Technical Efficiency in Production of Major Food Grains in Punjab, Pakistan

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Based on the 2016–2017 farm survey data, this study examines technical efficiency in the production of wheat, rice, and maize in Punjab province in Pakistan. Technical efficiency, under varying returns to scale, in wheat farming averaged 0.65; in rice, it averaged 0.74, and in the case of maize, it was 0.92. A great majority of the sample farmers were estimated to be operating under increasing returns to scale. Estimations of scale inefficiency in wheat cultivation hovered around 18%; in rice, it ranged from 16% to 21%, and in maize, it varied from 7% to 17%. These estimates are indicative of the scope and the potential for increasing technical and scale efficiencies in the production of all food grains, albeit to varying degrees for different crops.

Keywords: agriculture, data envelopment analysis, food grains, productivity, technical efficiency

JEL codes: D2, D24, Q1, Q18

I. Introduction

Resource productivity and efficiency in the use of farm inputs are the key elements in the development of agriculture in developing countries. In the wake of

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population growth, urbanization, and industrialization, the availability of arable land and water is facing intense pressure from nonfarm uses in Pakistan. Consequently, the per capita availability of arable land and irrigation water is declining, while demand for food and industrial raw materials is on the rise. The prices of farm inputs in Pakistan—such as fertilizers, pesticides, farm machinery, and diesel—have experienced a tremendous hike, resulting in the high cost of farm production and consumers crying hoarse over the rising prices of food and other commodities (Chandio et al. 2017). In addition, climatic changes—as manifested in rising temperatures, varying patterns of rainfall, and increased and intensified flooding—are also raising concerns for farmers and those dealing with the development of agriculture and food production in Pakistan.

The shortage of wheat production in the recent past, set against the domestic requirements of an ever-increasing population, has triggered price hikes, while imports strained the country's foreign exchange reserves. Rice exports have been an important source of earning foreign exchange, estimated at around $2 billion per year in recent years. Increasing maize production has supported the expanding poultry and livestock sectors in the country, as well as the edible oil industry. These crops are thus also important in the context of the balance of trade and payments, and increasing their production, especially through vertical and efficiency improvements, can have salutary effects on the balance of trade through import substitution as well as exports.

In view of the foregoing situation, it is imperative to increase the productivity of farm resources and improve the efficiency of inputs used in farm production. The area under these crops, estimated at 14 million hectares, accounts for approximately 55%–60% of Pakistan's total cropped area, and their annual production constitutes 98% of the total production of food grains in the country (Government of Pakistan 2020). Thus, the production and productivity of these crops play a crucial role in food security and food inflation and also impact the balance of trade in Pakistan. The contribution of Punjab to the annual production of food grains in the country is estimated at over 73% for the most recent years for which data are available (Government of Pakistan 2018), reflecting the province's status as the food grain basket of Pakistan. This study has been designed to ascertain technical efficiency in the production of food grains at the farm firm-level in Punjab.

The contents of the rest of this paper are arranged as follows. Section II discusses the methodological framework for measuring technical efficiency in crop production. The data used in the empirical analysis of the efficiency of food grain production and its source are explained in Section III. Results of the empirical estimation of the technical efficiency of wheat, rice, and maize crops and the related aspects are presented in Section IV. Limitations of data and analysis are given in Section V. The salient features emerging from the efficiency analysis of food grains and the policy implications thereof are summed up in Section VI, concluding the paper.

II. Methodological Framework for Efficiency Analysis

Productivity and efficiency have different meanings in real analysis. Productivity is an absolute concept, measuring the output–input ratio, while efficiency compares the actual production with the optimal level. Thus, it is a ratio between the actual and optimal production levels and provides for the multi-combination analysis of inputs and outputs relating to production frontier (Farrell 1957). The analytical methods to measure efficiency with respect to the production frontier are divided into two categories. One is the output-oriented distance function, and the second is the input-oriented distance function (Banker, Charnes, and Cooper 1984). The output-oriented distance function indicates how much output can be increased without changing inputs and technology, while the input-oriented distance function suggests how much input(s) can be reduced without affecting output(s) and technology. Fare et al. (1994) further extended these models to account for cost and allocative efficiencies.

Productivity and technical efficiency can be estimated using parametric and nonparametric techniques. The linear, nonlinear, and stochastic production functions are the most famous in the category of parametric techniques (Ahmad et al. 2002, Tavva et al. 2017). In case of nonparametric techniques, data envelopment analysis (DEA) is widely used in estimating technical efficiency (Battese, Malik, and Gill 1996; Hameed, Padda, and Salam 2014). This study uses the input-oriented DEA model presented by Banker, Charnes, and Cooper (1984) under constant and variable returns to scale and estimates the technical efficiency by solving the duality problem in linear programming as given below:

$$\begin{aligned} \text{Objective:} \quad & \min_{\theta,\lambda} \theta, \\ \text{Subject to:} \quad & -y_i + Y\lambda \geq 0 \\ & \theta x_i - X\lambda \geq 0 \\ & \lambda \geq 0 \end{aligned} \tag{1}$$

where θ is the technical efficiency of ith food grain crop farmers. Y is the output matrix for ith food grain crop farmers. y_i is the output vector for ith food grain crop farmers. λ is $I*1$ vector of constant weights. X is the inputs matrix for ith food grain crop farmers. x_i is the inputs vector of $x_{1i}, x_{2i}, \ldots, x_{8i}$ food grain crop farmers.

This model was used with the assumptions of constant and variable returns to scale, using the convexity constraint $N1'\lambda = 1$, which ensures that an inefficient farmer is only benchmarked against a farmer of similar size.

A number of studies have estimated, over time, the productivity and efficiency of various crops in Pakistan. The methodologies employed by these studies can be divided into three categories: conventional production function, stochastic frontier production function, and DEA. The studies using conventional production functions include Salam (1976, 1981), Iqbal et al. (2001), Abid et al. (2011), and Koondhar et al. (2018). These studies used direct inputs to the production function and assumed all growers were 100% efficient in their input utilization. Studies using stochastic production functions with one-step and two-step modeling approaches include Battese, Malik, and Gill (1996); Battese and Broca (1997); Ahmad, Qureshi, and Hussain (1999); Ahmad et al. (2002); Saddozai et al. (2013); Battese, Nazli, and Smale (2014); and Fatima, Almas, and Yasmin (2017). Studies using DEA are by Sohail et al. (2012); Javed et al. (2009); and Hameed, Padda, and Salam (2014). Most of these studies had a monocrop focus and were based on a small dataset, while quite a few have become dated. This study analyzes the technical efficiency of all the major food grains cultivated in Punjab. It is based on a large dataset collected through a stratified sample survey organized in the irrigated regions of the province.

Studies using the first two approaches have suffered from model specification issues and have assumed a normal distribution of variance (Pitt and Lee 1981, Kalirajan 1981, Battese and Coelli 1995). These methods are incapable of providing a detailed source of technical inefficiencies (Javed et al. 2009, Sohail et al. 2012). DEA is a linear programming technique that calculates the efficiencies by providing a nonparametric piecewise production frontier over the underlying output and input data. This is an engineering approach and has its own limitations (Coelli et al. 2005). Measurement errors, other noise, and outliers can affect the shape of the boundary and influence the results. The omission of significant input(s) or output(s) can also bias the results, constituting an important limitation of this approach. The key merit of DEA is its computational simplicity, as it can be accomplished without understanding the algebraic form of the input and output relationship. The input and output analysis can be evaluated without any functional form (i.e., linear, quadratic, or exponential) (Coelli et al. 2005). This nonparametric DEA approach estimates the technical efficiency by measuring the distance between the data points of the respective sample and the production frontier. Firms that lie at the production frontier are called technically efficient. Those firms that lie below the production frontier are technically inefficient, and their efficiency can be increased by reducing their distance from the production frontier (Coelli et al. 2005). As per the study objectives, DEA has been adopted to estimate the technical efficiency of major food grains from the farm survey data in Punjab, as discussed below.

III. Data and Source

This study is based on the farm survey data relating to the 2016–2017 (June–May) crop year, collected by the Punjab Economic Research Institute, Lahore. The salient features of the survey sample and data, as gleaned from Tahir, Azeem, and Danish (2018), are given below. The sample was selected through a multi-stage stratified random sampling. At the first stage, Punjab province was stratified into two regions based on the irrigation status and its mode: rain-fed and irrigated. The *barani* (rain-fed) region, as the name implies, primarily depends on natural precipitation for its farming activities, whereas in the irrigated areas, the dominant source of irrigation is canals. At the second stage of sampling, the *barani* region was subdivided into *barani* and partial *barani* regions.

The irrigated region was divided into three crop ecological zones: cotton–wheat, rice–wheat, and mixed-crop zones. From all these zones, 18 districts—4 from the rain-fed and 14 from the irrigated region—were randomly selected. The district is the administrative unit and is further subdivided into *tehsils* (subdivisions). From the sample districts, grouped into various ecological and crop zones, 38 *tehsils* were randomly selected. During selection, *tehsils* in districts were accorded equal weight and two *tehsils* from each district were included in the survey sample. Faisalabad and Vehari districts, being larger in size, each had three *tehsils* included in the sample.

From each sample *tehsil*, depending on the size, between two and four villages were randomly chosen for the selection of survey respondents. A complete census of households in the sample villages was organized and, in all, 766 households were selected according to the probability proportionate to size through the following formula:

$$n = \frac{Z^2P(1-P)N}{Z^2P(1-P) + nd^2} \tag{2}$$

where n is the sample size; Z is the normal variate; P is the population proportion; d is the maximum error deemed acceptable; and N is the target population.

The distribution of sample units at various stages of sampling is presented in Table 1.

Table 1. **Distribution of Survey Sample by Agriculture Zone**

Agriculture or Crop Zone	Number of Districts	Number of *Tehsils*	Number of Villages
Rain-Fed Areas	4	8	14
Barani	2	4	6
Partial ***barani***	2	4	8
Irrigated Areas	14	30	39
Rice–wheat	5	10	12
Mixed zone	3	7	8
Cotton–wheat	6	13	19
Total	18	38	53

Source: Authors' compilation based on Tahir, Azeem, and Danish (2018). *Farm Accounts, Family Budgets of Rural Families and Cost of Production of Major Crops in Punjab (2016–2017)*. Lahore: Punjab Economic Research Institute.

A team of research assistants, posted in various villages, collected data for the 2016–2017 crops, conducting interviews with household heads and recording responses in a pretested survey questionnaire. The crop-specific data covered all the farm operations and activities, from land preparation to harvesting and marketing of the produce. The data, *inter alia*, are related to crop area, use of various farm inputs and field operations on a per crop acre basis, crop yield, unit prices of inputs, customs, and rates of various farm operations. This study is based on the crop production data of 551 farm households in the irrigated region only. This subset of the sample belonged to 14 irrigated districts and was spread over 39 villages. Actually, there were 577 households in the irrigated region, but data from some of these respondents were not complete and had to be discarded.

IV. Empirical Results

As already mentioned, wheat, rice, and maize are the major food grains cultivated in Punjab. Efficiency in their production has an important bearing not only on the growth rate of agriculture in the province but also on the overall food security situation in Pakistan. Empirical results of efficiency analysis in the production of food grains, based on 2016–2017 crops' data, are detailed below.

A. Land Productivity

Basic statistics relating to land productivity of food grains and yield per acre on sample farms and grouped according to their crop zone are presented in Table 2.

Table 2. **Land Productivity of Food Grains on Sample Farms**

	Agriculture Zone	Rice–Wheat	Cotton–Wheat	Mixed Zone	Overall
Wheat	Number of observations	167	274	110	551
	Mean yield	1,695	1,584	1,477	1,596
	Standard deviation	195.7	265.7	247.9	254.3
Rice	Number of observations	161	47	48	256
	Mean yield	1,625	1,517	1,271	1,538
	Standard deviation	532	432	405	510
Maize	Number of observations	—	—	—	62
	Mean yield	—	—	—	1,995
	Standard deviation	—	—	—	445

— = not applicable.
Note: Crop yields in kilogram per acre; rice yield in terms of paddy.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

Variation between the yields is reported in Appendix (Table A1). As per these data, there is a lot of variation in crop yields, both within and across the crop zones. The self-reported yield of wheat, averaging 1,695 kilograms (kg) per acre, was the highest in the rice–wheat zone, followed by 1,584 kg per acre in the cotton–wheat zone, and 1,477 kg per acre in the mixed zone. The overall wheat yield, for the entire sample of irrigated districts, was estimated at 1,596 kg per acre, with a minimum of 600 kg and a maximum of 2,480 kg per acre. In the rice–wheat zone, the per acre yield ranged from 1,200 kg to 2,000 kg, and in the cotton–wheat zone the minimum and maximum yields were reported at 800 kg and 2,480 kg, respectively. In the mixed zone, the per acre yield ranged from 600 kg to 2,280 kg. The coefficients of variation in crop yields, ranging from 0.12 to 0.17, averaged 0.16, reflecting substantial variation and scope for increasing production through a reduction of yield gaps across farms.

Rice (paddy) yield, in the rice–wheat zone, ranging from 800 kg to 2,800 kg per acre, averaged 1,625 kg, with a coefficient of variation (CV) of 0.33. The paddy yield in the mixed zone, varying from 640 kg to 2,680 kg, averaged 1,271 kg, with its CV estimated at 0.32. In the cotton–wheat zone, the paddy yield oscillated between 720 kg and 2,600 kg, averaging 1,517 kg and with a CV of 0.28. As per these data, the paddy yield in the rice–wheat zone, having the largest number of observations, was relatively higher but also reflected greater variability.

In view of the small number of observations of maize-growing farmers (62), analysis of this crop is based on the total sample without subdividing the observations into crop zones. Maize yields, ranging from 1,080 kg to 3,200 kg per acre, averaged

1,995 kg. Notwithstanding the adoption of improved cultivars, maize yield data reflect the substantial variation as manifested by a high value of the standard deviation.

To ascertain statistical significance of the differences in crop yields, within and across zones, a Bonferroni test was applied to compare multiple hypotheses with multiple comparisons (Armstrong 2014). As per results of the test, the differences in wheat yield across the crop zones were statistically significant at the 1% level. Similarly, the differences in average rice yields across different zones were statistically significant at the 1% and 5% levels (Table A2).

B. Technical Efficiency

Using DEA under the input-oriented technique, we have estimated technical efficiency of food grains production under constant (TE_{CRS}) as well as variable returns to scale (TE_{VRS}). DEA, as explained earlier, is a linear programming technique that calculates the efficiencies by producing a nonparametric, piecewise production frontier encompassing the underlying output and input data. This also enables the estimation of slacks in the use of important inputs, without changing the level of output and technology (Coelli et al. 2005).

1. Technical Efficiency under Constant Returns to Scale

Technical efficiency scores under constant and variable returns to scale along with the scale efficiencies, as estimated from the survey data, are presented in Table 3.

As per results of the efficiency analysis, wheat farmers in the mixed zone had the highest mean TE_{CRS} score of 0.80, with a range from 0.35 to 1.00. The average technical efficiency scores in the cotton–wheat and rice–wheat zones were estimated at 0.74 and 0.61, respectively. TE_{CRS} in rice farming in the rice–wheat zone ranged from 0.37 to 1.00 and averaged 0.72. The mean values of technical efficiency were estimated at 0.67 in the mixed zone and 0.70 in the cotton–wheat zone, while the minimum values stood at 0.30 and 0.40, respectively. The technical efficiency of maize on sample farms ranged between 0.38 and 1.00, averaging 0.76.

As per the estimates, technical efficiency in the production of all food grains, across various crop zones and representing different farming systems and cropping patterns, exhibits large variation. On average, wheat farmers can reduce their inputs by 20%–39% on the basis of the technical efficiency of constant returns to scale without changing the current level of output and technology. Similarly, rice farming across various crop zones demonstrates large variation. The metrics suggest vast scope for increasing production through improving the technical efficiency of rice farmers. On

Table 3. **Technical Efficiency Coefficients in Food Grains Production**

		Wheat		Rice		Maize	
Zones	**Efficiencies**	**Mean**	**Minimum**	**Mean**	**Minimum**	**Mean**	**Minimum**
Rice–wheat	TE_{CRS}	0.61	0.28	0.72	0.37	—	—
	TE_{VRS}	0.71	0.38	0.85	0.54	—	—
	SE	0.88	0.56	0.84	0.56	—	—
Cotton–wheat	TE_{CRS}	0.74	0.44	0.70	0.40	—	—
	TE_{VRS}	0.90	0.72	0.87	0.60	—	—
	SE	0.83	0.47	0.8	0.41	—	—
Mixed zone	TE_{CRS}	0.80	0.35	0.67	0.30	—	—
	TE_{VRS}	0.86	0.57	0.83	0.52	—	—
	SE	0.93	0.44	0.79	0.42	—	—
Overall sample	TE_{CRS}	0.58	0.30	0.64	0.30	0.76	0.38
	TE_{VRS}	0.65	0.40	0.74	0.42	0.92	0.52
	SE	0.89	0.40	0.86	0.39	0.82	0.45

— = not applicable, SE = scale efficiency, TE_{CRS} = technical efficiency under constant returns to scale, TE_{VRS} = technical efficiency under variable returns to scale.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

average, rice farmers can reduce their inputs by 28%–36% on the basis of the technical efficiency of constant returns to scale without changing the current level of output and technology. Maize farmers can reduce their inputs by 24% without changing the current level of output and technology.

The assumption of constant returns to scale may not be tenable under conditions observed on the ground, which are characterized by several input constraints and the inelastic supply of land. We have also estimated technical efficiencies of food grains production under varying returns to scale. The results of this estimation are also set out in Table 3. Further discussion of efficiency analysis in this study is based on results of varying returns to scale (TE_{VRS}) and scale efficiency (SE).

2. Technical Efficiency under Varying Returns to Scale

The mean value of TE_{VRS} for wheat, estimated at 0.90, was the highest in the cotton–wheat zone, followed by 0.86 in mixed zone and 0.71 in rice–wheat zone. Technical efficiency scores of wheat farmers in the cotton–wheat zone, ranging from 0.72 to 1.00, also reflected the lowest variation, while rice–wheat zone farmers' efficiency scores ranged from 0.38 to 1.00 and reflected the highest variation. A large fraction of wheat farmers, in all zones, had efficiency scores that were lower than their respective zonal averages. About 65% of farmers in the rice-wheat zone had an efficiency score well below the sample average of 0.71. In the cotton–wheat zone, about 50% of the wheat growers had an efficiency score of 0.90 or above. In the mixed zone, 42% growers were estimated to have an efficiency score of 0.90 or above, while 54% had an efficiency score ranging from 0.60 to 0.90. It is worth mentioning that wheat farming in the rice–wheat zone was not only less efficient but its efficiency score also reflected a skewed distribution toward the lower end of the spectrum. In the cotton–wheat zone, the technical efficiency score was not only higher but also was concentrated toward the higher end of distribution, with 93% of sample farmers having a score of 0.80 or more.

The average efficiency score of 0.87 in rice farming for the cotton–wheat zone, under varying returns to scale, was higher than the corresponding scores of 0.85 and 0.83, calculated for the rice–wheat and mixed zones, respectively. The technical efficiency scores in the cotton–wheat zone ranged between 0.60 and 1.00, reflecting smaller variation compared to the rice–wheat and mixed zones, which ranged from 0.54 to 1.00 and from 0.52 to 1.00, respectively. About 81% of sample farmers' efficiency scores in maize farming are estimated to have exceeded 0.90. The high efficiency scores in maize farming have their origin in the increasing adoption of improved technologies centered on using hybrid varieties of maize.

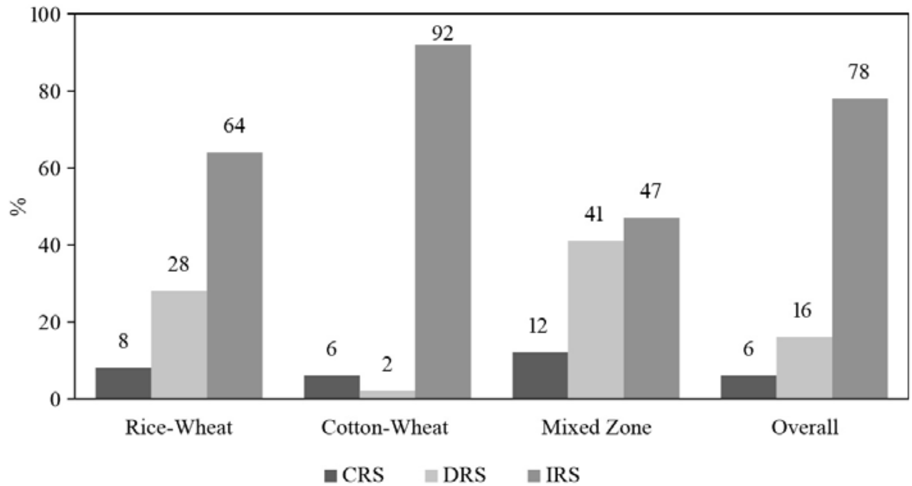
3. Scale Efficiency and Returns to Scale

The scale efficiency score was calculated by dividing the technical efficiency score under constant returns to scale by the corresponding efficiency score under variable returns (Coelli 1996). A scale efficiency score of 1 (100%) implies operating at optimal scale or size, while a score of less than 1 (< 100%) is indicative of either too small or too big a farm relative to its optimal size. The situation in terms of returns to scale in wheat farming, for various crop zones, is depicted in Figure 1.

About 78% of all wheat growers were operating at increasing returns to scale, while 16% had decreasing returns to scale. The inter-zone comparison of returns to scale indicated the cotton–wheat zone has the highest proportion (92%) of increasing returns to scale and only a tiny fraction (> 2%) exhibit decreasing returns to scale. In the mixed zone, 41% of farmers have decreasing returns, while 59% are working under constant or increasing returns to scale. The rice–wheat zone fell in between the cotton–wheat and mixed zones, as 72% of farmers enjoy either increasing or constant returns to scale.

The overall scale efficiency score for wheat farming stood at 0.89, while for rice farmers it averaged 0.86, implying less than optimal scale because of the small size

Figure 1. **Returns to Scale in Wheat by Zones**

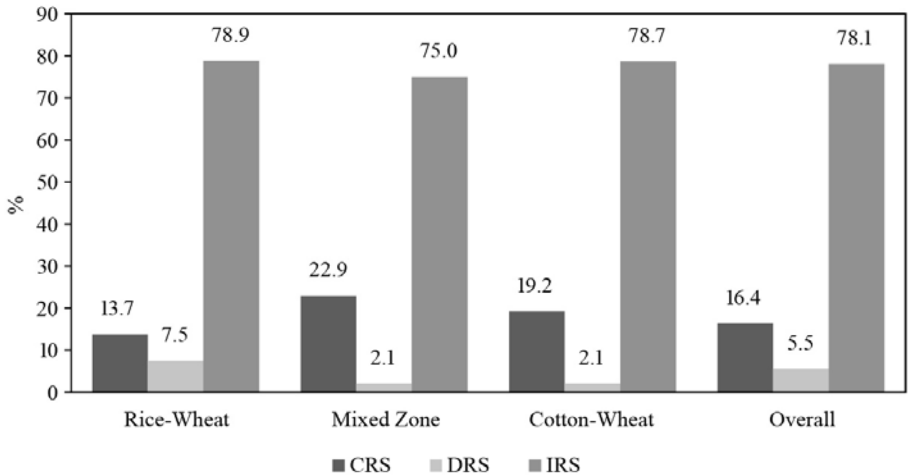


CRS = constant returns to scale, DRS = decreasing returns to scale, and IRS = increasing returns to scale.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

of operations. Thus, there is scope for increasing scale efficiency. However, a large majority of rice farmers have had small land areas, which may be their main hurdle in realizing increasing returns to scale. The estimates of scale efficiency of rice crop show that, on average, rice farmers in the rice–wheat and mixed zones, respectively, experienced scale inefficiencies of 16% and 21% (Figure 2). The corresponding value for the cotton–wheat zone stood at 20%. Although farmers in the rice–wheat zone had the highest average yield, they were found to be less efficient compared to the cotton–wheat and mixed zone farmers. The estimation of scale efficiency of wheat farmers suggests that growers, across various zones, had inefficiency scales ranging from 7% to 17% implying that there is much scope for increasing output by applying an optimal mix of inputs without changing the technology being used (Table 3).

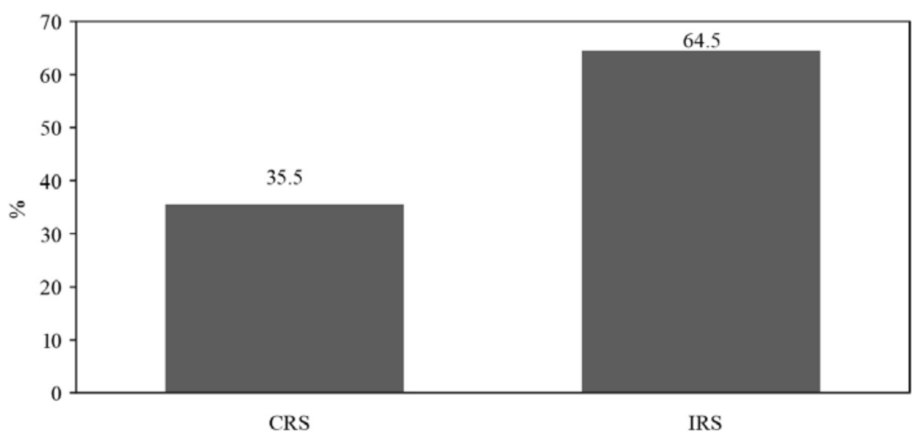
About 64.5% of maize growers were estimated to be operating with increasing returns to scale, while 35.5% had constant returns to scale (Figure 3). The scale efficiency for maize farming averaged 0.82, implying that farmers are operating at less than optimal scale and scope for increasing scale efficiency. However, as a great majority of the sample farmers have small areas for crops, exploiting economies of scale will, among other things, involve enlarging the size of their farms.

Figure 2. **Returns to Scale in Rice Farming by Zones**



CRS = constant returns to scale, DRS = decreasing returns to scale, and IRS = increasing returns to scale.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

Figure 3. **Returns to Scale in Maize**



CRS = constant returns to scale, IRS = increasing returns to scale.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

C. Slacks in Inputs Use

Data on average use of selected inputs and field operations (converted into costs) and slacks in the production of food grains, by agricultural zones, are set out in Table A3, while a summary of the results is presented in Table 4. Data relating to use level of inputs underscore the contribution of land preparation, seed and sowing, irrigation, plant protection (weedicides and pesticides), and fertilizers in the cultivation of food grains. The costs of these inputs, across various crops and regions and cropping zones, depict substantial variation, reflecting regional diversity in resource endowment, agronomic requirements of crops, and cultural operations.

As per the results of slack analysis, there is considerable potential for effecting economies in the use of inputs and reducing the costs of field operations in all the crops and across crop zones. The cotton–wheat zone is characterized by relatively higher slack in both wheat and rice crops. Major slacks are estimated in the costs of supplementary irrigation, use of chemicals in plant protection, and use of fertilizer materials. Wheat growers in cotton–wheat zone suffered higher slacks in plant protection (52.2%), irrigation (24.6%), and land preparation (18.1%) compared to rice–wheat and mixed zones. Cotton–wheat zone farmers can reduce their cost of various inputs by 2,947 Pakistan rupees (PRs) per acre by cutting their use

Table 4. **Use of Important Inputs in Food Grains and Slacks**

	Land Preparation	Seed and Sowing	Irrigation	Plant Protection	Fertilizer
			Wheat		
Mean (PRs/acre)	2,768	5,327	2,749	2,709	5,593
Slacks (PRs/acre)	102	9	203	917	146
Slack (%)	3.68	0.17	7.38	33.85	2.61
			Rice		
Mean (PRs/acre)	4,182	3,987	11,894	962	6,265
Slacks (PRs/acre)	78	25	1,050	42	121
Slack (%)	1.87	0.63	8.83	4.37	1.93
			Maize		
Mean (PRs/acre)	3,060	1,034	3,762	1,576	8,050
Slacks (PRs/acre)	16	21	727	136	843
Slack (%)	0.52	2.03	19.32	8.63	10.47

PRs = Pakistan rupees.
Note: These data are the average of all the observations for the respective crops.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

of irrigation, plant protection, and fertilizers without reducing output and technology. In rice-wheat zones, there is also scope for a cost reduction of PRs993 per acre through application of the inputs mentioned above.

As per the results of the slack analysis, slacks in the important inputs in relation to average use per cost in the cotton–wheat zone in rice farming ranged from PRs43 to PRs1,218 per acre. The cotton–wheat zone experienced the highest slack at PRs2,526 per acre compared to PRs1,047 and PRs1,191 for the rice–wheat and mixed zones, respectively. Land preparation, seed and sowing, irrigation, and fertilizers account for the bulk of slack. The amount of slack in irrigation costs in the cotton–wheat (18%) and the mixed zone (11.3%) is higher as compared to the rice–wheat zone. The estimated slacks in important inputs in relation to average use in maize farming, on sample farms, ranged from PRs16 to PRs843 per acre. The overall slack worked out to PRs1,743 per acre and included PRs727 for irrigation and PRs843 for fertilizers.

Adequate land preparation is important for ensuring good seed germination and the establishment of crop stand in a field. As per the estimates, it is the second most expensive farming input after the use of chemicals. According to the input-oriented slack analysis, slacks in seed and sowing costs across all food grains are only marginal. After land preparation and sowing, irrigation, plant protection, and fertilizers are the most important expenditures for growing food grains. These items also constitute the most important slack and source for cutting costs through judicious use and mix of these inputs. Most of the growers use nitrogen and phosphate fertilizers, and only a few apply potash fertilizer to their food grains. Farmers tend to spend from PRs6,000 to PRs8,000 on fertilizers for various food grains. Most farmers are understood to apply their fertilizers without any soil testing or crop analysis.

Fertilizer use is often predicated on availability rather than the best practices recommended by crop experts, resulting in considerable wastage and slack in the application of precious nutrients, varying between 2.0% and 10.5% of the cost of fertilizers. The plant protection measures comprise the use of different herbicides and weedicides. Pesticides and fungicides also form a part of the slacks that need to be addressed through improving farmers' awareness about the efficient and judicious use of these chemicals. Application of these materials is estimated to cost between PRs1,000 and PRs2,700 per acre, and slacks constitute from 4% to 33% of the costs, wheat having the highest expenditure as well as the largest slack. Indiscriminate use of these chemicals not only adds to the cost of cultivation, but also causes environmental pollution and health hazards. Irrigation costs offer another opportunity for savings.

D. Intercrop Comparison of Efficiencies

Average technical efficiency for the overall sample, under varying returns to scale, worked out to 65% in wheat farming, 74% in rice farming, and 92% in maize production. The wide variations in efficiency across crops are a manifestation of the conditions under which the crops are raised and the adoption of technology. They are also indicative of the potential for increasing production through raising productivity and bridging the efficiency gap across various farm groups and crop zones. Higher relative efficiency in maize farming may be on account of the wide adoption of technological packages propagated by the seed companies. Whereas for rice and wheat, the majority of farmers generally rely on their own seeds and seldom use the full technological package. Nevertheless, it needs to be emphasized that in all crops, farmers cannot operate at the same level of efficiency but need to minimize and bridge the gaps across farm groups and regions.

V. Limitations of the Data and Analysis

This paper has estimated technical efficiency in the production of food grains from the data collected through a one-shot survey. Efficiency in farming hinges on many diverse factors, including not only the use of technology as embedded in modern and other farm inputs, but also on a host of other variables like quality of land and water resources, timely or otherwise availability and judicious mix of various inputs, location of farms, and management practices. Data on the latter type of variables can seldom be captured in one-shot field surveys, often conducted after the crop has been harvested and, *inter alia*, may suffer from recall errors of omission and commission.

These surveys are also unable to capture the dynamics of farming systems best captured through participation and observations of the ongoing process. Notwithstanding such limitations of data common to all field surveys, it is imperative to have periodic assessments of the efficiency of farm enterprises, and gaps therein, and ascertain constraints confronting farmers in their performance of various agronomic activities. Akimowicz et al. (2018) and Fresco et al. (2021) have discussed at length the strengths and weaknesses of such data, and they have suggested alternate methods and approaches for the consideration of researchers in this context. Estimating enterprise efficiency and related economic aspects does require quantitative data on the use of various inputs, intensity and frequency of different farm operations and management practices, and farm gate prices of inputs and outputs. However, these data ought to be supplemented by information on the variables listed above to help in ascertaining the factors constraining efficiency so as to adopt remedial measures and actions to bridge the efficiency and productivity gaps.

The comparative advantage of growing major crops, including food grains in Punjab under import and export situations, is well established and documented (Quddus and Mustafa 2011, Salam 2012, Salam and Tufail 2016). Wheat production in the recent past has fallen short of the requirements of the burgeoning population, necessitating large imports. Rice exports provide valuable foreign exchange. Efficiency analysis helps in assessment of the situation for chalking out strategies for increasing production based on import substitution or export promotion.

VI. Concluding Observations

Analysis of land productivity and technical efficiency in the production of major food grains in the Punjab has highlighted substantial variation and scope for increasing production by improving productivity and technical efficiency at the farm-firm level. The overall TE_{VRS} scores in wheat farming, ranging from 0.40 to 1.00, hovered around 0.65. A great majority of wheat farmers were estimated to be operating under increasing returns to scale. The scale efficiency averaged 0.89. Technical efficiency and estimates of slacks in the use of important inputs in wheat farming in various crop zones indicate that farmers can reduce the level of important inputs from 10% to 29% without changing the current level of output and technology. TE_{VRS} scores in rice farming averaging 0.87 in the cotton–wheat zone were higher than the corresponding scores of 0.85 and 0.83 calculated for the rice–wheat and mixed zones, respectively. About 78% of the rice farmers were estimated to be operating under increasing returns to scale. The overall scale efficiency for rice crops averaged 86% and at a minimum was 39%.

The estimated slacks in the important inputs in relation to the average use in the cotton–wheat zone in rice farming ranged from PRs43 to PRs1,218 per acre. Land preparation, seed and sowing, irrigation, and fertilizer account for the bulk of slacks. The overall sample slack averaged PRs1,316 per acre. TE_{vrs} in maize farming averaged 0.92, ranging between 0.52 and 1.00. About 65% of maize farmers operate under increasing returns to scale. The scale efficiency estimates indicated that maize farmers, on average, had inefficient scale of 18%. Empirical results depict farmers experiencing between 16% and 21% scale inefficiency for rice, followed by 18% for maize and from 7% to 17% for wheat, which is indicative of inefficient scale of production, *albeit* varying, in all food grains.

A large variation in technical efficiency is a manifestation of the substantial potential for increasing farm productivity and the production of food grains in the province. However, successful efforts need to be predicated on detailed analysis and diagnosis of the underlying factors for each region and crop. Akimowicz et al. (2018) and Fresco et al. (2021) have provided useful guidelines on the subject. The variation observed in the technical efficiency estimates, across various zones, suggests a regional and bottom-up approach to improve the situation. It calls for regular monitoring of the technical performance and socioeconomic constraints, availability of various inputs, and marketing challenges, as well as addressing these issues as and when they arise.

A large fraction of the sample farms in different crop zones, varying from crop to crop, is estimated to be working below their respective average technical efficiencies. The overall number of such farms is over 20%, a large number that must be a matter of serious concern to all interested in the development of agriculture and alleviating rural poverty. The route to mitigating poverty in the rural countryside passes through increased farm production and productivity, given its vast forward and backward linkages. This requires a proper strategy and policy framework based on in-depth analysis of the ground situation. There is also a need to probe various factors that hamper technical efficiency. There is considerable potential and scope for effecting economies in the use of inputs and reducing unit costs of production by adjusting and managing the use of important farm inputs.

The results of the study indicate that farmers are, by and large, operating at increasing returns to scale and, therefore, have the potential to increase their efficiency and productivity by increasing their scale of activities and operation. This implies that the farmers in Punjab are operating on less than optimal scale and increasing it would facilitate more effective use of inputs and lower marginal costs of production. However, as a great majority of farmers have small holdings and land is a major constraint in this context, some out-of-the-box thinking is required to tap this potential.

As far as the slacks in input use are concerned, a few points regarding the use of chemical technologies and inputs like fertilizers, weedicides, and pesticides are in order. No doubt the use of chemicals—including fertilizers to increase and maintain soil fertility and ensure adequate plant nutrition; plant protection measures to protect crops against the ravages of various insects, plant diseases, and other pathogens; and weedicides and herbicides to control weeds in crop fields—has assumed a critical role in increasing crop production and productivity. However, it is the judicious use of these chemicals—based on proper soil and crop analysis in the case of fertilizers and proper pest scouting and the identification of various insects, stage of pest's life cycle, and the timing and dosage of the chemicals based on expert advice—that can yield optimal results. Similarly, the application of weedicides gives the best results when accompanied by expert advice on the selection, timing, and dose of such materials. In the absence of such precautionary measures, the indiscriminate use of fertilizers, pesticides, and weedicides is not only inefficient and wasteful, but also it can result in environmental pollution, resource degradation, and health hazards and challenges. The slacks estimated in the use of various chemical fertilizers and pesticides point to their indiscriminate use and underscore the need for developing and adopting an integrated approach incorporating agronomic practices and crop rotations. It is also imperative to develop and follow standard operating procedures in the use of agricultural chemicals. These procedures must be propagated through print, electronic, and other media for dissemination and adoption at the grassroots level to achieve sustainable development in agriculture.

Given the constraints to expanding arable land and declining per capita availability of land and water resources, it is imperative to streamline and strengthen the agricultural research and extension systems, develop institutional capacity in Punjab to address emerging challenges and issues, develop region-specific crop production technology packages, and guide farmers through all media in the adoption of these packages. Needless to emphasize, steps must be taken to ensure the timely and adequate availability of these packages. It is also important to develop an agricultural policy package to cater to the short-term and long-term objectives of agricultural development and food security requirements as *ad hoc* policy packages cannot be a substitute for a thoughtful strategy for the development of agriculture in Pakistan.

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[**]This paper was prepared based on information available for Afghanistan as of 31 July 2021.

Appendix

Table A1. **Wheat, Rice, and Maize Yield Variation by Zone**

Crop	Agriculture Zone	Minimum Yield	Maximum Yield	Coefficient of Variation
Wheat	Rice–wheat	1,200	2,000	0.12
	Cotton–wheat	800	2,480	0.17
	Mixed zone	600	2,280	0.17
	Overall	600	2,480	0.16
Rice	Rice–wheat	800	2,800	0.33
	Mixed zone	640	2,680	0.32
	Cotton–wheat	720	2,600	0.28
	Overall sample	640	2,800	0.33
Maize	Overall sample	1,080	3,200	—

— = not applicable.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

Table A2. **Comparison of Wheat and Rice Yields**

	Between Groups	Wheat within Groups	Total	Between Groups	Rice within Groups	Total
Sum of squares (SS)	3,242,942	32,332,452	35,575,395	4,654,954	61,648,421	66,303,375
Degrees of freedom (DF)	2	548	550	2	253	255
Mean square (MS)	1,621,471.1	59,000.8	64,682.5	2,327,477	243,670	260,013
F-test		27.48			9.6	
Prob. > *F*		0.000			0.0001	
Bartlett's test for equal variances		Chi 2(2) = 18.1692 Prob. > Chi 2 = 0.000			Chi 2(2) = 6.6339 Prob. > Chi 2 = 0.036	

	Comparison of Wheat Yield by Using Bonferroni Test		Comparison of Wheat Yield by Using Bonferroni Test	
Row Mean–Column Mean	**Rice–Wheat Zone**	**Mixed Zone**	**Rice–Wheat Zone**	**Mixed Zone**
Mixed Zone	−218.36*	—	−353.7*	—
Cotton–Wheat	−110.93*	107.43*	−108***	245.7**

— = not applicable.
Notes: * < 1%, ** < 5%, and *** < 10%.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.

Table A3. **Use of Important Inputs and Slacks in Wheat, Rice, and Maize Farming (PRs/acre)**

		Rice–Wheat		Cotton–Wheat		Mixed Zone		Overall Sample	
Crops	**Inputs**	**Mean**	**Slacks**	**Mean**	**Slacks**	**Mean**	**Slacks**	**Mean**	**Slacks**
Wheat	Land preparation	3,099	6.1%	2,641	18.1%	2,582	10.3%	2,768	3.7%
	Seed and sowing	5,103	0.4%	5,417	0.1%	5,441	0.6%	5,327	0.2%
	Irrigation	3,598	11.5%	2,541	24.6%	1,978	15.1%	2,749	7.4%
	Plant protection	1,513	21.0%	4,060	52.2%	1,160	17.2%	2,709	33.9%
	Fertilizer	5,390	4.8%	5,868	3.5%	5,217	1.3%	5,593	2.6%
Rice	Land preparation	4,540	5.2%	4,348	1.0%	2,818	4.7%	4,182	1.9%
	Seed and sowing	4,334	1.8%	3,646	12.1%	3,155	0.0%	3,987	0.6%
	Irrigation	14,388	3.4%	6,751	18.0%	8,568	11.3%	11,894	8.8%
	Plant protection	879	6.4%	1,011	6.3%	1,191	5.0%	962	4.4%
	Fertilizer	5,787	3.2%	7,834	9.7%	6,334	0.5%	6,265	1.9%
Maize	Land preparation	—	—	—	—	—	—	3,060	0.5%
	Seed and Sowing	—	—	—	—	—	—	1,034	2.0%
	Irrigation	—	—	—	—	—	—	3,762	19.3%
	Plant Protection	—	—	—	—	—	—	1,576	8.6%
	Fertilizer	—	—	—	—	—	—	8,050	10.5%

— = not applicable, PRs = Pakistan rupees.
Source: Authors' calculations based on Punjab Economic Research Institute, Lahore's farm survey data for crop year 2016–2017.