punjab, and area increase means bringing more marginal land under cultivation. The negative coefficient of area change implies that with increase in the area changed (usually area increase) the wheat yield actually decreased because the maximum area is already under wheat cultivation in kharif season. But the area change coefficient was insignificant. This is not surprising because it is clearer by looking at the area trend under wheat cultivation and yield over time. While wheat yield has increased from 1344 kg per hectare to 3368 kg per hectare (250%) in the period 1980-2009 the area under wheat has not increased too much, in fact it increased from 178.8 thousand hectares to 289.9 thousand hectares which makes it 162% (GOP, 1979-2009). Thus it is evident from the above statistics that increase in wheat yield is less associated to area change and more to other variables, as

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suggested by the model.

The interaction between the change in planted area and the change in input use was also statistically insignificant though positive as expected for wheat yield response. The result suggested that increases in the area of less productive land planted to a crop can still result in increases in yield provided additional inputs were used. The positive value of interaction and its insignificance suggest that yield response was positive to combine increase in area and input used but due to less awareness or lack of finance, farmers cannot respond to less productive lands with high input use resulting in very low yield response to these variables combined.

Technological advances as captured by time trend variable also increased average yield. Overtime yield has increased significantly. This model suggested that each year yield increased by 8.27 kg per hectare keeping all other economic, site and climatic variables at given fixed level. This change was significant at 10% level of significance (Table 4).

As the coefficients of the economic and site variables are generally small the impact on yield distribution is also relatively small. The relatively small effects of the non-climatic variables aside suggest that climatic variables should have a major effect on yield distribution. Mean maximum temperature at maturity stage (average of March and April) has positive and significant effect on wheat yield (Table 4). Its value is significant at 1% level of significance. The model predicted that each one unit increase in mean maximum temperature at maturity increased the wheat yield by 56.64 Kg per hectare. The impact of this variable was highest on yield as compared to all other economic, site and climatic variables. This is because higher temperature at the maturity stage helps the crop to mature and be harvested with less field losses.

Wheat yield response to average rainfall is positive and is significant at 10% level of significance.

Our result is an agreement with Ashfaq et al. (2011), who also found a positive relationship between wheat yield and temperature at the maturity stage.

Wheat yield increases by 17.11 Kg per hectare with each one millimetre increase in average rainfall in Punjab holding all other variables constant. Khan et al. (2003) also found similar results, they concluded that 1 percent increase in water availability increases the wheat production by 0.6838 percent. This impact is very important in the wake of growing shortage of water and less rainfall years at proper time of wheat cultivation. The effect of rainfall was also found to be significant on sugarcane yield by Chaudhry and Chaudhry (1990).

Thus, the factors influencing wheat yield in order of priority among the independent variables were climatic, economic and location respectively. The wheat yield response was found to be highest to lowest towards maximum temperature at the maturity stage, the input change, average rainfall, technological variable, and the area change respectively.

Conclusion and Recommendations

The results of regression analysis indicated that wheat yield response was relatively flat towards economic and location variables. Economic incentives increased wheat yield at increasing rate. Area response to yield was negative i.e., yield actually decreased due to increase in area. The impact of climatic variables was found highest. Increase in mean maximum temperature at maturity stage of wheat production increases wheat yield, except in the occasion of sudden temperature increases, and this affect was highest as compared to all other variables. Average rainfall, of wheat growing season, has positive affect on wheat yield. This is particularly important in view of growing water shortage in the country.

Vertical expansion has a greater scope in Punjab. Punjab is major supplier of wheat which means that by increasing the yield through more intensive use of inputs using the same area under cultivation Pakistan still has an opportunity to feed its future generations by utilizing domestic resources. Horizontal expansion is not the solution to meet our food security needs. More marginal lands will produce lesser in terms of yield.

There should be training programmes for the farmers by the extension staff. Timely availability of inputs at reasonable prices should be ensured because it is also determining factor in yield. Because of the likely changes in climate, wheat varieties should be developed which are more adaptive to changing climatic conditions. Water shortage in Punjab is critical, so improvement in water availability and its use should be of high priority. There is a need to build upon this research by investing the effect of more economic, social and environmental variables so as to completely understand the dynamics of wheat yield response. These may include the long term effect of different wheat varieties, market conditions, and price trends.

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