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Application of Data Envelopment Analysis (DEA) for assessing the efficiency of Laser Land Leveling Technology in Punjab Agriculture

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Abstract

This study was carried out to assess technical efficiency in wheat and paddy cultivation with regard to laser land leveling technology in two regions of Central Punjab. For this purpose, the data were collected from 80 farmers, using multi-stage random sampling method. The results indicated that those sample farmers whose fields were leveled with laser leveler were better water managers. The results revealed that the reduction in the use of inputs by up to 23 % will make the sample farmers reach the optimum scale of efficiency. The adoption of laser land leveling technology resulted into water saving of 28 % and 12 % in paddy and wheat crops, respectively. Further, the incremental increase in returns over variable cost was ₹ 3311 per ha in paddy crop, whereas it was ₹ 4268 per ha in wheat crop.

Keywords;Region,Technical,Optinum, Adoption

Acute water shortages are being observed in many countries all over the World including India. 70 % of Indian population depends on agriculture for their livelihood which in turn is the major user of water. Irrigated agriculture accounts for 80 % of the total water use of the country. Agriculture being an important component of food security policies in the main consumer of supplied water. Punjab being an agriculturally advanced state of the country (giving 43.8 % of wheat and 25.4 % of rice to the central pool) with its 83 % of the total area under cultivation is under water stress (Anonymous, 2012). The Punjab state, where the green revolution was responsible for countering the country's food deficit, has largely being successful due to ground water irrigation. However, currently effects of overdraft like premature failure of wells, decline in ground water yield and lowering water tables are apparent.(Chandrakanth *et al.*, 2004; Diwakhara and Chandrakanth, 2007; Nagaraj *et al.*, 2005; Mukherji and Shah, 2005; Shah *et al.*, 2008, Manjunatha *et al.*, 2011). In spite of improvements in ground water extraction and water and water use technologies, the situation is expected to further worsen due to population growth and the increase in effective demand for ground water by intensive agricultural production. Within this context, this paper examines whether conservation practices have the potential to contribute to improved water use efficiency.

Over the past three decades or so, internationally, rapid strides have been made to evolve and spread resource conservation technologies like laser land leveling, zero and reduced tillage systems, better management of crop residues and planting systems, which enhance conservation of water and nutrients. Conservation agriculture (CA) which has its roots in universal principles of providing permanent and leveled soil cover (through precision leveling, crop residues, cover crops, and agroforestry), minimum soil disturbance and crop rotations is now considered the principal road to sustainable agriculture: a way to achieve goals of higher productivity while protecting natural resources and environment. Conservation agriculture is currently practiced on more than 80 million ha worldwide in more than 50 countries and the area is expanding rapidly (Sangar *et al*, 2004).

Conservation agriculture leads to sustainable improvements in the efficient use of water and nutrients by improving nutrient balances, and availability, infiltration and retention by soils reducing water losses due to evaporation and improving the quality and availability of ground and surface water. Laser leveling of agricultural land is a recent resource conservation technology initiative in India. It has the potential to change the way food is produced by enhancing resource-use efficiency of critical inputs without any disturbing and harmful effects on the productive resilience of the ecosystem (Jat *et al*, 2006). Rice-Wheat Consortium has estimated that extension of laser-assisted precision land leveling system to just two million hectares of area under rice-wheat system could save 1.5 million hectare-meter of irrigation water, save diesel up to 200 million litres and improve the crop yield amounting to US$ 500 million in three years. Laser land leveling is leveling the field within certain degree of desired slope using a guided laser beam through out the field. The benefits of laser leveling include improved crop yields, reduced labour time spent in weeding and in particular a reduction of 20-25 % in irrigation water usage. This last benefit represents a positive externality. Because groundwater use is unpriced in Punjab state, farmers have minimal incentives to conserve on it. Subsidized agricultural input stimulates the extensive use of these inputs (1992). Furthermore, laser–assisted precision land leveling system is likely to increase the cultivable area in the range of 3-6 % (due to reduction in bunds and channels in the field).

In lieu of this, only a few studies (Kaliranjan, 1981, Kaliranjan and Shand, 1994; Mythil and Shanmugam, 2000) have been carried out to measure technical efficiency of rice production in India using the cross-section data. The present study uses the nonparametric technique of Data Envelopment Analysis (DEA) to measure the technical efficiency of the farms in Punjab under intensive agriculture (i.e. paddy-wheat rotation) for two groups i.e. adopters vs. non-adopters of the technology during the agricultural year 2011-12.

Materials and Methods

Data collection

The multi-stage random sampling design was used to collect the primary data from 80 sample farms of Punjab during the agricultural year 2011-12. Based on the rapid ground water table depletion, the districts of Ludhiana and Tarn Taran were selected. Further, one block from each selected district i.e. Ludhiana-I from Ludhiana district and Naushera Pannua from Tarn Taran district was selected randomly. At the third stage, two villages from each of these two blocks were randomly chosen. The villages chosen were Nurpur Bet and Issewal from Ludhiana-I block and Dhotian and Naushera Pannua from Naushera Pannua block.

The farmers were selected using simple random sampling technique, 40 adopters i.e. 10 adopters from each village were taken for the study. In order to undertake impact assessment task of this technology, almost an equal number of non-adopters from the same vicinity were taken as a control group in the analysis. Therefore, a total sample of 80 farmers (40 adopters plus 40 non-adopters) covering four villages, two blocks and two districts of Central Zone of Punjab was finally chosen for the ultimate analysis.

Technical Analysis

Data Envelopment Analysis (DEA) was used to analyze the technical efficiency, i.e. ability of a unit to obtain maximum output from a given set of inputs. Data Envelopment Analysis (DEA) calculates the relative efficiency scores of various Decision Makin Units (DMUs) in a particular sample. The DMUs are the individual sample farmers in this study, whether adopters or non-adopters. Our hypothesis is that because of the role played by this conservation technology, adopters will be more water efficient than non-adopters.

Data Envelopment Analysis was introduced by Farrell (1957) and later on extended by Charnes *et al.* (1978), to incorporate multiple inputs and multiple outputs simultaneously for estimating technical efficiency relative to a production frontier. Several other measures of technical efficiency i.e. ordinary least squares (OLS) regression, stochastic frontier analysis (SFA) and total factor productivity (TFP) indices using price-based index number (PIN) have been used by various studies but all these measures required these specifications of a functional form for the production technology.

DEA approach overcomes most of the limitations as it does not require specification of a functional or distributional form and can accommodate scale issues. Furthermore, different units of measurement can be used for the various inputs and outputs and knowledge of their relative prices is not required.

DEA is non-parametric in the sense that it requires few a priori assumptions regarding the functional relationship between inputs and outputs. Instead, the production frontier is constructed as a piece wise linear envelopment of the observed data points, here farms in specific year. This means that the best performing farms are identified as those using the least amount of inputs to produce their individual levels of output (Frija *et al.*, 2004). Linear, or convex, combinations of those best performers constitute the production frontier. The efficiency of the farms is then measured relative to this estimated frontier of best performers.

In the present study, only input oriented (IOM) version of the DEA technical efficiency measurement methodology was applied to the data. An input-oriented model is used in order to obtain the given level of output by input minimization. We choose input orientation instead of output-oriented DEA because in the context of increasing water scarcity, it is more relevant to consider potential decrease in water-use than increase in output. In order to specify the mathematical formulation of IOM, let us assume that we have K farmers (DMU) using N inputs to produce M outputs. Inputs are denoted by x_{jk} (j=1,2,…….,n) and the outputs are represented by Y_{ik} (i=1,2,……..,m) for each farmer k (k=1,2,………,K). The

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efficiency of the farmers can be measured as (Coelli *el al.*, 1998; Worthington and Dollery, 1999):

$$\mathrm{TE}_k = \sum_{i=1}^{m} u_i y_{ik} / \sum_{j=1}^{n} v_j x_{jk}$$

where, Y_{ik} is the quantity of the i-th output produced by the k-th farmer, x_{jk} is the quantity of j-th input used by the k-th farmer, and u_i and v_j are the output and input weights respectively. The farmer maximizes the technical efficiency, TE_k, subject to

$$\mathrm{TE}_k = \sum_{i=1}^{m} u_i y_{ik} / \sum_{j=1}^{n} v_j x_{jk} \leq 1$$

where, u_i and $v_j \geq 0$

The above equation indicates that the technical efficiency measure of a farmer cannot exceed 1, and the input and output weights are positive. The weights are selected in such a way that the farmer maximizes its own technical efficiency which is executed separately. To select optimal weights the following linear programming (input-oriented) model is specified:

Min TE_k

Subject to

$$\sum_{i=1}^{m} u_i y_{ik} - y_{jk} + w \geq 0$$

where, k=1,2,……………,K

$$x_{jk} - \sum_{j=1}^{n} u_j x_{jk} \geq 0$$

and u_i and $v_j \geq 0$

The above model shows TE under constant returns to scale (CRS) assumption if w = 0 and it changes into variable returns to scale (VRS) if w is used unconstrained. In the first case it leads to technical efficiency (TE) and in the second case pure technical efficiency (PTE) is estimated. Pure Technical efficiency could separate both technical and scale efficiencies. The main advantage of this model is that the scale inefficient farms are only compared to efficient farms of a similar size. If a DMU has the full pure technical efficiency score, but a low technical efficiency score, then it is locally efficient but not globally efficient due to its scale size. Thus, it is reasonable to characterize the scale efficiency of a DMU by the ratio of the two scores. The relation among the scale efficiency, technical efficiency and pure technical efficiency can be expressed as:

$$\text{Scale efficiencey} = \frac{\text{Technical efficiencey}}{\text{Pure technical efficiency}}$$

In this study TE under VRS was estimated and results were presented by using Data Envelopment Analysis Program (DEAP) version 2.1.

The production of paddy and wheat crops per hectare (in quintals) was taken as the output (Y). The different inputs considered for the analysis were as follows:

X_1 = Water use (m^3ha^{-1})

X_2 = Fertilizer (Kg ha^{-1})

X_3 = Total human labour (hour ha^{-1})

X_4 = Total machine use (hour ha^{-1})

X_5 = Seed used (Kg ha^{-1})

Results and Discussion

Socio Economic Characteristics

Socio-economic profile of the farmers showed that more than half of the adopters were young i.e. age-group of less than 40 years, while identical percentage of non-adopters i.e. 62.5% were old age farmers (Table 1).

Table 1: Socio-economic characteristics of sample farmers, Punjab, 2011-12

Indicators	Adopters	Non-adopters
Age (years)		
up to 40	21(52.5)	15(37.5)
40 – 50	8(20)	14(35)
Above 50	11(27.5)	11(27.5)
Education		
Up to Primary	1(2.5)	7(17.5)
Matric	17(42.5)	25(62.5)
Secondary	22(55)	8(20)
Experience in farming (years)		
Up to 10	9(22.5)	7(17.5)
10 – 20	13(32.5)	12(30)
Above 20	18(45)	21(52.5)

Note: figures in parenthesis are percentages to the farmers in their respective category.

About half of adopters had passed secondary level education, while, 80 % of non-adopters had passed up to matric level. About 55 % of adopters had farming experience of less than or equal to 20 years, which clearly indicated that the adoption of this technology was made by young, educated and progressive farmers.

Input-use, Yield and Returns

The perusal of the Table 2 gives an overview of the input and output variables used in the DEA model. The average water-use of paddy crop in non-laser leveled fields was 8679 cubic metre per hectare

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(m^3ha^{-1}) whereas; it was 6243 m^3ha^{-1} in laser leveled fields; depicting a water saving of 28%. This clearly implied that the adopters of laser leveling technology were more water efficient than non-adopters. The average use of other inputs (labour, machine power, fertilizer etc.) in paddy crop was also high for non-adopters than adopters. The adoption of this technology led to four % increase in paddy yield and hence the gross returns increased to ₹ 2990 per hectare. Unlike paddy crop, the average use of all the inputs in wheat crop was higher in case of non-adopters over adopters. The per hectare gross returns in wheat crop increased by eight % due to the adoption of laser leveling technology at farmer‘s field. The higher yield realized by the adopters of the technology was due to the fact that water spreads uniformly throughout the surface giving more grains per square metre.

Likewise, Mobtaker, 2012 proposed the contribution of water (83.48 %) for irrigation input from total cost saving, which was the highest share, followed by machinery and chemical fertilizers input costs.

Table 2: Descriptive statistics on inputs and output of paddy and wheat crop used in the DEA model

Variables	Farmer Category	
	Adopters	Non-adopters
Paddy		
Water-use ($m^{-3}ha^{-1}$)	6243.38	8678.82
Labour (hr ha^{-1})	228.49	256.35
Machine power (hr ha^{-1})	176.57	222.86
Fertilizers (kg ha^{-1})	524.12	536.33
Yield (Q ha^{-1})	71.19	68.29
Gross Returns (¹ ha^{-1})	73490.77	70500.09
Variable Cost (¹ ha^{-1})	18571.75	18892.34
Net Returns (¹ ha^{-1})	54919.03	51607.76
Wheat		
Water-use ($m^{-3}ha^{-1}$)	2138.18	2435.03
Labour (hr ha^{-1})	95.93	103.79
Machine power (hr ha^{-1})	70.43	79.79
Fertilizers (kg ha^{-1})	511.36	523.98
Yield (Q ha^{-1})	50.67	46.88
Gross Returns (¹ ha^{-1})	56758.71	52512.54
Variable Cost (¹ ha^{-1})	18170.26	18192.19
Net Returns (¹ ha^{-1})	38588.55	34320.31

Note: Adopters are those who have adopted the laser leveling technology and vice-versa.
The figures represent the average of respective variable

Regions of Operations in the Production Frontier

In addition to knowing about the number of efficient farms, extent of inefficiency and optimum scale of operation, it is also important to understand the distribution of farms in the three regions of production frontier, i.e. how many farms are under increasing, decreasing or constant returns. These were estimated using the equations given under methodology and the results have been presented in Table 3.

In case of Paddy cultivation, only three % of the technology adopted farms were found operating in the region of increasing returns or the suboptimal region, whereas, none of the technology non-adopter ones were found in respected region. The production scale of these farms could be increased by decreasing the costs, since they were performing below the optimum production scale. Further, about 32.50 % and 97.50 % of laser leveled and non-laser leveled paddy farms, respectively were found in the decreasing returns region i.e. they could increase their technical efficiency by reducing their production levels. This region is also called as supra-optimal, i.e. the farms were performing above the optimum scale of production. In the constant region of frontier, i.e. optimum scale of production, about 60.00 % of laser leveled farms and only 2.50 % and non-laser leveled paddy farms were found operating that means more than half of the laser leveled farms had optimal efficiency level.

Table 3: Distribution of paddy and wheat farms according to the types of returns

Types of return	Paddy		Wheat	
	Adopters	Non-adopters	Adopters	Non-adopters
Increasing returns	3 (7.50)	-	4 (10.00)	1 (2.50)
Constant returns	24 (60.00)	1 (2.50)	18 (45.00)	9 (22.50)
Decreasing returns	13 (32.50)	39 (97.50)	18 (45.00)	30 (75.00)

Note: Figures in parentheses indicates the % to the total number of farmers in the category

In case of wheat cultivation, about half of the technology adopters (45 %) and only 22.50 % non-adopter farms were operated in the constant returns region i.e. these farms were performing at the optimal scale of production, whereas, only 10 % of laser leveled farms and 2.50 % of the non-laser leveled farms were found in the region of increasing return to scale i.e. they were performing below the optimum production scale. It is interesting to note that 75 % of the non-adopter wheat farms were operating in the decreasing return region of production frontier i.e. they could increase their technical efficiency by reducing the input use.

Technical Efficiency using DEA

To obtain the efficiency levels of each of the farms as decided by the physical inputs (quantities), DEA models, which are input-oriented, were used at different production scales under the assumption of constant returns to scale (CRS). After introducing convexity in the CRS model, the variable returns to scale (VRS) were estimated. By using the efficiency levels of the CRS and VRS models (termed as technical efficiency and pure technical efficiency), the scale efficiency for each farm was obtained. The results on efficiency measures (TE and PTE) and their comparison between adopters vs. non-adopters are given in Table 4. The technical efficiency of different inputs was computed individually to observe the individual efficiency effect of each respective input on the output. Further, the percentage difference of all the efficiency measures represents the efficiency level of adopters over non-adopters.

In paddy cultivation, the mean average technical efficiency score was 0.87 and 0.78 for adopters and non-adopters, respectively, of the technology, which indicated that laser leveled farms could reduce the use of inputs by up to 13 % of the present usage level, whereas; the non-laser leveled farms will have to reduce by up to 23 % to reach the optimum scale efficiency (Table 4).

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Table 4: Efficiency measures between each input and output in Punjab: A comparison between Adopters vs. Non-adopters

		Technical Efficiency	Pure Technical Efficiency	Scale Efficiency
Paddy				
	Water Use			
	Adopters	0.62	0.94	0.65
	Non-adopters	0.43	0.88	0.48
	% difference	30.26	6.41	25.36
	Total Hired Labour			
	Adopters	0.81	0.94	0.86
	Non-adopters	0.68	0.88	0.77
	% difference	16.03	6.59	10.18
	Fertilizer			
	Adopters	0.79	0.94	0.84
	Non-adopters	0.73	0.88	0.82
	% difference	7.60	6.10	1.71
	Total Machine Use			
	Adopters	0.61	0.94	0.63
	Non-adopters	0.43	0.88	0.48
	% difference	28.72	6.42	23.75
	Overall			
	Adopters	0.87	0.95	0.94
	Non-adopters	0.78	0.88	0.88
	% difference	10.16	7.21	6.34
Wheat				
	Seed			
	Adopters	0.87	0.95	0.92
	Non-adopters	0.81	0.88	0.92
	% difference	7.10	7.58	0.12
	Fertilizer			
	Adopters	0.91	0.95	0.94
	Non-adopters	0.82	0.87	0.94
	% difference	7.89	7.65	0.25
	Water Use			
	Adopters	0.71	0.95	0.74
	Non-adopters	0.58	0.88	0.66
	% difference	17.96	7.99	10.85
	Total Machine Use			
	Adopters	0.62	0.95	0.65
	Non-adopters	0.51	0.88	0.59
	% difference	17.06	7.94	9.91
	Overall			
	Adopters	0.95	0.96	0.97
	Non-adopters	0.86	0.89	0.97
	% difference	9.04	8.05	0.72

Note: The percentage difference represent the difference of technical efficiency of adopters over non-adopters

The difference of technical efficiency of adopters over non-adopters in machine-use was 28.72 %, whereas, this difference was highest in case of water-use (30.26 %) this shows that laser land leveling technology improves water-use efficiency and machine-use efficiency of paddy crop by 30.26 % and 28.72 %, respectively.

Similarly, in wheat cultivation, the mean average technical efficiency score was 0.95 and 0.86 for adopters and non-adopters, respectively, of the technology, which indicated that laser leveled farms were nearly efficient and could reduce the use of inputs by merely five % of the present usage level, whereas; the non-laser leveled farms will have to reduce by up to 14 % to reach the optimum scale efficiency (Table 4).

The perusal of Table 4 further revealed that the difference of technical efficiency of adopters over non-adopters in wheat cultivation was highest in water-use (17.96 %) followed by 17.06 % in machine-use, which clearly indicated that laser land leveling technology improves water-use efficiency and machine-use efficiency of paddy crop by 17.96 % and 17.06 %, respectively.

As regards to the scale efficiency in paddy and wheat production in Punjab, the results revealed that most of the farmers had pure technical efficiency score more than 90 % but technical efficiency scores ranging between 43 % to 95 % which implies they were individually efficient but globally inefficient due to their scale size. Likewise, Murthy *et al.*, 2009 suggested that there was potential to increase the output, production and efficiency through the application of more inputs. It had been found evident from the fact that the medium farmers could realize higher productivity largely due to use of higher level of inputs.

Frequency Distribution of water-use efficiency of sample farms

The results of the study clearly depicted that the majority of inputs used by sample farmers were almost similar or statistically at par except the water-use in both crops. Hence, the frequency distribution of technically efficient farmers' w.r.t water-use in paddy cultivation was presented in Table 5.

Table 5: Distribution of farmers according to the level of technical efficiency w.r.t water-use in the paddy cultivation, Punjab, 2011-12

Levels of technical efficiency (%)	Adopter	Non-adopter
Up to 30	0(0)	2(5)
30 – 40	1(2.5)	8(20)
40 – 50	4 (10)	21 (52.5)
50 – 60	13(32.5)	7 (17.5)
60 – 70	14(35)	2 (5)
70 – 80	7 (17.5)	0 (0)
80 – 90	0(0)	0 (0)
90 – 100	1 (2.5)	0 (0)

Note: Figures in parentheses indicates the % to the total number of farmers in the category

The perusal of Table 4 revealed that the majority of the technical efficient farmers (55 %) who had leveled their farms with laser leveler had the technical efficiency of equal to or more than 70 %. While

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majority of the farmers (77.5 %) who had not used laser leveler on their farms had water-use efficiency of less than 50 %. Thus, a larger proportion of the farmers who adopted the technology were in between the efficiency level of 60 to 70 %, whereas the non-adopters of the technology were less efficient. None of the non-technology adopter had water-use efficiency of more than 70 %.

Table 6: Distribution of farmers according to the level of technical efficiency w.r.t water-use in the wheat cultivation, Punjab, 2011-12

Levels of technical efficiency (%)	Adopter	Non-adopter
Up to 30	0 (0)	2 (5)
30 – 40	2 (5)	12 (30)
40 – 50	3 (7.5)	19 (47.5)
50 – 60	15 (37.5)	6 (15)
60 – 70	14 (35)	1 (2.5)
70 – 80	4 (10)	0 (0)
80 – 90	1 (2.5)	0 (0)
90 – 100	1 (2.5)	0 (0)

Note: Figures in parentheses indicates the % to the total number of farmers in the category

The perusal of Table 6 presented the frequency distribution of technical efficiency w.r.t water-use for adopters and non-adopters in wheat crop. The table showed that the majority of the adopters (37.5 %) in the study area had the technical efficiency ranged between 50 to 60 %. Whether, almost half of the non-adopters had the technical efficiency ranged between 40 to 50 %, showing the substantial change in efficiency with the adoption of laser land leveling technology. In the case of non-adopters, water-use efficiency started from the level of less than 30 % and ends up to 60 to 70 % efficiency level showing inefficiency with the non-adoption of laser land leveling technology

In the case of non-adopters, two farmers were less than 30 % efficient and no farmer had reached efficiency level of more than 70 %. The picture reversed in case of adopters of the technology. All the adopters had water-use efficiency of more than 30 % and even some of them were 95 % efficient.

Conclusion

Socio-economic profile of the farmers clearly revealed that the adoption of this technology was made by young, educated and progressive farmers. The adoption of laser land leveling technology resulted into water saving of 28 % and 12 % in paddy and wheat respectively. Further, the incremental increase in returns over variable cost was ₹ 3311 per ha in paddy crop, whereas it was ₹ 4268 per ha in wheat crop. In the case of technical efficiency, about 60.00 % of laser leveled paddy farms were found operating in the region of constant returns to scale that means more than half of the laser leveled farms had optimal efficiency level. The difference of technical efficiency of adopters over non-adopters in machine-use was 28.72 %, whereas, this difference was highest in case of water-use (30.26 %) this shows that laser land leveling technology improves water-use efficiency and machine-use efficiency of paddy crop by 30.26 % and 28.72 %, respectively. Therefore, to encourage the rapid adoption of this technology, there is need to strengthen Agro Service Centre in all co-operative societies, so that the timely availability of the laser leveler could be enhanced. Furthermore, subsidizing cost of laser leveling per acre will increase the area under laser leveling as the small and marginal farmers will go for its adoption.

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