44 *Research Report*

Productivity and Performance of Irrigated Wheat Farms across Canal Commands in the Lower Indus Basin

Intizar Hussain
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and
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International Water Management Institute

Research Reports

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Summary

Despite the widespread adoption of green-revolution technology over the last three decades, enormous differences in agricultural productivity exist across farms and regions in Pakistan. Recent farm-level data from Sindh, for example, indicate that irrigated wheat output per hectare varies from 0.5 to 5.4 tons across farms. Improving and sustaining productivity, narrowing the existing productivity gaps, and enhancing resource use efficiencies to meet food requirements of a rapidly growing population is now a central goal of agricultural policy in the country. However, serious concerns over rapid degradation of both land and water resources are emerging. There is growing evidence that land quality is deteriorating with severe problems of waterlogging and salinity. In addition, irrigation water is becoming increasingly scarce with growing demand and increasing competition across sectors and regions. Poor management of these resources is one of the major contributing factors to this situation.

This study attempts to enhance the understanding of the factors that determine differences in agricultural productivity. The main objective of this report is to evaluate performance of irrigated wheat farms with a view to analyze cross-sectional productivity differences and to determine the productivity potential in Sindh. In contrast to most other similar studies done in Pakistan, the present study focuses on examining the influence of quality of resources and adequacy of irrigation water on farm productivity.

The study is based on cross-sectional data collected from a random sample of 1,220 irrigated wheat farms located in 14 canal commands in the Lower Indus Basin of Sindh Province. The basic approaches used in the study consist of evaluating farm performance using Data Envelopment Analysis (a non-parametric programming method), and quantifying elasticities and marginal productivity of production inputs by estimating aggregate and disaggregated production functions. The combination of these two methods provided insight into the factors that determine the observed farm productivity gaps within and among canal commands in the province. Average farm level performance index was estimated at 74 percent, implying that wheat producers can reduce inputs by 26 percent by adopting the best practices of efficient producers. The results show that the best performing producers in Sindh comprise 20 percent of the total with a performance index estimated at 100 percent. A further 30 percent is operating at a fairly high level of performance with the index ranging from 70 to 90 percent, and the remaining 50 percent is operating at low levels with the performance index ranging from 40 to 69 percent. Shortage of irrigation water in some canal commands and poor land quality in others are two fundamental constraints to productivity increases in the province. Unless these constraints are removed, benefits from other production enhancing programs, including subsidies on inputs (seed, fertilizer, credit, etc.), are likely to be very limited. Marginal productivity of irrigation water is found to vary significantly across canal commands. The analysis suggests that productivity gains in the immediate short run can be achieved by the effective reallocation of water across canal commands. However, sustained productivity increases in the long run would be achieved through effective management of, and additional investments in, both land and water resources.

Productivity and Performance of Irrigated Wheat Farms across Canal Commands in the Lower Indus Basin

Intizar Hussain, Fuard Marikar, and Waqar Jehangir

Introduction

Since the advent of the green revolution in the 1960s, increase in productivity was a key element of agricultural development policy in Pakistan. Early gains from the adoption of new seed, fertilizer and irrigation technology provided incentives for the development of additional land and water resources. While these developments made significant contributions to substantially increased food grain production in the country, gains from the new technology were not uniform across farms and regions. A general consensus seems to have emerged that the full potential of this technology has not been realized in Pakistan. Extremely wide gaps in agricultural productivity exist among farms and regions in the country. Recent farm-level data from Sindh, for example, indicate that irrigated wheat output per hectare varies from 0.5 to 5.4 tons across farms.

There are significant constraints to further expansion of both land and water resources. The closing of the land frontier and the increased costs of irrigation infrastructure, combined with increasing pressure on available water supplies, highlight the fact that further increases in production could be achieved mainly by improving and sustaining the productivity levels and enhancing resource-use efficiencies. However, there is growing evidence that these resources are being degraded; land quality is deteriorating with severe problems of waterlogging and salinity. In addition, irrigation water—one of the most important agricultural production inputs—is becoming increasingly scarce with growing demand and increasing competition across sectors and regions. A recent study by the International Water Management Institute (IWMI) on the world water supply and demand has classified Pakistan in Group 1, which consists of countries that are likely to face serious water scarcity in the future (Seckler et al. 1998). On the other hand, sustained increases in food grain production are needed to meet the requirements of a rapidly growing population in the country. Thus, sustaining and improving food grain production within the constraints of existing resources through effective management of land and water is a major policy goal in Pakistan.

Objective

While there is a considerable amount of literature on this subject in Pakistan, most past studies have focused on productivity impacts of socioeconomic and agronomic factors. It is only in recent years that attention is being given to management aspects of land and water resources and performance of irrigation systems. (For recent research on this subject and for other references on previous studies, see

Jehangir and Ali 1998.) In contrast to most previous studies in Pakistan, this study focuses on examining the influence of resource quality and adequacy of irrigation water on farm productivity. It attempts to identify factors that determine existing enormous differences in irrigated farm productivity within and across canal commands and to quantify the influence of these factors on farm performance. The main objective is to evaluate performance of irrigated wheat farms with a view to analyze cross-sectional productivity differences and to determine the productivity potential in Sindh.

The study is based on cross-sectional data collected from irrigated wheat farms in the Lower Indus Basin. The basic approaches used in this research consist of evaluating farm performance using Data Envelopment Analysis, and quantifying elasticities and marginal productivity of production inputs by estimating aggregate and disaggregated production functions. The combination of these two methods provided insight into the factors that determine the observed productivity gap within and among canal commands in the province. The results of this study indicate that wheat farms, on average, can reduce inputs by 26 percent by adopting the best practices of efficient farms. Shortage of irrigation water in some canal commands and poor land quality in others are two fundamental constraints to productivity increases in the province. Unless these constraints are removed, benefits from other production enhancing programs, including subsidies on inputs (seed, fertilizer, credit, etc.), are likely to be very limited. The analysis suggests that productivity gains in the immediate short run can be achieved by the effective reallocation of water across canal commands. However, sustained productivity increases in the long run would be achieved through effective management of, and additional investments in, both land and water resources.

Study Location

The Lower Indus Basin was the location of the study. It lies in Sindh, which is one of the four provinces of Pakistan. With a geographical area of 14.09 million hectares, Sindh extends to the Arabian Sea in the southwest (the head of the Lower Indus Basin), and to the border with India in the southeast (fig. 1). The climate of the province is arid and hot. Rainfall is generally low (averaging less than 260 mm a year) and the temperature is high (average summer maximum is over 37° C), with high evaporation. The distribution of rainfall through the year is quite uneven, with most of the rainfall occurring during July-September, the monsoon period. Estimates by Rehman and Rehman (1998) indicate that rainfall contributes only 2 to 3 percent of the total water supply during *rabi* (the mid-October to mid-April cropping season); of the other sources, canal water, groundwater and sub-irrigation contribute 73 to 78 percent, 5 to7 percent, and 15 to 17 percent, respectively.

The total cultivated area (fallow plus net area sown) of the province in 1997-98 is estimated by the Government of Pakistan at 5.68 million hectares, with 2.56 million hectares classified as irrigated area. With groundwater in most of Sindh being brackish and unsuitable for crop irrigation (Rehman and Rehman 1998), over 95 percent of the irrigated areas rely on surface water resources (Government of Pakistan 1997-98).

FIGURE 1.

Indus Basin, Pakistan.

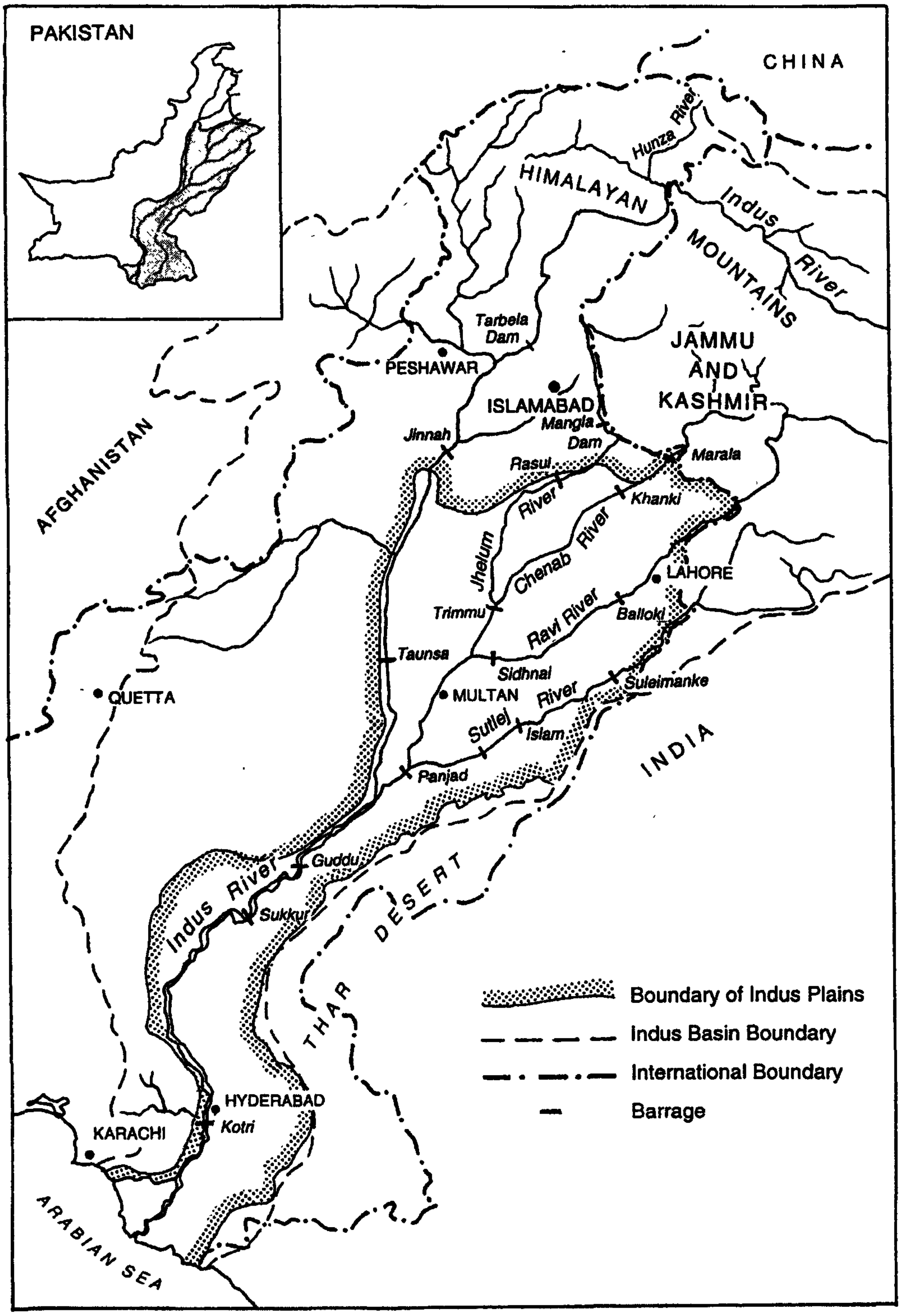
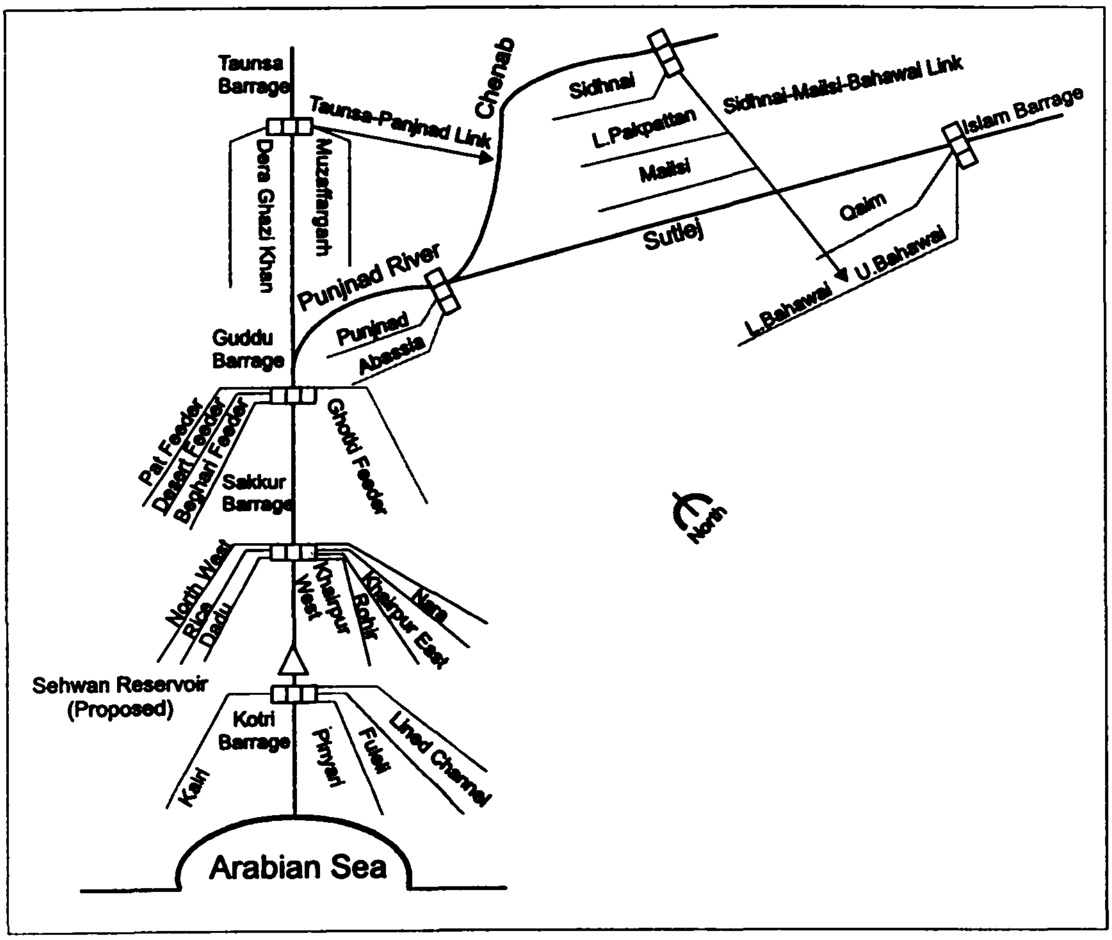


FIGURE 2.
Lower Indus Basin irrigation system: Schematic diagram.



Overview of Irrigation System

The present irrigation system of the Lower Indus Basin consists of 3 barrages (namely, Sukkur, Kotri, and Guddu), 14 feeder and main canals,[1] 1,462 branch canals, distributaries and minors, and a large number of water channels at tertiary or farm level. The first 5 canals in table 1 are located on the Right Bank (RB) and the remaining 9 on the Left Bank (LB) of the Indus River (fig. 2). There are significant differences in the culturable command area (CCA) across canals, with Desert and Rohri being the smallest and the largest commands, respectively. Rice Canal and Begari canals on RB and Pinyari and Fuleli on LB were originally non-perennial type canals. However, canal operation data for 1995-96 suggest that three of these canals (Rice Canal being the exception) have been converted into more or less perennial systems.

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[1] Two other canals, namely, Kalri Beghar Feeder (which also provides water for urban use in Karachi) and Pat Feeder (which also carries some water to Baluchistan province) were not included for analysis in this study due to unavailability of consistent data.

There are two main cropping seasons in Sindh, namely, *kharif* (mid-April to mid-October) and *rabi* (mid-October to mid-April). Surface irrigation water supplies, in general, are scarcer in the rabi season than in the kharif season, with barrage withdrawals in the Lower Indus Basin averaging 19 billion cubic meters for rabi and 35 billion cubic meters for kharif during 1989-90 to 1995-96. Water shortages during rabi, which basically reflect low reservoir levels and overall water scarcity in the Indus Basin during the season, appear to be growing over time. It is evident from data in table 1 that water diversions at canal head per CCA in Sindh as a whole have decreased from 3,595 cubic meters in 1989-90 to 3,333 cubic meters in 1995-96 (excluding changes in the Jamrao canal). This decrease is not only due to overall expansion in CCA, it also reflects reduced total rabi diversions (Appendix B, table B2). However, there are significant spatial variations in canal water diversions during this season, with rabi diversions (at canal head) per CCA in 1995-96 ranging from 823 cubic meters for Desert to 4,725 cubic meters for Khairpur East canal (table 1).

TABLE 1.

Canal command level crop and water data for the Lower Indus Basin.

Canal command	CCA ('000 ha)		WD (m^3/ha)		CP	CI (%)
	1989-90	1995-96	1989-90	1995-96		
Rice Canal	210	210	1,238	1,762	R-W	192
Begari	405	341	1,012	1,496	R-W	180
Desert	133	158	1,880	823	R-W	190
North West	331	309	3,656	4,628	R-W	170
Dadu	236	245	4,237	3,796	R-W	170
Ghothki	347	368	3,833	2,446	C-W	183
Khairpur East	151	182	5,828	4,725	C-W	182
Khairpur West	169	195	4,438	2,974	C-W	166
Fuleli	373	361	3,083	3,518	R-W	123
Pinyari	307	323	2,801	3,313	R-W	124
Lined Channel	203	220	3,054	2,591	R-W	115
Rohri	1,036	1,045	4,537	3,732	C-W	144
Nara	881	883	4,279	4,088	C-W	106
Jamrao	na	na	na	na	C-W	131
Sindh	4,782*	4,840*	3,595	3,333	-	158

* Total CCA for Sindh here is the sum of 13 canal commands and excludes CCA of Jamrao and canal commands of Pat Feeder and Kalri Begar Feeder (which are not included in this study due to unavailability of consistent data for these commands).

Notes: *CCA* = culturable command area in thousand hectares; *WD* = water diversions in cubic meters (m^3) per CCA, based on CCAs in respective years; *CP* = dominant cropping pattern in each canal command based on farm survey results; *R-W* = rice-wheat; *C-W* = cotton-wheat; *CI* = cropping intensity in percentage based on farm survey results; na = not available.

The entire irrigation system in Pakistan, except watercourses, is owned and managed by the government. The three major government organizations or departments responsible for maintenance and operation of the irrigation system are: (1) Water and Power Development Authority (WAPDA), (2) the Indus River System Authority (IRSA), and (3) Provincial Irrigation Departments (PIDs). WAPDA operates and maintains the reservoirs (as it controls hydropower generation) and inter-provincial link canals and main canals. IRSA serves as a coordinating agency between WAPDA and PIDs and helps implement water allocation policy. Provincial level water allocations in the Indus Basin is done in accordance with the Water Apportionment Act (WAA) of 1991, with IRSA monitoring water allocations and implementing the Act. Theoretically, water allocations are based on a range of factors including available water supplies, historical diversions, canal capacities, crop water requirements, and so on. PIDs are responsible for operations and maintenance of the irrigation network and distribution of water in their respective provinces. Canal water allocations within a province are based on available supplies, canal capacities, and internal policies of the provincial government. At the tertiary or farm level, available supplies are distributed to irrigators through a fixed roster of turns and the duration of each irrigation turn is proportional to irrigator farm area within a watercourse command area.

At present, the Indus Basin System is facing a number of problems. These include aging and deterioration of irrigation infrastructure, inadequate operation and maintenance, insufficient cost recovery, low levels of efficiency in water delivery and use, waterlogging and salinity, and drainage problems (resulting from poor natural drainage and inadequate drainage systems). These problems pose a threat to the sustainability of the irrigated agricultural economy, particularly in the Lower Indus Basin (World Bank 1994).

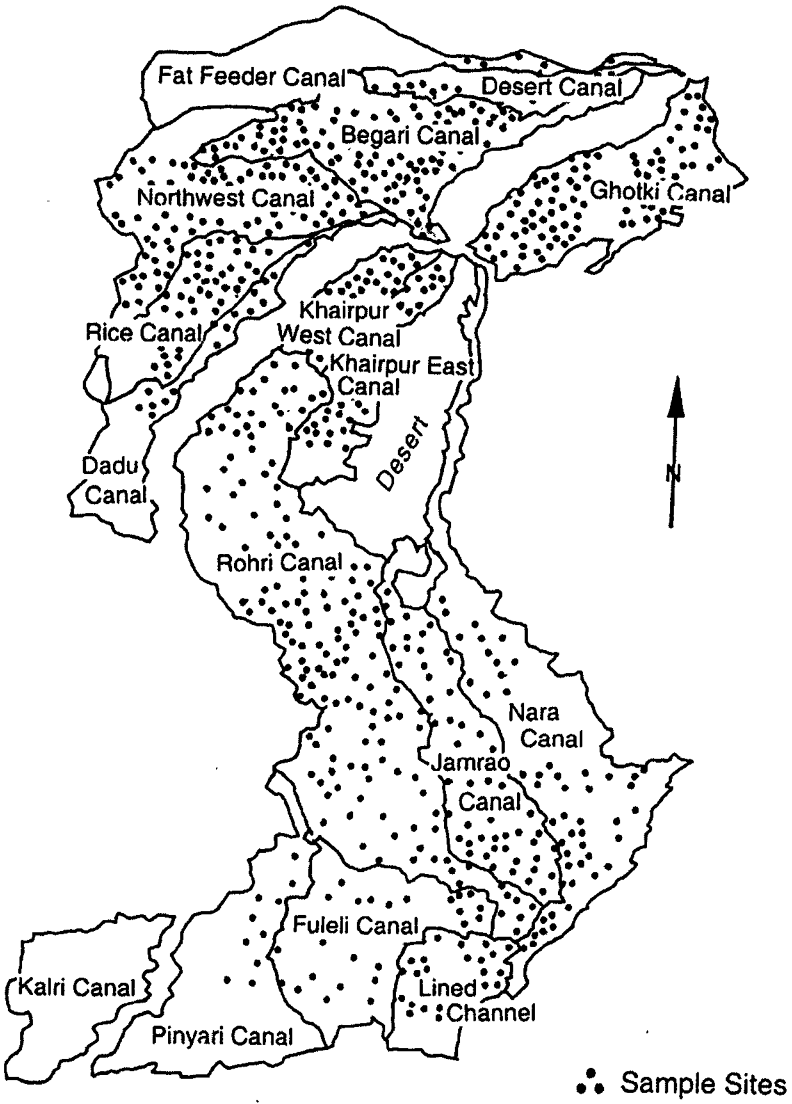
Cropping Patterns

As in other provinces, cropping systems in Sindh are fairly complex. Crops grown in the province include wheat, rice, cotton, sugarcane, orchards, rabi and kharif oilseeds, pulses, fodders, and vegetables. Among these, the first four crops are classified as major crops. Accordingly, major cropping patterns in the province are cotton-wheat and rice-wheat. Cotton and rice are the major kharif crops, while wheat is the principal rabi crop. Sugarcane, being a perennial crop, spans over both seasons. The rice-wheat cropping pattern is dominant in all RB canal commands, while the cotton-wheat cultivation is significant in LB commands. Also, annual cropping intensities vary significantly across canal commands, ranging from 106 percent in Nara to 192 percent in Rice Canal command. In general, cropping intensities are higher in RB commands (mainly due to higher cropping intensity during kharif). Since the primary focus of this study is on the water-short rabi season, wheat, the dominant crop in this season, was chosen for detailed analysis. However, estimations of seasonal crop water supplies, requirements, surpluses and shortages, and the resulting discussions on water allocations do account for all rabi crops.

Data and Methodology

The data used in this study were obtained from IWMI's database in Pakistan. In 1997-98, IWMI undertook an extensive survey of irrigated farms, covering the entire Sindh province, with a view to identify geographical distribution of resources in the Lower Indus Basin. A total of 1,539 farms selected through random sampling, located in 795 sample areas across 14 canal commands, were surveyed (fig. 3). Sample areas were identified and selected using GIS modeling. Detailed information on physical and financial characteristics of farms was collected using a pre-tested structured questionnaire in face-to-face interviews. For more details on sampling

FIGURE 3.
Location of IWMI sample sites across Sindh hydrological divides.



methodology and data collection procedures see Rehman et al. 1998 and Jehangir and Ali 1998. This survey showed that wheat is grown on 1,220 farms and this sub-sample of farms was used for further analysis in this research study. In addition to primary data, the study uses secondary data and information that were obtained from various published sources (as referenced).

Data for water diversions (*WD*), water surpluses and shortages (*WS/S*), and total wheat area (*TA*) for 14 canal commands in Sindh were obtained from Rehman and Rehman 1998. *WD* are the average water diversions at the canal head during the 1995-96 rabi season. *WS/S* for each canal command are the averages for 1995-96 rabi and are based on crop water requirements and supplies at the root zone for all rabi crops. Rehman and Rehman derived these estimates through water balance computations using crop water requirements and supplies from surface irrigation, groundwater sources, and rainfall. They used the World Bank's Indus Basin Revised Model, with some modifications of the model and updates of data, to generate estimates of water surpluses and shortages by canal command. Details of water balance computations, coefficients for crop water requirements, and assumptions about effective rainfall and irrigation system efficiencies used in the model are given in Rehman and Rehman 1998.

Measuring Performance of Producers

There are a number of ways in which performance of producers can be measured. The simplest measure is the ratio of output to a single input such as land productivity (yield per hectare). Although easy to compute, this measure could be misleading as it takes account of only one of the inputs in a real world, multi-input production process. However, there are other techniques, though analytically involved, that can be used to account for more than one input in measuring performance of producers. These may be classified into two broad groups: parametric and non-parametric methods. The former group involves econometric estimation of parametric functions while the latter group is based on mathematical programming techniques to measure performance.

This study employs the Data Envelopment Analysis (DEA) technique to measure performance of wheat farms in Sindh. DEA is a non-parametric method and uses mathematical programming techniques to define a performance frontier. The estimated frontier represents the smallest quantity of inputs required to produce a given amount of output, or conversely, the largest possible amount of output from given inputs. Unlike parametric methods, which fit a line through sample observations, DEA allows construction of a surface over the data. In DEA, each producer is compared with only the best producers and thus may be considered an extreme point method. The main advantage of this method is that, unlike partial measures that are based on a ratio of output to a single input, it can account for more than one input in estimating the performance index. The detailed description of this method and the specification of the model are presented in Appendix A.

Results of Data Envelopment Analysis (DEA)

The DEA results for Sindh wheat producers are summarized in table 2. The average Performance Index (PI)[2] for Sindh as a whole is estimated at 74 percent. This implies that wheat producers can, on average, reduce their inputs by 26 percent by adopting practices of the best performing producers. However, there is a considerable variability among producers, with the PI ranging from 44 percent to 100 percent across the province as a whole.

The results for the individual wheat producers suggest that, of the 1,220 producers, 20 percent are the best performing with PI estimated at 100 percent, and about 30 percent are operating at average to above average levels with PI between 70 and 99 percent. The remaining 50 percent, with PI between 44 and 69 percent, may be considered below average or poorly performing producers (table 2). These variations in the performance indices across farms imply that there are large differences in quantities of inputs used by producers to produce a unit of wheat output. The best performing farms produce almost twice the amount of wheat output per unit of fertilizer or irrigation water than the poorly performing farms (as is evident from the last two columns of table 2). However, it should be noted that land productivity or yields of the best performing farms are lower than those of average or below average ones.

In Pakistan, yields have traditionally been used as a measure of farm performance. In fact, wide variations in average farm yields in

TABLE 2.

Performance of wheat farms in Sindh.

Performance Index (%)	Number of farms	Percentage of total farms	Average output (kg/ha)	Average output (kg) per kg of NPK	Average output (kg) per irrigation
100	249	20.4	1,437	21.4	1,269
90- 99	16	1.3	2,516	20.4	805
80- 89	119	9.8	2,193	16.5	621
70- 79	209	17.1	2,434	14.3	607
60- 69	367	30.1	2,167	11.9	497
50- 59	214	17.5	1,947	10.4	466
40- 49	46	3.8	1,996	10.7	491
Total	1,220	100	2,026	13.3	579

Mean = 74
Minimum = 44
Maximum = 100
Standard Deviation = 16

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[2] Performance Index, its estimation, and interpretations are described fully in Appendix A. Basically, a higher performance index indicates greater efficiency of the production process. For example, producers achieving a performance index of 1 (or 100 percent) produce a unit of wheat output with the least amount of all inputs relative to other producers within a sample.

Pakistan have led to the coining of the terms "progressive farmers" and "non-progressive farmers" by policy makers. Using yield as a performance criterion, farmers achieving below average yields have traditionally been called non-progressive farmers. However, evaluating performance by accounting for major, variable production inputs suggests that farmers achieving lower yields may not necessarily be non-progressive. Indeed, their performance in terms of producing output per unit of all major inputs is substantially higher than that of the so-called progressive farmers. Overall, these results suggest that there is considerable scope for improving productivity of inputs in the province.

The question arises as to why only some producers are able to achieve high performance while others operate at low performance levels, and also why the best performing producers achieve lower yields, and vice versa. Theoretically, given a particular production technology, differences in performance across farms or regions could be attributed to a range of factors. These may be categorized into three broad groups: 1) socioeconomic factors—availability of funds and credit, farm assets, management skills including experience and education of producers, tenurial status, and the degree of land fragmentation; 2) agronomic factors—land preparation, timing of crop sowing, variety and quality of seed, timing of application of inputs, timing of crop harvest, and availability of extension services; and 3) quality of land and quality and adequacy of irrigation water. For a review of analyses of some of the factors in groups 1 and 2 see, for example, Byerlee et al. 1984, Hussain et al. 1999, and Parikh and Shah, 1994.

Land Quality Index

In order to gain more insight into performance constraints and, specifically, the effects of land quality on productivity and performance of wheat farms, the authors constructed a land quality index based on data for geographic location and other characteristics of farms, including soil type, salinity levels, waterlogging, and water availability of each farm.

In IWMI's farm surveys, soil data were classified into a number of categories, following FAO's soil classification procedures with some modifications according to local conditions. These categories were based on a number of criteria, including suitability for cultivation, levels of salinity and sodicity, depth of watertable, permeability and so on[3] (for more details on soil data collection and classification, see Bhatti et al. 1998, and Rehman et al. 1998). The following ranking indicates the quality and degree of suitability of land for cultivation.

0. Unsuitable land, due to severe salinity/ sodicity and low permeability
1. Marginally suitable clayey land, due to low permeability and workability, high watertable and severe salinity
2. Marginally suitable land, due to very sandy nature and complex topography
3. Marginally suitable land, due to high watertable and severe salinity
4. Moderately suitable land, due to moderate salinity associated with high watertable
5. Moderately suitable land, due to moderate depth to sand and high watertable.

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[3] In the available datasets, land classes were constructed such that each of the farms was assigned a single land class, thus averaging individual field or plot conditions at the farm level. While disaggregated plot level data would have been ideal for constructing land quality indices, farm level averages of plot conditions (as reflected in the above classes) are still a good indicative of overall land quality on farms in various canal commands.

6. Moderately suitable clayey land, due to low permeability and workability and high watertable
7. Moderately suitable land due to high watertable (90-200 cm).
8. Moderately suitable land, due to moderate salinity.
9. Moderately suitable clayey land, due to low permeability and workability.
10. Highly suitable land.

Using the above soil classes, the authors constructed an index of land quality for each of the canal commands in the study region. A canal-command specific land quality index was calculated as:

$$LQI_i = [(p*10) + (q*9) + (r*8) + (s*7) + \ldots\ldots\ldots \ldots\ldots + (y*1) + (z*0)]/n \ldots\ldots\ldots\ldots\ldots (1)$$

where *LQI* is a land quality index for canal command i (where $i = 1, 2, \ldots\ldots\ldots 14$); n is the total number of farms in canal command i, with p farms having a soil quality weight of 10 (highest weight for relatively highly suitable or very good soils), and z farms having a soil quality weight of 0 (for soils not suitable for cultivation due to severe salinity and waterlogging related problems). Depending upon the quality of soils, the weights range from 0 to 10 and accordingly the index value will range from a minimum of 0 (indicating all farms have degraded and unsuitable soils in a canal command) to a maximum possible of 10 (indicating all farms have, relatively, highly suitable soils).[4]

For our sample of 1,220 farms, *LQI* for canal commands ranged from 4.2 to 9.8, with an average value of 8.4 for Sindh as a whole. Rice Canal, Begari, Rohri and Desert canal commands achieved an *LQI* of 9 or more suggesting that the majority of farms in these commands have good quality lands.[5]

Table 3 presents the maximum, minimum and mean estimated performance indices of wheat farms for each of the 14 canal commands. Analysis by canal command reveals a distinct geographic pattern in performance indices of the farms being evaluated, with the best and poorly performing farms concentrated in separate canal commands. The majority of the best performing farms are concentrated in the first four canal commands (Rice Canal, Begari, Desert and North West), while the poorly performing farms are mainly located in the other canal commands (particularly, Nara, Ghothki, Jamrao, Khairpur East and Khairpur West).

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[4] The weights may be constructed based on quantified relationships between crop yields and land quality using dummy variables. While the idea is quite appealing, this procedure did not produce any meaningful results for further analysis. While one would expect a significant positive correlation between land quality and crop yields, these relationships may be influenced by other severe constraints to yield increases, as will be explained later in this report, such as shortage of irrigation water particularly in areas where land quality is relatively better but water is a major constraint to crop yield increases.

It is important to note here that these weights represent a relative scale for farmlands within Sindh. For example, farms that are assigned a weight of 10 have relatively better lands as compared to those assigned lesser weights. So, in this context, assigning a maximum weight of 10 to relatively better lands does not necessarily mean that these lands are absolutely free from any environmental constraints, but these are certainly better than those assigned a weight of say 5. Similarly, the above weightings adopted for Sindh may not be directly comparable with those for other provinces. For example, farms achieving a maximum weight of 10 in Sindh may be ranked lower on the scale when compared with highly suitable farmlands in Punjab.

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[5] As expected, *LQI* is strongly and positively correlated with estimated cropping intensities for canal commands (with $r^2 = 0.74$), i.e., the higher the *LQI* the greater the cropping intensity in that canal command (see Appendix B, table B2). For example, Rice Canal, Begari and Desert canal commands have the highest *LQI* values and the greatest cropping intensities, while Nara, Lined Channel, Fuleli and Pinyari have the lowest *LQI* values and the least cropping intensities.

TABLE 3.

Performance indices of wheat farms by canal command.

Canal command	Mean	Min	Max	SD error	No. of farms
Rice Canal	0.97	0.63	1.00	0.07	56
Begari	0.97	0.60	1.00	0.09	117
Desert	0.95	0.65	1.00	0.11	48
North West	0.82	0.50	1.00	0.16	100
Dadu	0.75	0.58	1.00	0.12	25
Ghothki	0.64	0.44	1.00	0.14	180
Khairpur East	0.67	0.47	1.00	0.12	75
Khairpur West	0.68	0.44	1.00	0.15	50
Fuleli	0.75	0.53	1.00	0.12	45
Pinyari	0.71	0.55	0.87	0.11	13
Lined Channel	0.73	0.54	0.90	0.09	36
Rohri	0.69	0.47	1.00	0.11	249
Nara	0.64	0.45	0.82	0.07	100
Jamrao	0.65	0.45	1.00	0.08	126
Sindh	0.74	0.44	1.00	0.16	1,220

Notes: Min = minimum; Max = maximum; SD error = standard error.

It is interesting to note that in Nara, Pinyari and Lined Channel commands none of the farms was able to attain a performance index of 100 percent (the maximum estimated performance index varied between 82 and 90 percent) and these three canal commands also had the lowest land quality indices. The value of land quality index is found to be high in the first three canal commands (table 4), while it is generally low for the other canal commands (except Ghothki).

Estimated performance indices and land quality indices are generally high for water-short canal commands, while both of these measures are generally low for water-surplus canal commands (table 4). For example, most farms in Rice Canal, Begari and Desert canal commands, which are water short, have high performance indices (>0.95) as well as high land quality indices (>9). Fuleli, Pinyari, Lined Channel, and Dadu are water-surplus canal commands but the majority of farms in these canal commands have low performance indices (0.64 –0.75) as well as low land quality indices (4.2-7.9). These geographic patterns and the positive correlations between land quality indices and performance indices of farms provide evidence to suggest that land quality is a contributing factor to differences in farm productivity and performance.

Yield per hectare is generally low in canal commands where a majority of farms are found to be operating at high levels of performance (this is consistent with our earlier observation), such as Rice Canal, Begari, Desert and North West. Average wheat yields in these canal commands are almost half of those in Nara, Ghothki, Jamrao, Khair Pur East, Khair Pur West and Rohri, where most farms are found to be operating at low levels of performance.

TABLE 4.
Average performance indices and other related variables by canal command.

Canal command	PI	I	WD (m^3/ha)	WS/S (10^6 m^3)	LQI	Y (kg/ha)
Rice Canal	0.97	0.7	1,762	- 53	9.8	1,210
Begari	0.97	1.1	1,496	-137	9.4	1,327
Desert	0.95	1.2	823	-112	9.0	1,348
North West	0.82	2.3	4,628	304	7.5	1,468
Dadu	0.75	3.3	3,796	155	7.9	1,927
Ghothki	0.64	3.4	2,446	-201	9.1	2,106
Khairpur East	0.67	3.7	4,725	- 10	8.7	2,299
Khairpur West	0.68	3.7	2,974	- 82	7.9	2,020
Fuleli	0.75	4.0	3,518	326	7.1	1,835
Pinyari	0.71	4.2	3,313	275	7.5	2,098
Lined Channel	0.73	4.3	2,591	109	4.2	1,682
Rohri	0.69	4.6	3,732	-69	9.3	2,564
Nara	0.64	4.8	4,088	-122	6.9	2,395
Jamrao	0.65	5.2	na	na	7.8	2,284

Notes: PI = estimated average Performance Index of wheat farms; *I* = number of irrigations; *WD* = water diversion at canal head per canal command area in rabi season (cubic meters per hectare); *WS/S* = water surpluses (+)/shortages (-) in million cubic meters (these are based on crop water requirements and supplies at the root zone for all rabi crops); *LQI* = land quality index; *Y*= wheat yield in kg per hectare; na = not available.

As mentioned earlier, rice-wheat and cotton-wheat are the main cropping patterns in Sindh. The PI for wheat is found to be much higher for rice-wheat farms than for cotton-wheat farms, i.e., wheat productivity is higher if it is sown after rice than after cotton. In Rice Canal, Begari, Desert and North West canal commands, all wheat is grown after rice (as cotton is not grown in these areas) and these are the commands where farmers achieve the highest PI. In other words, farms growing wheat after cotton are relatively less productive in wheat. Regressions of PI for wheat and the dominant cropping patterns suggest that PI is positively correlated with rice-wheat while it is negatively correlated with cotton-wheat pattern—coefficients of both variables are statistically significant.

The question arises as to why yields are low in canal commands where most producers are highly efficient, and vice versa. As can be seen in table 4, water shortage is a major constraint to achieving higher yields in these commands. For example, in the Begari and Desert commands, where shortage of water restricts farmers to applying only about one irrigation on average, the yields are only 1.3 tons per hectare as compared to average yields of over 2 tons per hectare in water-surplus canal commands where farmers are able to apply four or more irrigations. Since other inputs, particularly fertilizers, must be used in a balanced combination with water to achieve higher yields, any constraint on the availability of water is likely to result in lower use of other inputs as well and consequently in lower yields. This is evident from differences in average levels of inputs used and wheat yields achieved in various canal commands (table 5). For example, severe

TABLE 5.

Average levels of input use and wheat output achieved by canal command.

Canal command	A	S	F	I	L	LP	Y
Rice Canal	4	103	51	0.7	12	1,227	1,210
Begari	24	121	73	1.1	13	884	1,327
Desert	35	134	64	1.2	11	912	1,348
North West	7	126	90	2.3	12	1,113	1,468
Dadu	2	120	131	3.3	15	1,548	1,927
Ghothki	8	147	175	3.4	17	1,659	2,106
Khairpur East	2	136	171	3.7	17	1,644	2,299
Khairpur West	3	133	171	3.7	17	1,889	2,020
Fuleli	4	117	146	4.0	14	2,055	1,835
Pinyari	4	121	165	4.2	17	2,033	2,098
Lined Channel	5	113	169	4.3	13	1,923	1,682
Rohri	11	134	181	4.6	18	1,676	2,564
Nara	16	140	210	4.8	16	1,958	2,395
Jamrao	14	136	200	5.2	17	2,113	2,284

Notes: *A* = average wheat area per farm in hectares; *S* = seed in kg per hectare; *F* = fertilizer (NPK) in kg per hectare; *I* = number of irrigations;*L* = labor in person days per hectare; *LP* = land preparation cost in rupees per hectare; *Y* = wheat yield in kg per hectare.

shortage of irrigation water in Rice Canal, Begari and Desert restricts farmers to applying only small amounts of other inputs, such as fertilizers. This means that producers in the most efficient canal commands having good quality lands are unable to attain higher yields mainly due to the constraint on irrigation water. Therefore, wheat yields on farms in these canal commands could be raised by providing additional water.

Higher water use is generally associated with high levels of complementary inputs such as fertilizers, seed, etc., in water-surplus canal commands. However, poor land quality constraints any significant increases in yields, resulting in lower performance levels in these commands. Alternatively, greater use of inputs may be due to poor land quality. To compensate for the poor quality of the soil, farmers apply a larger quantity of inputs in order to increase yields. As a result, farmers in these commands continue to operate at low performance levels but achieve higher yields than those in higher performing canal commands. In order to further understand input-output relationships, production function analysis was undertaken for each canal command with a view to quantify elasticities and marginal productivity of the various production inputs, and to determine the potential for increasing the productivity of farms in Sindh.

Production Function Analysis

Production function analysis was carried out for Sindh as a whole and for individual canal commands. All production functions were estimated using a functional form of the Cobb-Douglas type (although other functional forms such as linear, log linear and quadratic forms were also used, the Cobb-Douglas form was finally chosen based on algebraic signs, plausibility of estimated parameters and their statistical significance). The dependent variable used was the average yield per hectare. The independent variables used in estimation were seed (S) in kg/ha, fertilizer (F) as sum (kg) of nutrients N, P and K in kg/ha, labor (L) in number of person days/ha, number of irrigations (I) and land quality index (LQI). A Cobb Douglas functional form, with five input variables, used in estimating production functions was:

$$Y \;=\; AS^{\alpha s}\, I^{\alpha i}\, F^{\alpha f}\, L^{\alpha l}\, LQI^{\alpha lqi} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where αs αi, αf, αl and αlqi, are the partial elasticities (coefficients) of the input variables. For example, partial elasticity of variable I can be represented as:

$$\alpha i = (dY/dI) * (\bar{I} / \bar{Y}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The marginal productivity for each of the inputs was obtained at the mean levels of output and the respective inputs were obtained using estimated partial elasticities. For example, marginal productivity for irrigation water was obtained as:

Marginal Productivity of
$$I = dY/dI = \alpha i * (\bar{Y} / \bar{I}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The above equation (2) was transformed into the following log-log form for estimation of the parameters.

$$Ln\,Y = LnA + \alpha s\, LnS + \alpha i\, LnI + \alpha f\, LnF + \alpha l\, LnL + \alpha lqi\, LnLQI \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Estimated equations for Sindh as well as for individual canal commands are presented in table 6.

Overall, the results of the estimated equations are mixed. All estimated coefficients of aggregate production function for Sindh as a whole are significant. However, quite a few coefficients in equations for individual canal commands are insignificant (Appendix B, table B1). The estimated partial elasticities, which reflect output responses to the inputs, vary significantly for all inputs across canal commands. In general, estimated coefficients of irrigation and labor are higher as compared to those for other variables, including fertilizer. Coefficient of land quality variable, though significant for aggregate production function for Sindh, is insignificant in most of the equations for individual canal commands. Given that most farms within a canal command have more or less similar land quality, this result should not be surprising. For example, most farms in Rice Canal command achieve an *LQI* of 10 with none having an *LQI* below 9; on the other hand, a majority of farms in Lined Channel achieve an *LQI* of 3 with none having an *LQI* above 6. Given that *LQI* varies significantly across canal commands, it is reflected in its significant coefficient in the aggregate production function.

TABLE 6.

Estimated production functions by canal command.

Canal command	Estimated production functions					
Rice Canal	713.4	$S^{-.05}$	$I^{.59}$	$F^{-.01}$	$L^{.16}$	$LQI^{.10}$
Begari	162.4	$S^{.31}$	$I^{.24}$	$F^{.08}$	$L^{.25}$	$LQI^{-.16}$
Desert	74.4	$S^{.30}$	$I^{.08}$	$F^{.10}$	$L^{.18}$	$LQI^{.25}$
North West	328.8	$S^{.19}$	$I^{.15}$	$F^{.04}$	$L^{-.13}$	$LQI^{.29}$
Ghothki	2018.3	$S^{.04}$	$I^{.13}$	$F^{.06}$	$L^{-.13}$	$LQI^{-.11}$
Khairpur East	235.1	$S^{-.03}$	$I^{.16}$	$F^{.06}$	$L^{.92}$	$LQI^{-.33}$
Khairpur West	311.1	$S^{-.01}$	$I^{.31}$	$F^{.12}$	$L^{.37}$	$LQI^{-.08}$
Fuleli	104.6	$S^{.09}$	$I^{.23}$	$F^{.10}$	$L^{.36}$	$LQI^{.34}$
Pinyari	0.7	$S^{-.20}$	$I^{-.20}$	$F^{.80}$	$L^{1.57}$	$LQI^{.90}$
Lined Channel	31.5	$S^{.55}$	$I^{.14}$	$F^{.10}$	$L^{.33}$	$LQI^{-.16}$
Rohri	1510.2	$S^{-.15}$	$I^{.02}$	$F^{.06}$	$L^{.18}$	$LQI^{.15}$
Jamrao	82.3	$S^{.32}$	$I^{-.09}$	$F^{.06}$	$L^{.46}$	$LQI^{.12}$
Sindh	210.6	$S^{.14}$	$I^{.26}$	$F^{.07}$	$L^{.28}$	$LQI^{.09}$

Estimated partial elasticities for irrigation vary from -0.20 to 0.59. In general, these are high for water-short canal commands and low or negative for water-surplus commands. These results suggest that irrigation has a large effect on wheat yields in water-short canal commands (five out of eight water-short commands). However, the effect on yields of additional irrigation is very low or even negative in water-surplus canal commands (in four out of the six water-surplus commands).

This is further reflected in the estimates of marginal productivity of irrigation water presented in table 7. It is clear from these estimates that marginal productivity of irrigation water is generally high in water-short canal commands. In six out of the eight water-short canal commands marginal productivity of irrigation ranges from 81 kg/ha in Ghothki to 1,025 kg/ha in Rice Canal command. In the other two water-short commands, the marginal productivity of irrigation is low at around 10 kg/ha. On the other hand, in three out of six water-surplus canal commands, marginal productivity of irrigation is negative. For farms applying more than four irrigations (as is the case in four out of the six water-surplus canal commands and two out of the eight water-short canal commands), the contribution to yields of each additional irrigation above four irrigations is very low or even negative. There is, therefore, some scope for increasing production by reallocating water from water-surplus to water-short commands and within distributaries in certain water-short commands as, for example, Rohri and Nara.

Further, it should be noted that there is a greater variability in irrigation applications per hectare across than within canal commands. Variance for number of irrigations across commands is estimated at 2.96, while within canal commands variances range from 0.29 for Desert to 1.61 for Fuleli (Appendix B_1 table B2). These differences further support cross-canal water reallocations. With effective reallocation of water, it is possible to increase crop yields in water-short commands. If water is reallocated in such a way that per hectare irrigation

TABLE 7

Estimated marginal productivity at mean levels of output and respective inputs.

Canal Command	Marginal Productivity (kg/ha)				WS/S (10^6 m^3)
	S	I	F	L	
Rice Canal	-0.6	1,024.7	-0.2	16.1	-53
Begari	3.4	280.3	1.1	25.5	-137
Desert	3.0	89.3	2.1	21.9	-112
North West	2.2	97.0	0.7	-16.4	304
Dadu	4.0	-29.0	2.2	34.2	155
Ghothki	0.6	81.3	0.7	-15.8	-201
Khairpur East	-0.5	99.6	0.8	123.3	-10
Khairpur West	-0.2	168.4	1.4	43.7	-82
Fuleli	1.4	105.0	1.3	46.7	326
Pinyari	-3.5	-101.0	7.7	199.6	275
Lined Channel	8.2	54.4	1.0	41.6	109
Rohri	-2.9	11.2	0.9	26.1	-69
Nara	1.6	9.9	1.4	47.2	-122
Jamrao	5.4	-39.9	0.7	62.9	na
Sindh	2.2	150.4	0.9	33.8	na

Notes: *S* = seed in kg per hectare; *I* = number of irrigations; *F* = fertilizer (NPK) in kg per hectare; *L* = labor in person days per hectare; *WS/S* = water surpluses (+)/shortages (-) in million cubic meters; na = not available.

applications in the currently extremely water-short commands, such as Rice Canal, Begari and Desert, increase to the province-level average (i.e., 3.5 irrigations per hectare), wheat yields in these commands can be increased by 76 percent, 25 percent and 8 percent, respectively, without any reduction in yields in water-surplus commands. These projections are based on the production functions estimated above. Also, in certain canal commands where within a command (as in Fuleli, Dadu, Khairpur West, Rohri and Nara) variability is relatively greater than others, effective internal reallocation is likely to improve overall yields of irrigated farms. Improvement in overall water allocations will indeed be a step forward in narrowing and ultimately closing observed wide yield gaps in the province.

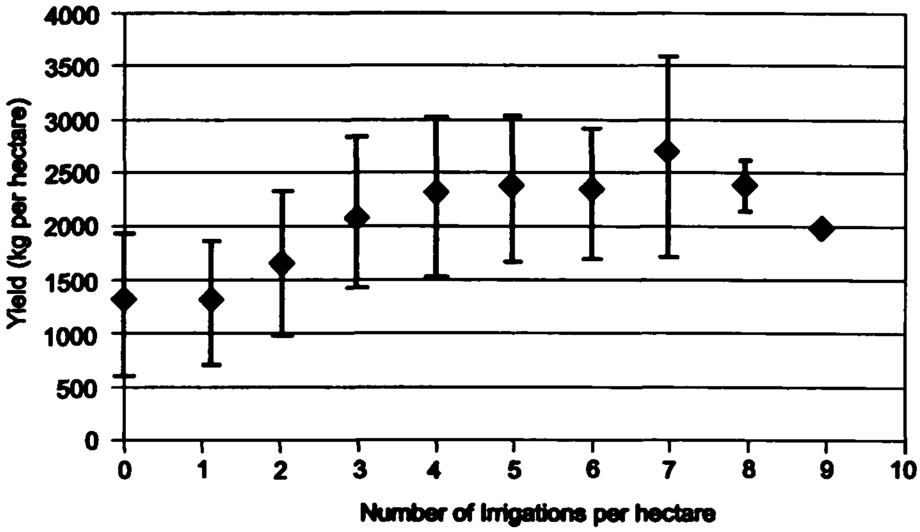
With availability of additional water supplies through reallocation to water-short canal commands, farmers in these commands are likely to increase the use of other inputs such as fertilizers to increase their yields. This, in turn, is likely to lead to a change in their overall input mix and, therefore, a change in their production functions. As a result of these changes, PI on average may fall along the presently high PI commands; however, it is likely to increase in water-surplus commands as well as across Sindh as a whole—overall it would be a positive change.

Irrigation and Water Supply

The general recommendation of the Agricultural Extension Department for the wheat crop in Sindh is to apply 4 irrigations (first irrigation of 4 inches [10.16 cm] followed by three irrigations of 3 inches [7.62 cm] each or approximately 3,250 m^3 per hectare). However, in salinity affected areas, such as in most water-surplus areas of Sindh, a large number of farmers tend to apply more than four irrigations, as can be seen in figure 4. The application of excess water leads to waterlogging and drainage problems. In these situations, some farmers operate on the declining part of the yield-water curve as indicated by negative marginal productivity of irrigation for some water-surplus canal commands. A common notion in the area of shallow groundwater is that heavy irrigation restricts saline groundwater from approaching the surface.[6] While farmers attempt to keep a freshwater lens on top of saline groundwater to reduce salinity by overapplication of water, it results in aggravating waterlogging and drainage problems.

FIGURE 4.

Wheat yield per number of irrigations per hectare in Sindh.



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[6] Overapplication of irrigation water may also be attributed to the present water charging system, both the level and structure of charges in Sindh (in fact, in Pakistan as a whole), which does not provide any incentives to farmers to use water efficiently. For example, survey data used in this study indicate that the average annual water charge in Sindh in 1997-98 was less than US$2 per hectare (which is roughly 2 percent of gross farm income). In comparison, farmers in Shaanxi province in north China (using on average 2,000 m^3 per hectare of irrigation water for the wheat crop—with winter rainfall about the same as in the northern part of Sindh—which is much lower than the per hectare water application in most water-surplus canal commands in Sindh) pay on average around US$70-150 per hectare as annual irrigation service fee (which is between 5 to 10 percent of gross farm income). This illustrates that higher water charges could provide incentives to farmers to avoid wasteful use of water. Realistic adjustment of level and modification of the current structure of water charges may lead to more efficient use of this valuable resource.

Overall, wheat production in Sindh can be increased by reallocating water from water-surplus canal commands to water-short canal commands until the marginal productivity of irrigation water equals across all canal commands. With appropriate reallocation of water, farmers operating on the rising part of the yield-water curve will be pushed up while those operating on the declining part of the curve will be pulled back. It should be noted that the current canal allocations are mainly based on historical diversions and may not reflect actual crop water requirements in canal commands. Given that almost all canals operate below capacity during the rabi season, infrastructure or canal capacity is unlikely to be a major constraint for reallocating water from water-surplus to water-short canal commands. Thus, immediate short run gains are possible from effective reallocation of available water supplies.

However, given that Sindh as a whole is a water-short region, the medium- and long-term strategy should be to invest in water storage infrastructure to increase overall supply of irrigation water during the rabi season. A recent IWMI study on surface water resources in the Indus Basin (Khan 1999) indicates that there is some potential to tap the excess water flowing to the sea. This study estimates average annual system inflows (surface inflows in Indus Basin) and outflows (to the Arabian Sea), over the period 1977-78 to 1996-97, at 180 billion cubic meters (bcm) and 50 bcm, respectively.[7] Maximum outflows to the sea occur during July-August when the entire system is operating at peak level. While there is no general consensus on required minimum water flows to sea for environmental purposes, estimates of requirement vary from 5 bcm to 30 bcm. Even if we assume the higher estimate of 30 bcm as the requirement for the environment, there is some scope for capturing the excess water flowing to sea.

However, given the capacity constraint, as the existing reservoirs operate at full capacity during peak periods, all the available water cannot be stored in the existing reservoirs. Furthermore, there is a problem of sedimentation in the existing reservoirs.The storage capacity of the major reservoirs in Pakistan is reported to have diminished by 20 percent due to sedimentation. While desilting of these reservoirs would provide some additional capacity, investments will be needed to develop new storage facilities to capture excess water.

As mentioned in the earlier part of this paper, a large part of the Lower Indus Basin has poor natural drainage and inadequate drainage systems. This situation leads to high watertables and soil salinity problems. Over 71 percent of the farms surveyed in Sindh reported facing drainage problems. Given this situation, there is a need to address the drainage problems through appropriate measures (including providing additional proper drainage systems and better management and maintenance of the existing drains) in order to achieve maximum benefits from reallocations and increased overall water supplies through additional storage development. (There is no general consensus on any single approach to the drainage problem in Sindh. In the past, engineering approaches such as deep tubewells, tile drains, and surface drains have been adopted. However, their success and sustainability are still questionable.) While some drainage problems can be avoided through

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[7] These estimates are consistent with output from IWMI's Policy Dialogue Model (PODIUM). In PODIUM, total renewable water resources in Pakistan are estimated at 226 bcm. Of this, 86 percent (194 bcm) is estimated to be potentially utilizable. About 74 percent (144 bcm) of the potentially utilizable water resource is estimated to be developed water supply, i.e., it is being captured by the system with existing infrastructure. There is some potential for capturing a part or whole of the remaining 50 bcm currently flowing to the sea.

reallocation of surface water and water conservation (World Bank 1994), there could be a risk of shifting or spreading problems to less affected areas. This requires a very detailed analysis of drainage and scientific reallocation of water, and this is beyond the scope of the present study.

Conclusions and Implications

Wheat yields across farms in Sindh vary from 0.5 ton per hectare to 5.4 tons per hectare, with the average at around 2 tons per hectare. The wide variations in average farm yields have led to the coining of the terms "progressive farmers" and "non-progressive farmers" by policy makers in Pakistan. Using yields as a measure of performance, farmers achieving below average yields have traditionally been called non-progressive farmers. However, measuring performance based on several production inputs, as in this study, reveals that farmers obtaining lower yields may not necessarily be non-progressive. In fact, most farms achieving below average yields are found to be the best practice farms in that they produce a unit of wheat output with the least amount of inputs. Constraints on adequacy and quality of resources limit the ability of farmers to achieve higher yields. However, if these constraints are removed, they are likely to achieve yields higher than those achieved by the so-called progressive farmers.

Using Data Envelopment Analysis (DEA), the average farm-level performance index is estimated at 74 percent, implying that wheat producers, on average, can reduce inputs by 26 percent by adopting the practices of the best performing producers. The results suggest that 20 percent of producers in Sindh are the best performing, 30 percent are operating at average levels, and the remaining 50 percent are operating at fairly low or poor levels of performance. Scarcity of irrigation water and poor land quality appear to be the main constraints to productivity increases in the province. The analysis reveals that there is a geographic pattern in these constraints, which has implications for setting priorities both for future remedial actions as well as for investments of regional development funds.

Production function analysis indicates that the marginal productivity of inputs, particularly irrigation water, varies significantly across canal commands; it is very high in some canal commands and is negative in others. Current water allocations, which reflect historical diversions, are such that some canal commands receive excess supplies while others are highly water short. The results of this study suggest that, in the short run, farm yields can be increased by appropriate and effective reallocation of water from water-surplus canal commands to highly water-short canal commands.

However, in the medium and long term, the problem of growing overall water shortages, increasing land degradation, and drainage problems should be addressed by increasing investments in these sectors. Water scarcity problems could be addressed by desilting reservoirs to restore lost capacity due to sedimentation and, where feasible, developing additional storage facilities. Other measures such as exploring and introducing water saving technologies, modifying the existing system of water charges, and establishing water markets to avoid wasteful use of water should be evaluated. However, land degradation problems need to be addressed through specific land improvement programs. Unlike most past programs that lacked focus, efforts should be targeted specifically on areas where the situation is worsening. Based on the findings of this study, 5 of the 14 canal commands in Sindh where salinity and waterlogging are major constraints to productivity increases, i.e., Lined Channel, Nara, Fuleli, Northwest and Pinyari, should be given priority in providing much needed remedial action for improving land resources.[8] There is a lack of rigorous economic evaluation of alternative solutions to the land degradation problem in Pakistan.

From the viewpoint of agricultural policy, it should be noted that without removing these fundamental constraints to productivity, benefits from production enhancing programs, including subsidies for production inputs such as seed, fertilizers and credit, are likely to be very limited.

The results of this study could be useful not only to researchers but also to policy makers and planners in prioritizing development investments and for water managers for considering effective reallocation of water at the canal level in Sindh. In addition, DEA methodology and results for individual wheat producers (available from the authors) could be potentially useful to agricultural extension workers for identifying, observing, and promoting the practices of the best performing wheat producers in various canal commands in the province.

While this study has primarily focused on wheat, there is a need to undertake similar in-depth studies for the entire irrigated agricultural sector of Sindh, i.e., involving all rabi and kharif crops, to further enhance understanding of determinants of performance in irrigated agriculture and to evaluate the productivity potential in the province. The availability of an extensive database for Sindh offers an excellent opportunity to undertake detailed integrated analyses of socioeconomic, hydrologic, environmental, and spatial factors influencing crop productivity in the province.

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[8] For a review of various approaches to the land degradation problem in Pakistan, including engineering, reclamation and saline agriculture, see Qureshi and Barrett-Lennard 1998, and Prathapar and Qureshi 1999.

Appendix A

DEA Methodology

The basic assumption in this method is that if a producer *A* can produce a unit of output *y* with a least amount of *x* inputs, then producer *B* should also be able to do the same if it is to operate efficiently. Since *A* produces a unit of *y* with the least amount of *x*, DEA will identify *A* as a best practice producer for *B* and other producers in the dataset. Given that *B* produces a unit of *y* with a relatively larger amount of *x*, it is possible for *B* to reduce *x* by adopting the best practices of *A*. The potential reduction in *x* by *B* to be as efficient as *A* indicates inefficiency of producer *B*. Given data on input-output combinations, DEA constructs a performance frontier (or what may be called an ideal producer) and compares each producer with this frontier. Producers close to the frontier use fewer inputs per unit of output and, therefore, receive a higher index value compared with producers further away from the frontier. It should, however, be noted that the performance frontier in DEA is constructed from the observed data, which reflects relative performance rather than the theoretical maximum or minimum.

There are two basic types of specifications in DEA to construct a performance frontier, namely, Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). The application and appropriateness of each type depends largely on the implicit economic assumption regarding scale behavior. The CRS specification assumes that all the producers being evaluated are operating at optimal scale. However, if this is not the situation in reality due to any constraints, the CRS will result in performance measures that will not be independent of scale effects (i.e., overall technical efficiency). The VRS specification, on the other hand, accounts for variable returns to scale situations and generates performance measures that are independent of scale effects (i.e., pure technical efficiency).

Both CRS and VRS models may be formulated as input or output oriented. The former formulation maximizes the proportional decrease in inputs while the latter maximizes the proportional increase in output. The two formulations provide the same value under CRS specification, but values may be different under VRS assumption.

The DEA approach was first proposed by Charnes, Cooper, and Rhodes (1978) based on Farrell's (1957) work on frontier estimation and productive efficiency measurement. The methodology has been developing over the years and is being used extensively for evaluating efficiency of production units in a number of industries including education, health, communication, and agriculture. For a review of DEA and its applications see Banker, Charnes, and Cooper 1984, Seiford and Thrall 1990, Ali and Seiford 1993, and Fried, Lovell, and Schmidt 1993.

Specification of DEA Model

Assume there are *N* wheat producers in Sindh, with each using varying amounts of different inputs to produce varying quantities of wheat output. Let *Y* be a (*1* x *N*) row vector of wheat output with elements y_i representing wheat output of *ith* producer. Let *X* be a (*K* x *N*) matrix of inputs with elements x_{ki} representing the *kth* input of the *ith* wheat producer. The VRS input—oriented measure of performance for the *ith* wheat producer—could be estimated by formulating and solving the following mathematical problem:

$$
\begin{array}{lccc}
\min_{\lambda\,\theta} & \theta & & \\
st & y^i & \leq & Y\lambda \\
 & X\lambda & \leq & \theta x^i \\
 & I\lambda & = & 1 \\
 & \lambda & \oplus & 0
\end{array}
$$

where y^i represents wheat output and x^i represents the column vector of inputs, both representing output and inputs, respectively, of the *ith* wheat producer being evaluated. λ is a $(N \times 1)$ column vector of weights—to be determined by solving the above problem. The element λ_i represents the weight given to the *ith* wheat producer in constructing the performance frontier. I is a $(1 \times N)$ row vector of ones; $I\lambda = 1$ represents the convexity constraint. θ is the performance index so that, always, $0 \leq \theta \leq 1$. It is a scalar value and represents the proportional reduction in all inputs, with $\theta^i x^i$ representing the efficient level of inputs for the *ith* producer. The value of $\theta = 1$ for producer i indicates that this producer is the best performing and inputs cannot be reduced further.

The above problem must be solved separately for each of the wheat producers being evaluated in the sample, which in the present study comprises 1,220 producers. This was done by using the Data Envelopment Analysis Program (DEAP) developed by Coelli (1996) at the University of New England, Australia. The variables used in the model were wheat output and major inputs used in wheat production. Wheat output was defined as output (kg) per hectare. The inputs used in the model were seed (kg); fertilizer as the sum (kg) of nutrients—nitrogen (N), phosphate (P) and Potash (K) in the total quantity of fertilizer applied per hectare; number of irrigations per hectare of wheat; amount of labor used (person days) per hectare; cost of land preparation (rupees) per hectare; and cost of harvesting and threshing (rupees) per hectare. For the last two variables, costs instead of quantities were used. This is because land preparation involves a variety of operations (deep tillage, ploughing, leveling, etc.) and their aggregation in terms of values, instead of quantities, was considered more appropriate. Similarly, the costs of harvesting and threshing, instead of quantities, were aggregated to construct a more meaningful single variable to represent these operations.

Appendix B

TABLE B1.

Estimated partial elasticities of the input variables by canal command.

Canal command	LnA	αs	αi	αf	αl	αlqi
Rice Canal	6.56^{a}	-0.05	0.59^{b}	-0.01	0.16	0.10
Begari	5.09^{c}	0.31^{a}	0.24^{b}	0.06^{b}	0.25^{b}	-0.16
Desert	4.31^{c}	0.30^{a}	0.08	0.10	0.18	0.25
North West	5.78^{c}	0.19	0.15^{a}	0.04	-0.13	0.29
Dadu	4.10^{b}	0.25	-0.05	0.15	0.26	0.40^{a}
Ghothki	7.61^{c}	0.04	0.13^{b}	0.06^{b}	-0.13	-0.11
Khairpur East	5.46^{c}	-0.03	0.16	0.06	0.92^{c}	-0.33^{a}
Khairpur West	5.74^{c}	-0.01	0.31^{b}	0.12	0.37	-0.08
Fuleli	4.64^{c}	0.09	0.23^{b}	0.10^{c}	0.36^{c}	0.34
Pinyari	-0.39	-0.20	-0.20	0.60^{b}	1.57	0.90
Lined Channel	3.45^{b}	0.55^{a}	0.14	0.10	0.33^{b}	-0.16
Rohri	7.32^{c}	-0.15	0.02	0.06	0.18^{a}	0.15
Nara	5.74^{c}	0.09	0.02	0.12	0.32^{b}	-0.01
Jamrao	4.41^{c}	0.32^{a}	-0.09	0.06^{b}	0.46^{c}	0.12
Sindh	5.35^{c}	0.14^{c}	0.26^{c}	0.07^{c}	0.26^{c}	0.09^{c}

Notes: ^{a} denotes significance at 10 percent level; ^{b}denotes significance at 5 percent level; ^{c}denotes significance at 1 percent level.

TABLE B2.

Data for other related variables by canal command.

Canal command	CCA	TWD		CI	WA	TWA	I	VAI
		1989-90	1995-96					
Rice Canal	210	260	370	192	31	23.7	0.7	0.47
Begari	341	410	510	180	51	53.2	1.1	0.34
Desert	158	250	130	190	95	34.6	1.2	0.29
North West	309	1,210	1,430	170	47	31.9	2.3	1.01
Dadu	245	1,000	930	170	65	59.6	3.3	1.39
Ghothki	368	1,330	900	183	55	102.7	3.4	1.32
Khairpur East	182	880	860	182	65	52.9	3.7	1.13
Khairpur West	195	750	580	166	51	81.8	3.7	1.55
Fuleli	361	1,150	1,270	123	23	17.0	4.0	1.61
Pinyari	323	860	1,070	124	17	6.2	4.2	0.97
Lined Channel	220	620	570	115	34	12.0	4.3	1.03
Rohri	1,045	4,700	3,900	144	37	310.9	4.6	1.36
Nara	883	3,770	3,610	106	58	159.9	4.8	0.65
Jamrao	na	na	na	131	46	na	5.2	0.93
Sindh	4,840*	17,190	16,130	158	49		3.5	2.96

* The total CCA for Sindh here is the sum of 13 commands and excludes CCA for Jamrao and two other canal commands, Pat feeder and Kalri Begar Feeder (which are not included in this study) due to the unavailability of consistent data for these commands.

Notes: *CCA* is total culturable command area in 1995-96, in thousand hectares; *TWD* is total rabi water diversions at canal head in million cubic meters; *CI* is cropping intensity in percentage (based on survey results); *WA* is wheat area as a proportion of cultivated farm area in percentage (based on survey results); *TWA* is total area sown to wheat in 1995-96, in thousand hectares; *I* is number of irrigations per hectare; and *VAI* is variance of number of irrigations per hectare.

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