Research Article

Received: 1 March 2014 Revised: 15 August 2014 Accepted article published: 23 August 2014 Published online in Wiley Online Library: 25 September 2014

(wileyonlinelibrary.com) DOI 10.1002/jsfa.6887

Efficiency of irrigation water application in sugarcane cultivation in Pakistan

Muhammad Arif Watto[a,c*] and Amin W. Mugera[a,b]

Abstract

BACKGROUND: Diminishing irrigation water supplies are threatening the sustainability of irrigated agriculture in Pakistan. Within the context of dwindling water resources and low agricultural water productivity, it is imperative to improve efficiency in agricultural production and to make efficient use of available water resources. This study employs a non-parametric approach to estimate the extent of technical and irrigation water efficiency in sugarcane cultivation in Pakistan.

RESULTS: The mean technical efficiency score is 0.96 for tube-well owners whereas it is 0.94 for water buyers. The mean irrigation water efficiency score is 0.86 for tube-well owners whereas it is 0.72 for water buyers. We find that across all farms, 59% of the tube-well owners and 45% of the water buyers are fully technically efficient, whereas only 36% of the tube-well owners and 30% of the water buyer are fully efficient in irrigation water use.

CONCLUSIONS: This study finds that sugarcane growers are operating at fairly high technical efficiency levels. But, there is considerable potential to improve irrigation water efficiency. This study proposes expanding the role of agricultural extension services from merely agronomic grounds to guide farmers to undertake cost benefit analysis of the available production technology, would help achieve higher efficiency levels.

Keywords: sugarcane technical efficiency; irrigation water efficiency; tube-well owners; water buyers; sub-vector model; Punjab, Pakistan

INTRODUCTION

As in many parts of the world, water scarcity in Pakistan has become an increasingly social and economic concern for policy makers and competitive water users.[1,2] Dwindling water supplies are threatening the sustainability of irrigated agriculture and bode serious challenges to the country's food security status. Whilst the demand for irrigation water continues to increase, the surface water supply continues to decrease, mainly as a result of climate change.[2–4] Consequently, it is expected that increases in the demand for irrigation water would increase reliance on groundwater resources.[4]

Currently, Pakistan is the third largest groundwater consumer, accounting for about 9% of the global groundwater withdrawals.[5] With more than one million tube-wells installed across the country, Pakistan meets more than 50% of irrigation requirements through groundwater abstractions.[6,7] A tube-well is a type of water well, drilled to extract sub-surface water through a pump. In Pakistan, tube-wells of 5–7 inch (approx. 12.7–17.8 cm) diameter are usually drilled to extract groundwater. These tube-wells are mounted with either 15–25 horsepower (approx. 11.25–18.75 kW) diesel engines or 15–30 horsepower (approx. 11.25–22.5 kW) electric motors depending upon the depth of the water table.

The utilisation of groundwater resources through private tube-well development has been playing a key role in agricultural development for a long time. A sharp increase in groundwater use started during the early 1960s. At that time, the adoption of tube-well technology was mainly aided by government support policies, such as rural electrification, subsidisation of electricity, diesel and drilling services, free pump sets and easy long-term loans.[8–11] Later, higher yields and greater economic returns from the cultivation of high-yielding crop varieties, which was made possible by reliable irrigation supplies from groundwater extractions,[12,13] encouraged farmers to adopt tube-well technology even without government support.[8,14–16] In subsequent years, with the continued increase in irrigation demands, more and more water supplies were being rendered through groundwater abstractions.[17–19] In 1960, groundwater contribution to the total irrigation water supplies was about 8% but 25 years later this share had gone up to 40%.[13] In later years, the diminishing surface water supplies further increased reliance on groundwater for irrigation purposes by more than 50%. Exceeding the annual recharge of 55 km^3, recent abstraction rates of up to 60 km^3, massive groundwater abstractions have gone beyond the limits they are replenished each year.[5] The declining water tables, besides making groundwater extraction expensive, are also causing many environmental concerns with serious repercussions for the sustainability of irrigated agriculture.[7,20–24] Within this context, the

* Correspondence to: Muhammad Arif Watto, School of Agricultural & Resource Economics, The University of Western Australia M089, 35 Stirling Highway, Crawley 6009 WA, Australia. E-mail: arifwattoo@ymail.com

a School of Agricultural & Resource Economics, The University of Western Australia M089, 35 Stirling Highway, Crawley 6009 WA, Australia

b The Institute of Agriculture, The University of Western Australia M089, 35 Stirling Highway, Crawley 6009 WA, Australia

c The University of Agriculture, Faisalabad, Pakistan

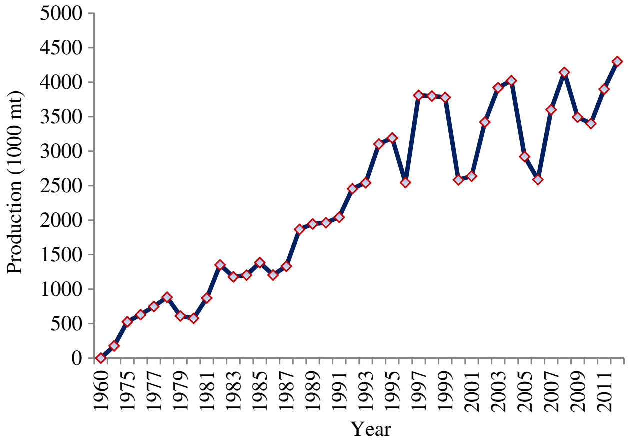

Figure 1. Sugar production trends in Pakistan between 1960 and 2011.

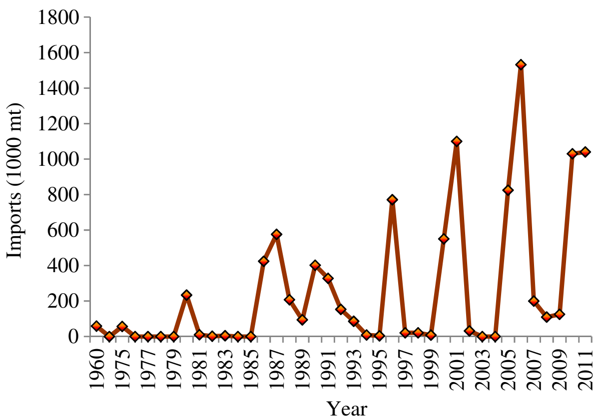

Figure 2. Sugar import trends in Pakistan between 1960 and 2011.

ongoing water crises have raised serious concerns to examine the efficiency of water use in the agriculture sector more closely than ever before.[25] Moreover, increases in inter-sectoral water demands have added further impetus to improve efficiency and productivity of water in the agriculture sector.

Pakistan is amongst the major sugarcane producing countries in the world. It is the world's fifth largest sugarcane producer; the country produced 58.4 million tonnes of sugarcane in 2012.[26] Sugarcane holds an important position in the national economy, accounting for 3.6% to the value added in agriculture and 0.8% to the country's gross domestic product. As sugarcane is the only major source of sugar production the whole crop is processed and used domestically. Last year, Pakistan produced 4.8 million tonnes of sugar form sugarcane while only 0.2 million tonnes was from sugar beet. Due to high domestic consumption, Pakistan had a brief history of exporting surplus sugar in 1994–1995 (total 0.47 million tonnes). The short-lived exports are now completely dominated by tonnes of sugar imports, with 1.04 million tonnes imported in 2012. Figure 1 shows the historical trends of sugarcane production and Fig. 2 shows sugar imports in Pakistan between 1960 and 2011.

Sugarcane is a high water-requiring crop. Unfortunately, neither sugarcane yield (46 t ha^{-1}) nor sugarcane water productivity (2.01 kg m^{-3}) in Pakistan is comparable with the world averages of yield (80–150 t ha^{-1}) and water productivity (3.5–5.5 kg m^{-3}).[27–29] Because of high irrigation water requirements, sugarcane production is required to use input combinations to provide higher efficiency levels. Sugarcane production efficiency has been examined by different studies in Pakistan.[30,31] However, irrigation water efficiency in sugarcane production has not been investigated in Pakistan. Moreover, studies evaluating irrigation water efficiency are rare and mainly focus at the farm level with few estimating irrigation water efficiency at the crop level. Amongst the existing studies, Karagiannis *et al.*[1] measured irrigation water efficiency of out-of-season vegetable farming in Greece. Speelman *et al.*[32] and Frija *et al.*[33] estimated irrigation water efficiency among small-scale irrigators in South Africa and small-scale greenhouse vegetable farmers in Tunisia. Manunatha *et al.*[34] examined irrigation water efficiency of different horticultural crops in India. But, the extant literature does not show significant evidence of irrigation water efficiency estimation in sugarcane production.

The objective of this study was to estimate technical and irrigation water efficiency and the factors affecting farmers' efficiency in sugarcane cultivation. The study employs a non-parametric data envelopment analysis (DEA) and the DEA sub-vector approach to estimate technical and irrigation water efficiency using a dataset of 84 sugarcane farms from the Punjab province of Pakistan. A second-stage truncated regression is used to identify the factors influencing farmers' technical and irrigation water efficiency. The findings of this study can be used to advise policy makers and agricultural extension field staff to suggest measures for improving irrigation water efficiency in sugarcane production in Pakistan.

The rest of the paper is organised as follows. The next section describes the methodological framework explaining the non-parametric concept of technical and irrigation water efficiency. The empirical DEA technical efficiency model and the sub-vector irrigation efficiency models are also presented in this section. The third section describes the data and principal features of the study areas, and this is followed by the results and discussion. The final section draws conclusions and provides some policy implications.

METHODOLOGICAL FRAMEWORK

Approaches to efficiency measures

The efficiency and productivity of a decision making unit (DMU) is measured either by a parametric approach such as stochastic frontier analysis, or by a non-parametric measure such as data envelopment analysis (DEA). The DEA was introduced by Charnes *et al.*,[35] who extended Farrell's[36] idea of measuring technical efficiency (TE) relative to a production frontier to develop a multi-factor (multiple inputs and outputs) productivity analysis model. The DEA model proposed by Charnes *et al.*[35] assumed constant returns to scale. Later, Banker *et al.*[37] introduced a DEA model under variable returns to scale. The concept of constant returns to scale is not economically feasible in many situations when increasing input usage, does not increase output proportionally. Moreover, using input-orientated efficiency estimates, we can determine how much the input use can be reduced for different DMUs without compromising the output level. Therefore, we opt to use an input-oriented DEA model to estimate technical and irrigation water use efficiency in this study.

Estimating technical and irrigation water use efficiency

Technical efficiency

Technical efficiency is the ability of a firm to produce maximum possible output within the available set of inputs and the given state of technology. Let us consider n decision making units (DMUs) that produce an output Y using X inputs. The technical efficiency under the variable returns to scale specification for a given DMU_{j_o} can be computed by solving the following standard linear programming problem:

$$\text{Min}_{\left(\lambda_{j_o}\theta_{j_o}\right)}\theta_{j_o} \tag{1}$$

subject to:

$$-y_{j_o} + \sum_{j=1}^{n} Y_j\lambda_j \geq 0, \qquad \text{(i)}$$

$$\theta x_{j_o} - \sum_{j=1}^{n} X_j\lambda_j \geq 0, \qquad \text{(ii)}$$

$$\sum_{j=1}^{n} I\lambda_j = 1 \qquad \text{(iii)}$$

$$\lambda_j \geq 0, \qquad \text{(iv)}$$

where y_{j_o} is the output quantity for the DMU_{j_o}; x_{j_o} is the vector of input quantities; Y_j is $n \times 1$ vector of all output quantities for all n DMUs; X_j is $n \times m$ matrix of input quantities for all n DMUs; I is $n \times 1$ vector of ones; λ_j is vector of weights; and θ_{j_o} is scalar. The equation $\sum_{j=1}^{n} I\lambda_j = 1$ is a convexity constraint to compute technical efficiency under the variable returns to scale specification.

Irrigation water use efficiency: an economic perspective

The extant irrigation water efficiency measures are based on either engineering or agronomic rationales. Generally, irrigation water efficiency is defined from three perspectives: (1) efficiency of the irrigation system, i.e. water conveyance efficiency; (2) efficiency in water application at the farm gate; and (3) the response of a crop to irrigation water application, i.e. the amount of water actually utilised by the crop compared to the amount of water supplied to that crop.[38] Recently, increasing water scarcity has brought into great prominence the economic importance of irrigation water and describing irrigation water efficiency on economic principles. (Conceptually, economic efficiency is achieved when limited resources are allocated and utilised in such a way to generate the highest benefits.) The assertion that ‘more can be achieved with less water’ refers to better management, which usually involves improving allocative and/or irrigation water efficiency. Allocative efficiency is closely related to adequate pricing of irrigation water while irrigation water efficiency depends on the type of technology, soil and environmental characteristics etc. In such a context, improving allocative efficiency is the most important (if not the only) factor for increasing farm income and conserving water waste. But an exclusive focus on allocative efficiency issues is closely related to the definition of irrigation water efficiency used in the engineering literature.[1]

Irrigation water efficiency as the ratio of the volume of water that is actually utilised by the plant/crop to the volume of irrigation water applied is expressed as follows:

$$E_\text{i} = \left(\frac{V_\text{b}}{V_\text{f}}\right) \times 100 \tag{2}$$

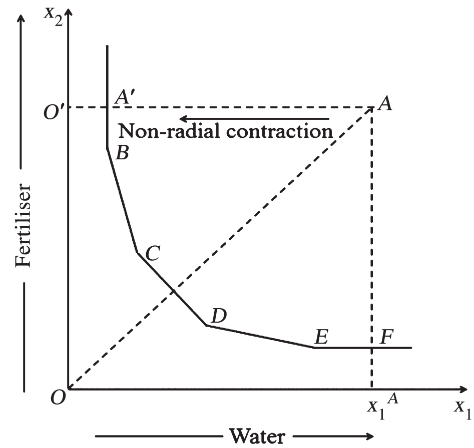

Figure 3. Graphical representation of technical and sub-vector irrigation water efficiency.

where E_i is the irrigation efficiency (%), V_b is the volume of water actually utilised (acre-inch), and V_f is the volume of water applied to the field (acre-inch). According to the above definition, a sprinkler irrigation system could reduce water use and increase irrigation water efficiency compared to a flood irrigation system, but with increasing cost. On the other hand, a drip irrigation system could be even more efficient than a sprinkler irrigation system.[1]

Irrigation water efficiency, as defined above, is a physical measure of a given irrigation system or technology which presumes a certain level of management, and is not directly comparable to technical efficiency as defined by Farrell,[36] which involves measurement of managerial capability of irrigators. A sprinkler irrigation system, however, like any other production system/technology, could be technically inefficient due to managerial incapability.[38] The economic measure of irrigation water efficiency is defined as the ratio of minimum feasible to observed use of irrigation water, conditional on observed levels of the desirable output and conventional inputs. More generally, irrigation water efficiency is the measure of technical efficiency of irrigation water use in the agricultural production process. The standard technical efficiency involves radial contraction of all inputs while the irrigation water efficiency concept involves estimation of technical efficiency of irrigation water non-radially. Figure 3 illustrates the concept and difference between technical efficiency (radial measure) and irrigation water efficiency (non-radial measure).

Let us consider six farms using two inputs, water and fertiliser, to produce a single output. Farms B, C, D, E and F are technically efficient because they are located on the frontier. However, farm A is inefficient because it is not located on the frontier. The radial contraction of inputs x_1 and x_2 produces a projected point A^0 on the frontier, which is a linear combination of all the observed data points. The technical efficiency of farm A with respect to farms B, C, D, E and F can be measured as $\text{TE}_A = OA^0/OA$. However, irrigation water efficiency involves non-radial contraction of a particular input while keeping other inputs and output constant. The non-radial efficiency (sub-vector efficiency) of farm A for input x_1 (irrigation water) could be measured by reducing x_1 to a point A' while keeping x_2 and the output constant. The sub-vector efficiency of input x_1 (water) for farm A can be given by the ratio $IE = O'A'/O'A$.

The sub-vector efficiency model

We use the sub-vector model to estimate the irrigation water use efficiency for a particular DMU$_{j_o}$ by solving the following linear programming problem, following Speelman *et al.*:[32]

$$\text{Min}_{(\lambda^w,\theta)}\theta^w \tag{3}$$

subject to:

$$-y_{j_o} + \sum_{j=1}^{n} Y_j \lambda_j \geq 0, \qquad \text{(i)}$$

$$x_{j_o} - \sum_{j=1}^{n} X_{m-w,j} \lambda_j \geq 0, \qquad \text{(ii)}$$

$$\theta^w x_{j_o} - \sum_{j=1}^{n} X_{w,j} \lambda_j \geq 0, \qquad \text{(iii)}$$

$$\sum_{j=1}^{n} I \lambda_j = 1 \qquad \text{(iv)}$$

$$\lambda_j \geq 0, \qquad \text{(v)}$$

where θ^w is the sub-vector efficiency of input *w* for a DMU$_{j_o}$. The constraints (i), (iv) and (v) are the same as in Eqn (1). In constraint (ii) the input *w* column is excluded and the constraint (iii) includes only the *w* input column. Similar to technical efficiency, irrigation efficiency measure (θ^w) can have a score between 0 and 1, where a score of 1 indicates that a DMU is the best performer and is located on the frontier, and there is no possibility of reduction in irrigation water use in the given agricultural production process. A value of less than 1 for a DMU indicates that irrigation water use inefficiency exists, meaning that there is some potential to save water use in irrigation.

Truncated regression analysis

In the extant literature, most of the studies have used Tobit regression in the second stage to investigate determinants of DEA efficiency measures (e.g. Speelman *et al.*,[32] Frija *et al.*,[33] Dhungana *et al.*[39] and Wadud and White[40]). The use of Tobit regression has been justified by the argument that efficiency scores are censored values because they vary between zero and 1. However, McDonald[41] argues that efficiency scores are not censored but are actually fractional values. Contrary to the Tobit model, Simar and Wilson,[42] proved that single bootstrap truncated regression performs better in terms of estimating confidence intervals. Thus, single bootstrap truncated regression is used to identify the determinants of technical and irrigation water efficiency. The model takes the form as follows:

$$Y_j = \alpha_j + \sum_{j=1}^{n} \beta_j z_j + \varepsilon_j \geq 0 \tag{4}$$

$$j = 1, \ldots, N$$

$$\varepsilon_j \rightarrow N\left(0, \sigma^2\right)$$

where Y_j is irrigation water use efficiency, α_j is the intercept, β_j is the vector of parameters to be estimated, z_j is the set of explanatory variables for $j = 1, \ldots 9$, σ is represents variance of the model, and ε_j is the error term.

Data description

This study was conducted in the northern agricultural territory of the Jhang district of the Punjab province in Pakistan during the cropping season of 2010–11. In the study area, rural households heavily rely on groundwater as a major source of irrigation. As a result of excessive pumping, groundwater tables are in gradual decline. Declining water tables have increased groundwater extraction costs many times over the last two decades. The variation in the bore depth was observed to be between 33 and 57 m during this field survey. Due to less dense tube-well population, farmers generally engage in informal groundwater trading. Such informal groundwater transactions have increased access to irrigation water for tenants and small farmers who do not own tube-wells.

A multi-stage sampling technique was used in data collection. In the first stage, one tehsil was selected purposively from the Jhang district. [Note that a *tehsil* is an administrative unit. A district is usually comprised of five to six tehsils (sub-districts).]

In the next stage, 10 villages (each containing 70–80 household farms) were selected at random from the selected tehsil. Finally, from each village 10 groundwater users (five tube-well owners and five water buyers) were selected randomly to obtain the differential impact of tube-well ownership and to reveal the difference of amount of water applied and production gains of tube-well owners and water buyers, thus making a total sample size of 100 respondents. However, during the cropping season of 2010–2011, only 44 tube-well owners and 40 water buyers cultivated sugarcane crop out of total 100 farming households.

The data were collected using an interview schedule. During the interview, we collected information on various inputs and output quantities. The inputs are measured as: (1) total labour, comprising hired (casual and permanent) and family labour in h acre^{-1}; (2) pesticide and farm operations as number of applications acre^{-1}; and (3) groundwater use in m^3 acre^{-1}. We computed irrigation water volume using an approximate estimation model, as used by Eyhorn *et al.*[43] and Srivastavaa *et al.*:[44]

$$Q = \frac{t \times 129574.1 \times \text{BHP}}{d + \left[\left(255.5998 \times \text{BHP}^2\right) / \left(d^2 \times D^4\right)\right]} \tag{5}$$

where *Q* represents the volume of water (in litres), *t* is the total irrigation time (in hours) applied to each farm during the entire cropping season, *d* is the depth (in meters) of the bore, *D* is the diameter (in inches (centimeters)) of the suction pipe, and BHP is the power (in horsepower (kW)) of the engine. Output (sugarcane

Table 1. Descriptive statistics of the variables used in the data envelopment analysis

Variable	Mean	SD	Min.	Max.
Inputs				
Total labour (h)	728	191	370	1526
Fertiliser (kg ha^{-1})	654	190	247	1235
Number of chemical applications	2.3	0.7	1	4
Number of farm operations	6.1	1.5	4	9
Irrigation water m^3 ha^{-1}	15944	3917	8163	26525
Cropped area (ha)	1.43	1.10	0.50	4.05
Output				
Sugarcane yield (t ha^{-1})	72.60	5.62	50.00	99.00

SD, standard deviation.

Table 2. Summary statistics of variables included in the truncated regression

Variable	Continuous variables				Proportion of farmers with dummy variables		
	Mean	SD	Min.	Max.	0	1	2
Farmer's age (years)	43.13	8.67	28	60	–	–	–
Family status (0 = single family, 1 = joint family)	–	–	–	–	31.25	68.75	–
Education (0 = illiterate, 1 = up to matriculation, 2 = above matriculation)	–	–	–	–	28.57	46.43	25.00
Off-farm income (0 = no, 1 = yes)	–	–	–	–	52.38	47.62	–
Land tenure status (0 = tenants, 1 = owners)	–	–	–	–	21.43	78.57	–
Tube-well ownership (0 = non-owners, 1 = owners)	–	–	–	–	54.76	45.24	–
Credit access (0 = no, 1 = yes)	–	–	–	–	64.29	35.31	–
Extension services (0 = no, 1 = yes)	–	–	–	–	60.71	29.31	–

yield) is measured in tonnes acre^{-1}. The descriptive statistics used in the analysis are presented in Table 1. The descriptive statistics show considerable variation in use of the inputs and the output produced by tube-well owners and water buyers. The average cultivated area is 5.42 acres for tube-well owners and 1.44 acres for water buyers. All farms in the sample are characterised as farms with a large share of family labour, and we see considerable variation in the number of hours worked at farms. Average per acre sugarcane yield is found to be 29.4 tonnes with 30.5 tonnes for tube-well owners while 28 tonnes for water buyers. There is a great variability across the farms in fertiliser and chemical application as well. In the case of irrigation water, tube-well owners applied 12.5% more groundwater compared to water buyers to irrigate 1 acre of sugarcane crop over the entire cropping season.

Table 2 presents the summary statistics of the explanatory variables. The average farmer's age is 43 years, ranging from 28 to 60 years. The rural sociology of the study district is dominated by the joint family system. Among the sampled farms, approximately 68% of the farming families are living as joint families. The statistics on education clearly reflect lack of education among the farming community. It was observed that 29% of household heads have no education at all with only 25% of the farmers having an education level above matriculation. A significant proportion of the surveyed farms cultivate their own land. Only 21.43% of the farmers are tenants. Because farming is a major livelihood activity among rural communities, only a small proportion (13%) of the farmers had alternative sources of income. In our sample size, 52.38% of sugarcane growers have their own tube-wells, while 47.61% purchase groundwater from the tube-well owners. Only 35% of the farmers managed to obtain credit from private banks or public agencies. Finally, 29% of the farmers participated in agricultural training programmes or they obtained advice from agricultural extension field staff regarding sugarcane production technology.

RESULTS AND DISCUSSION

The estimated results on technical and irrigation water efficiency under variable returns to scale are presented in Table 3. On average, we did not find substantial technical inefficiencies between both types of sugarcane growers, i.e. tube-well owners and water buyers. The mean TE score is 0.96 and ranges from 0.72 to 1.00 for tube-well owners, whereas the mean TE score is 0.94 and ranges from 0.73 to 1.00 for water buyers. The mean TE estimates imply that tube-well owners and water buyers are operating at fairly high technical efficiency levels. However, across all farms, only 59% of the tube-well owners and 45% of the water buyers were fully technically efficient (TE = 1). Previous studies report relatively lower technical efficiency scores in sugarcane production in Pakistan. Ali *et al.*[30] reported 0.75 mean TE estimates among sugarcane producers in north-west Pakistan and Lohano *et al.*[31] reported 0.77 mean TE in a combined study of sugarcane growers from Sindh and Punjab provinces.

Table 3. Frequency distribution of technical and irrigation water efficiency (IWE)

Efficiency range	Technical efficiency		Sub-vector IWE	
	Tube-well owners	Water buyers	Tube-well owners	Water buyers
<30	0	0	0	0
30–40	0	0	0	1
40–50	0	0	2	5
50–60	0	0	3	10
60–70	0	0	2	8
70–80	1	2	4	2
80–90	6	10	8	4
90–99	7	14	5	1
100	26	18	16	12
Mean	0.96	0.94	0.86	0.72
SD	0.07	0.07	0.17	0.21
Minimum	0.72	0.73	0.48	0.37
Maximum	1	1	1	1

SD, standard deviation.

The sub-vector irrigation water efficiency estimates, however, show large-scale inefficiencies in irrigation water application to sugarcane cultivation by both tube-well owners and water buyers. We see that the irrigation water use inefficiencies are more pronounced than the technical inefficiencies, as shown in the Fig. 4.

The DEA sub-vector estimates indicate that mean IWE score is 0.86 and ranges from 0.48 to 1.00 for tube-well owners, whereas the mean IWE score is 0.72 and ranges from 0.37 to 1.00 for water buyers. Only 36% of the tube-well owners and 30% of the water buyer were found to be fully efficient in irrigation water use (IWE = 1). These estimates indicate that there is a considerable

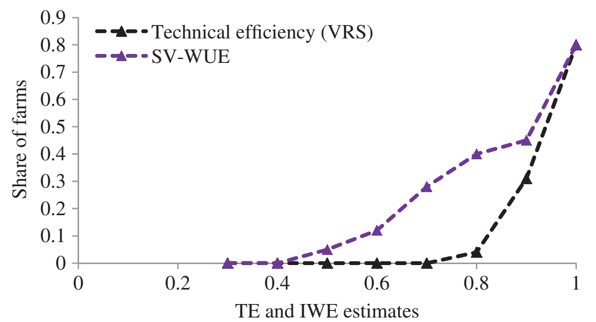

Figure 4. Cumulative frequency distribution for technical and irrigation water efficiency. VRS, variable returns to scale; SV-IWE, sub-vector irrigation water efficiency.

Table 4. Spearman's rank correlation between technical efficiency and irrigation water efficiency (IWE)

Variable	Technical efficiency	Sub-vector IWE
Technical efficiency	1.00	–
Sub-vector IWE	0.73*	1.00

*Indicate significance at 10%..

scope for reducing groundwater use by using the observed values of other inputs and maintaining the same output level. This means that if irrigation water efficiency improves, it would enable farmers to re-allocate some water to other uses and would help conserve groundwater resources. The correlation statistics (Table 4) imply that any improvements in irrigation water efficiency may also help improve overall technical efficiency in sugarcane production. Our IWE estimates suggest that by achieving 100% irrigation water efficiency, only 84 sugarcane farms can save a total volume of 0.49 million m^3 groundwater during one cropping season, which if put in monetary terms, they can potentially save US$7800 (based on monetary exchange rates at the time of data collection, i.e. June–November 2010) by paying less groundwater extraction costs.

The mean TE and IWE estimates suggest that water buyers are less efficient compared to tube well owners. Meinzen-Dick[12] found that tube-well owners were better off in terms of farm productivity compared to the water buyers, presumably as a result of greater control over groundwater access and supplies. Nevertheless, water buyers are risk prone to uncertain and delayed irrigation supplies. As groundwater trading is informal, it is highly influenced by the social ties between tube-well owners and water buyers. Hence, the absence of a formal contract sometimes leads to inequities in water allocation and distribution among the buyers.[6,45] Moreover, due to on-going energy crises water buyers face more uncertainties and delays in obtaining water for irrigation and it is highly likely that delayed water application may decrease the marginal product of other inputs such as fertiliser, labour and chemical inputs. Consequently, water buyers remain more inefficient than tube-well owners.

Most of the estimated coefficients in the second-stage regression model confirm to *a priori* expectations about their impact on efficiency levels. Our estimates (Table 5) indicate that a farmer's age does not significantly impact the level of efficiency either technical or irrigation water efficiency. Quite a number of other studies suggest that old farmers are more sceptical about adopting new farming techniques and technologies and hence lag in agricultural production.[32,46] Nevertheless, some studies found that with increasing age a farmer's level of efficiency increases.[1] The results suggest that a farmer's family status (single or joint family), does not significantly impact technical and irrigation water efficiency.

As expected, education and extension services have a positive impact on both technical and irrigation water efficiency, supporting the premise that increases in human capital enable farmers to improve resource utilisation and thus achieve higher efficiencies. In the literature, we find mixed results for the efficiency and education relationship, e.g. Karagiannis *et al.*[1] and Solís *et al.*[47] found the impact of education significant while Haji[48] and Speelman *et al.*[32] found the impact of education to be non-significant. These mixed results suggest that when interpreting the impact of education on efficiency levels researchers should consider the relevance of a farmer's education to his farming business. The impact of extension services on technical efficiency is consistent with the commonly established assumption that the farmers who tend to seek more extension advice and become involved in training programmes are technically more efficient than those who have less or no contact with the extension staff.[33,49]

The negative coefficient (although non-significant) of land tenure status contradicts the common intuition that, all things being equal, land owners usually invest more in new production technologies and, consequently, increase their expected returns.[32,33,50] However, some studies have also reported negative impact of land ownership on farm efficiency.[51]

We find that off-farm income is positively associated with technical efficiency, suggesting that with alternative income resources, farmers may have a better chance to purchase and use an optimal input mix which in turn results in better efficiency gains.[1] However, off-farm income was not found to be significantly associated with irrigation water efficiency. Unlike off-farm income resources, farmers who opted to obtain credit are more technically and irrigation water use efficient than those who did not. The impact of tube-well ownership on technical efficiency implies that tube-well owners have better assurance and control over irrigation in terms of spatio-temporal crop requirements and, hence, their expected returns (marginal product of other inputs) are higher than the water buyers. Tube-well ownership is negatively associated with irrigation water efficiency, probing out some of the tube-well owners might use more groundwater than what the incremental value they generate.

CONCLUSION

The objective of this study was to estimate technical efficiency (TE) and irrigation water efficiency (IWE) and the factors affecting a farmer's efficiency in sugarcane cultivation. The study employed a non-parametric approach, i.e. data envelopment analysis (DEA) to estimate TE and the DEA sub-vector model to estimate IWE using a dataset of 84 sugarcane farms from the Punjab province of Pakistan. The results obtained from a cross-sectional dataset of 84 sugarcane growers indicate that, on average, sugarcane growers are operating at fairly high technical efficiency levels. The mean TE score is 0.96 for tube-well owners, whereas the mean TE score is 0.94 for water buyers. Irrigation water efficiency estimates, however, indicate substantial inefficiencies in irrigation water applications to sugarcane cultivation by both tube-well owners and water buyers. The mean IWE score is 0.86 for tube-well owners, whereas the mean IWE score is 0.72 for water buyers. The mean IWE estimates suggest that tube-well owners and water buyers

Table 5. Bootstrapped truncated estimates of determinants of irrigation water use efficiency

	Technical efficiency		Irrigation water efficiency	
Explanatory variable	Coefficient	SE	Coefficient	SE
Farmer's age (years)				
Age	0.0178	0.0084	0.0097	0.0197
Age^2	−0.0002	0.0001	−0.0001	0.0002
Family status (0 = Single, 1 = Joint family)	−0.0098	0.0161	−0.0004	0.0397
Education dummy (0 = illiterate, 1 = up to matriculation, 2 = above matriculation)				
Up to matriculation	0.0616**	0.0244	0.0750	0.0482
Above matriculation	0.0779***	0.0293	−0.1796**	0.0759
Land tenure status dummy (0 = tenants, 1 = owners)	−0.0294	0.0203	−0.0032	0.0510
Off-farm income dummy (1 = yes)	0.0389**	0.0158	0.0217	0.0443
Cropped area (ha)	0.0018	0.0032	0.0095	0.0083
Tube-well ownership dummy (0 = water buyers, 1 = tube-well owners)	0.0433*	0.0246	−0.0951	0.0631
Credit dummy (0 = no, 1 = yes)	0.0381*	0.0177	0.1247**	0.0508
Extension services dummy (0 = no, 1 = yes)	0.0282*	0.0153	0.0801*	0.0479
Constant	0.5009**	0.1792	0.4408	0.4386
Log likelihood	114.85	–	39.80	–

*, **, *** indicate significant at 10%, 5% and 1% respectively.
Number of bootstraps = 4000.
SE, standard error.

can reduce 21% and 28% irrigations water application to sugarcane crop, respectively. By reducing groundwater application 21% and 28% both tube-well owners and water buyers can save 0.49 million m^3 groundwater from one cropping season.

Whilst one of the key underlying research objectives of this study was to estimate technical and irrigation water efficiency in sugarcane production, this study suggests that educating farmers, creating better credit and off-farm income opportunities and providing better extension services about the production technology would help o achieve higher technical and irrigation water efficiency in sugarcane production. A key finding of the study is that access to technology is not a major constraint in sugarcane production; rather, farmers can improve production given the technology available. In this regard, we suggest that expanding the role of agricultural extension advice form agronomic grounds (e.g. production technology) to economic grounds (e.g. cost benefit analysis of available production technology) would help farmers to achieve higher efficiency levels. In the longer term, for the required improvements in efficiency and productivity for the highly competitive sugar industry in Pakistan, there must be on-going technical efficiency improvements in sugarcane production within the efficient use of limited water resources.

REFERENCES

1 Karagiannis G, Tzouvelekas V and Xepapadeas A, Measuring irrigation water efficiency with a stochastic production frontier. *Environ Resour Econ* **26**:57–72 (2003).
2 Hussain I and Hanjra MA, Irrigation and poverty alleviation: Review of the empirical evidence. *Irrig Drain* **53**:1–15 (2004).
3 Barnett TP, Adam JC and Lettenmaier DP, Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature* **438**:303–309 (2005).
4 Archer DR, Forsythe N, Fowler HJ and Shah SM, Sustainability of water resources management in the Indus Basin under changing climatic and socio-economic conditions. *Hydrology and Earth Systems Sciences* **14**:1669–1680 (2010).
5 Giordano M, Global groundwater? Issues and solutions. *Annu Rev Environ Resour* **34**:153–178 (2009).
6 Rinaudo J-D, Strosser P and Rieu T, Linking water market functioning, access to water resources and farm production strategies: example from Pakistan. *Irrig Drain Syst* **11**:261–280 (1997).
7 Qureshi AS, McCornick P, Sarwar A and Sharma BR, Challenges and prospects of sustainable groundwater management in the Indus Basin, *Pakistan. Water Resour Manage* **24**:1551–1569 (2009).
8 Falcon WP and Gotsch CH, Lessons in Agricultural Development – Pakistan, in *Development Policy – Theory and Practice*, ed. by Papanek GF. Harvard University Press, Cambridge, MA (1968).
9 Papanek GF, *Pakistan's Development: Social Goals and Private Incentives*. Oxford University Press, New York (1968).
10 van Steenbergen F and Oliemans W, A review of policies in groundwater management in Pakistan 1950–2000. *Water Policy* **4**:323–344 (2002).
11 Johnson R, *Private Tube-well Development in Pakistan's Punjab: Review of Past Public Programmes/Policies and Relevant Research*. International Water Management Institute, Lahore (1989).
12 Meinzen-Dick RS, *Groundwater Markets in Pakistan: Participation and Productivity*. International Food Policy Research Institute, Washington DC (1996).
13 Byrelle D and Siddiq A, Has the green revolution sustained? The quantitative impacts of seed–fertilizer technology in Pakistan revisited. *World Dev* **22**:1345–1361 (1994).
14 Muhammad G, Some strategic problems in agricultural development in Pakistan. *Pak Dev Rev* **4**:223–260 (1964).
15 Muhammad G, Private tubewell development and cropping patterns in West Pakistan. *Pak Dev Rev* **5**:68–87 (1965).
16 Nulty L, *The Green Revolution in West Pakistan: Implications of Technological Change*. Praeger Publishers, New York (1972).
17 Shiva V, The green revolution in Punjab. *Ecologist* **21**:57–60 (1991).
18 Ahmad I, Hussain SAS and Zahid MS, Why the green revolution was a short-run phenomenon in the development process of Pakistan: A lesson for future. *J Rural Dev Admin* **35**:89–104 (2004).
19 Rodel M, Velicogna I and Famiglietti J, Satellite-based estimates of groundwater depletion in India. *Nature* **460**:999–1003 (2009).
20 Kijne JW, *Improving the Productivity of Pakistan's Irrigation: the Importance of Management Choices*. International Water Management Institute, Colombo (1999).
21 Shah T, David M, Sakthivadive R and David S, *The Global Groundwater Situation: Overview of Opportunities and Challenges*. International Water Management Institute, Colombo (2000).
22 Kelleners TJ and Chaudhry MR, Drainage water salinity of tubewells and pipe drains: A case study from Pakistan. *Agric Water Manage* **37**:41–53 (1998).

23 Kahlown MA and Azam M, Individual and combined effect of waterlogging and salinity on crop yields in the Indus Basin. *Irrig Drain* **51**:329–338 (2002).
24 Khan S, Rana T, Gabriel HF and Ullah M, Hydrogeologic assessment of escalating groundwater exploitation in the Indus Basin, *Pakistan. Hydrol J* **16**:1635–1654 (2008).
25 Watto MA and Mugera A, Measuring efficiency of cotton cultivation in Pakistan: a restricted production frontier study. *J Sci Food Agric* DOI: 10.1002/jsfa.6652 (2014).
26 FAO, *2012 FAOSTAT*. [Online]. Food and Agriculture Organization of United Nations (2012). Available: http://faostat.fao.org/site/339/default.aspx [19 December 2012].
27 Ashraf M, Nasir A and Saeed MM, Evaluation of the existing water productivity in the lower Bari Doab Canal (LBDC) Command – A case study. *Pak J Agric Sci* **47**:389–397 (2010).
28 Steduto P, Theodore CH, Elias F and Dirk R, *Crop Yield Response to Water*. Food and Agriculture Organization of the United Nations, Rome (2012).
29 Waclawovsky AJ, Sato PM, Lembke CG, Moore PH and Souza GM, Sugarcane for bioenergy production: An assessment of yield and regulation of sucrose content. *Plant Biotechnol J* **8**:263–276 (2010).
30 Ali G, Syed MAS, Dawood J, Abbasullah J, Mohammad F, Irfan U, *et al.*, Technical efficiency of sugarcane production in district Dera Ismail Khan. *Sarhad J Agric* **29**:585–590 (2013).
31 Lohano HD, Adnan N and Ali MK, Technical, allocative and economic efficiencies in sugarcane production in Pakistan: A non-parametric approach. *Business Rev* **6**:131–141 (2011).
32 Speelman S, D'Haese M, Buysse J and D'Haese L, A measure for the efficiency of water use and its determinants, A case study of small-scale irrigation schemes in North-West Province, South Africa. *Agric Syst* **98**:31–39 (2008).
33 Frija A, Chebil A, Speelman S, Buysse J and Van Huylenbroeck G, Water use and technical efficiencies in horticultural greenhouses in Tunisia. *Agric Water Manage* **96**:1509–1516 (2009).
34 Manjunatha AV, Speelman S, Chandrakanth MG and Van Huylenbroeck G, Impact of groundwater markets in India on water use efficiency: A data envelopment analysis approach. *J Environ Manage* **92**:2924–2929 (2011).
35 Charnes A, Cooper WW and Rhodes E, Measuring the efficiency of decision-making units. *Eur J Oper Res* **2**:429–444 (1978).
36 Farrell MJ, The measurement of productive efficiency. *J R Stat Soc A (Gen)* **120**:253–290 (1957).
37 Banker RD, Charnes A and Cooper WW, Some models for the estimation of technical and scale inefficiencies in data envelopment analysis. *Manage Sci* **30**:1078–1092 (1984).
38 McGuckin JT, Gollehon N and Ghosh S, Water conservation in irrigated agriculture: A stochastic production frontier model. *Water Resour Res* **28**:305–312 (1992).
39 Dhungana BR, Nuthall PL and Nartea GV, Measuring the economic inefficiency of Nepalese rice farms using data envelopment analysis. *Aust J Agric Resour Econ* **48**:347–369 (2004).
40 Wadud A and White B, Farm household efficiency in Bangladesh: A comparison of stochastic frontier and DEA methods. *Appl Econ* **32**:1665–1673 (2000).
41 McDonald J, Using least squares and tobit in second stage DEA efficiency analyses. *Eur J Oper Res* **197**:792–798 (2009).
42 Simar L and Wilson PW, Estimation and inference in two-stage, semi-parametric models of production processes. *J Econometrics* **136**:31–64 (2007).
43 Eyhorn F, Paul M and Mahesh R, *The Impact of Organic Cotton Farming on the Livelihoods of Smallholders. Evidence from the Maikaal bioRe Project in Central India*. Research Institute of Organic Agriculture (FiBL), Frick (2005).
44 Srivastavaa SK, Kumarb R and Singh RP, Extent of groundwater extraction and irrigation efficiency on farms under different water-market regimes in Central Uttar Pradesh. *Agric Econ Res Rev* **22**:87–97 (2009).
45 Jacoby HG, Murgai R and Rehman SU, Monopoly power and distribution in fragmented markets: The case of groundwater. *The Review of Economic Studies* **71**:783–808 (2004).
46 Villano R and Fleming E, Technical inefficiency and production risk in rice farming: Evidence from Central Luzon Philippines. *Asian Econ J* **20**:29–46 (2006).
47 Solís D, Bravo-Ureta BE and Quiroga RE, Technical efficiency among peasant farmers participating in natural resource management programmes in Central America. *J Agric Econ* **60**:202–219 (2009).
48 Haji J, Production efficiency of smallholders' vegetable-dominated mixed farming system in Eastern Ethiopia: A non-parametric approach. *J Afr Econ* **16**:1–27 (2007).
49 Parikh A and Shah K, Measurement of technical efficiency in the North-West Frontier Province of Pakistan. *J Agric Econ* **45**:132–138 (1994).
50 Gebremedhin B and Swinton S, Investment in soil conservation in Northern Ethiopia: The role of land tenure security and public programs. *Agric Econ* **29**:69–84 (2003).
51 Byiringiro F and Reardon T, Farm productivity in Rwanda: Effects of farm size, erosion, and soil conservation investments. *Agric Econ* **15**:127–136 (1996).

