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A Comparative Study of Parametric and Non-parametric Energy Use Efficiency in Paddy Production

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ABSTRACT

In the present study an attempt has been made to use a non-parametric method Data Envelopment Analysis (DEA) for assessing source-wise and operation-wise the Technical Efficiency (TE) and Return-to-Scale (RTS) for paddy production in four zones of the state of Punjab, India. The results were then compared to corresponding ones already obtained from a parametric method (Cobb-Douglas production function). The data from farmers growing rice in four zones including labor-h, machine-h, power source, horse power and hours used, kind of machinery used, physical inputs such as seed, fertilizers and pesticides (as inputs) and the yield (as output) were transformed into energy terms (MJ ha^{-1}). The results revealed that farmers in zone 2 with a source-wise TE of 0.91, have consumed energy from more efficient sources, followed by zone 4 (0.90) and then zones 3 and 5 (0.85). No significant correlation could be established between the parametric and non-parametric *TE* for source-wise energy inputs. According to the DEA results, it was observed that 55.6% and 64.1% of inefficient farmers had an increasing *RTS* for operation-wise and source-wise energy inputs, respectively. However, a constant *RTS* had been reported by the parametric frontier function.

Keywords*:* Data envelopment analysis, Energy efficiency, Paddy, Pure technical efficiency, Return-to-scale, Scale efficiency, Technical efficiency.

INTRODUCTION

Paddy production is one of the energy intensive production systems as reported by Singh *et al.* (1990). Mythili and Shanmugam (2000) conducted a study to measure the farm level technical inefficiency that can be a dominant factor in explaining the difference between potential and observed yields of rice at a given technology and input level. The Cobb-Douglas stochastic frontier function with input costs and a single-output was used as the production function. Data were gathered from states that have been classified into six zones according to agro-climatic factors such as rainfall, irrigation pattern and soil characteristics for the three years 1990-91, 1991-92 and 1992-93. The mean value of Technical Efficiency (TE) in Tamil Nadu was 82 percent for rice. This meant farmers could not technically use 18% of their inputs during crop production. According to the results, small farmers (below 1 hectare of land), who made up 16% of the sample size in all zones, had the lowest mean *TE* value (79.64%). The maximum mean *TE* (84.27%) was reported for farmers with 4 to 6 hectares land holdings. In addition to location and size-class factors, various socio-economic characteristics of farmers might cause differences in *TE*.

Bakhshoodeh and Thomson (2001) measured the *TE* of wheat producers in Kerman Province, Iran by using the Cobb-Douglas frontier function. It was found that

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the level of inefficiency was a function of farm size. In his research work, Singh (2001) fitted the Cobb-Douglas frontier for data on major crops (wheat, paddy, maize and cotton) in different agro-climatic zones of Punjab State (India) in the years 1997-1999. A relationship was established between yield (kg) as an output variable and energy inputs (MJ) for both operation-wise and source-wise conditions. During this study, both the *TE* and sensitivity of function were measured. The mean values of energy inputs revealed that the energy use patterns in different zones were different. This was due to differences in combination of farmers with various farm sizes, differences in the time of operations, diversity of technological level as well as uncontrollable conditions. There was a difference between the average efficiency in operation-wise and source-wise for all crops.

Manes and Singh (2003) used the Cobb-Douglas frontier function to estimate the Return-to-Scale (RTS) as well as *TE* of rice farmers in zones 2, 3 and 4 in Punjab State (India). They found that a constant *RTS* prevailed in all of the zones. It was also observed that 96.6% of farmers in zone 2 had *TE* more than 0.90. For zones 3 and 4, the *TE* was 43.6% and 12.2%, respectively. Overall results showed that farmers in zone 2 had the highest *TE* with a mean value of 0.947 as compared to 0.901 and 0.823 for zones 3 and 4, respectively. However, the stochastic frontier function has another feature for *RTS* as reported by Chiang *et al.* (2004). A study on 433 aquaculture milkfish farms using the Cobb-Douglas production function showed that milkfish farming exhibited diminishing *RTS*. The elasticity of inputs provided helpful information on how to reallocate input sources among farmers for helping them to raise productivity and *TE*.

The *TE* of meat sheep production systems in Spain were calculated using the Cobb-Douglas average frontier function (Perez *et al.,* 2007). The elasticities (relationship coefficients) showed that the sheep sector was more labor than capital intensive. Moreover, the sum of elasticities was significantly equal to unity at 5% level of significance; this implied that all farms are characterized by constant *RTS*.

Chauhan *et al.* (2006) used the Data Envelopment Analysis (DEA) approach to determine the efficiency of farmers in West Bengal (India). It was found that 37% of farmers have efficiently used energy from different sources when the BCC model was imposed on data. The results of the CCR model indicated that only 15.5% of farmers were efficient. The difference between efficiency of farmers for both models was described by new term Scale Efficiency (SE). Results of the *RTS* depicted that all BCC efficient farmers were operating at a constant *RTS*, whereas all inefficient ones exhibited a decreasing *RTS*.

The comparison between Chauhan's results (2006) and the results of Singh (2001) and Manes and Singh (2003) indicated that DEA established better conditions for classifying the farmers into different groups of *RTS*. Also, decomposition of *TE* in Chauhan's study was another merit of his work. However, Chauhan's study was only carried out on the basis of source-wise energy inputs. He recommended that a more precise conclusion could be obtained when the efficiency of source-wise and operation-wise energy inputs are considered simultaneously.

In the present study, an attempt has been made to develop the DEA method to estimate the efficiency and *RTS* conditions of farmers in different agro-climatic zones of Punjab state (India) and, then, to compare the findings with corresponding results that had been already reported by Manes and Singh (2003) using parametric frontier functions.

MATERIALS AND METHODS

The raw data for farmers growing rice in four zones of Punjab State, which had been collected by the structural questionnaire method, were taken from the "All India

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Coordinated Research Project on Energy Requirement in the Agriculture Sector", Department of Farm Power and Machinery, PAU, Ludhiana, for the years 1997-2000. The data were labor-h, machine-h, power source and horsepower and hours used, kind of machinery used, physical inputs such as fertilizers and pesticides, and the yield. The data was then transformed into energy terms (MJ ha^{-1}) by applying the appropriate conversion factors (Singh *et al*., 1996). Tillage, transplanting, irrigation, weeding, fertilizer application, spraying and harvesting (including threshing) were operational energy inputs and human, diesel, electricity, machinery, fertilizers and chemicals (aggregated) were source-wise energy inputs. Data were applied to input-oriented CCR and BCC models of DEA by using the DEA solver (Professional Release 4.1, Kluwer Academic Publishers, USA) to work out the *TE*, Pure Technical Efficiency (PTE) and *SE* as well as *RTS* of the farmers. The existence of significant difference among the aforementioned parameters in different zones was assessed by the non-parametric Kruskal-Wallis statistic (Siegel and Catellan, 1988). The SPSS software (SPSS for windows, release 12, SPSS Inc., 2003) was used to draw out and evaluate the descriptive information for data.

Input-oriented CCR and BCC Models

The CCR and BCC models, which were initially proposed by Charnes, Cooper and Rhodes (CCR model) (Charnes *et al*., 1978) and Banker, Charnes and Cooper (BCC model) (Banker *et al.,* 1984), respectively, are two most famous DEA models. Figure 1 shows these two envelop lines (frontiers) together. The dot line that passes through the origin and cuts the extreme data point is called the CCR envelopment line (CCR frontier). Inefficient Decision Making Units (DMUs) are below this line. The BCC frontier comprises of several piece-wise lines by which some extreme DMUs are connected together (broken-solid line). This envelop is representative of BCC efficient DMUs, and inefficient DMUs are set below the convex hull. One version of the CCR model which is called the input-oriented model, aims to minimize inputs while satisfying at least the given output levels. As shown in Figure 1, point *E* is representative of an inefficient DMU. The projection of *E* on the CCR frontier (E_1) represents the efficient position of *E* through the input-oriented model. Because farmers (DMUs) have control over their inputs and, on the other hand, the output (here yield) is affected by some uncontrollable factors such as weather conditions or variation in soil fertility, the input-oriented model was selected and used in this study (Chauhan *et al*., 2006; Cooper *et al*., 2004; Fraser and Cordina, 1999). Likewise, the efficiency of E can be measured by the input-oriented BCC model (projected point E_2).

Technical, Pure and Scale Efficiencies

Suppose there is an inefficient (Both CCR and BCC) DMU with one input and one output like point E in Figure 1, this DMU can be defined by $x= OO_2= O_1E$ and $y= O_2E= OO_1$. The line O_1E has intersections with the OM (CCR frontier) and BC (BCC frontier) lines at E_1 and E_2, respectively. So various efficiencies can be defined as:

Technical efficiency= O_1E_1/O_1E (1

Pure technical efficienc = O_1E_2/O_1E (2

Scale efficiency= O_1E_1/O_1E_2 (3

Cooper *et al.* (2004) expressed a relationship among these parameters as:

Technical efficiency= Pure technical efficiency × Scale efficiency (4

At point B (Figure 1) the value of *TE* is equal to *PTE*, namely, the value of *SE* is unity. The *TE* can be measured by the CCR model whereas *PTE* efficiency by the BCC model. In other words, the CCR model simultaneously evaluates *SE* and *PTE*, while the BCC model separates out the *SE* for precise evaluation (Banker *et al*., 1984).

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Return-to-Scale

The dy/dx mathematically defines the tangent to production function, economically called Marginal Productivity (MP). The value of *y/x* in economics terms is called Average Productivity (AP). The maximum value of *y/x* is achievable whenever the ratio of $\frac{x(dy)}{y(dx)} = e(x) =$ 1; this is called elasticity in economics. In other words, proportional change in output is equal to proportional change in input. It can be rearranged to $\frac{(dy/y)}{(dx/x)} = 1$. This equation represents *RTS*. The law of *RTS* explains the behavior of output in response to a proportional and simultaneous change in all inputs (Dwivedi, 2005). Keeping the above definition in the mind, when *e(x)= 1* is called Constant Return-to-Scale (CRS), *e(x)>1* is called Increasing Return-to-Scale (IRS) and *e(x)< 1* is called Decreasing Return-to-Scale (DRS). The concept of *RTS* can be extended from parametric to DEA, especially for the BCC model. As it is portrayed in Figure 1, the CCR model can act like the tangent of the production function, which passes though the origin. This model is recognized as the CRS model but the BCC model definitely has different *RTS* parts at one time because of its piece-wise lines form.

The CCR and BCC models were subjected to data in two stages. At the first stage, data of same zones for three successive years were used in the model and more efficient data were chosen for the second stage, so that there were four selected zones and 175 farmers. Selected data were subjected to the CCR and BCC models and the pre-discussed parameters were determined. Zone-wise mean value of energy inputs and productivity of selected data are summarized in Table 1.

Parametric Method

Singh (2001) and Manes and Singh (2003)

Table 1: Energy use (MJ ha^{-1}) and productivity of rice growing farmers in different agro-climatic zones.

Item	Zone 2	Zone 3	Zone 4	Zone 5
	Operation-wise Energy (MJ ha^{-1})			
Tillage	1254	1599	1804	1576
Transplanting	738	264	240	965
Irrigation	5438	8214	20904	13864
Weeding	110	72	2.4	132
Fertilizer application	12	337	11	18
Spraying	0	24	60	25
Harvesting	861	1078	1119	1171
Total	8415^{a}	11588^{b}	24160^{c}	17751^{d}
	Source-wise Energy (MJ ha^{-1})			
Human	1387	850	967	867
Diesel	2603	5626	5168	5810
Electricity	4888	5214	17249	8693
Machinery	839	853	1148	918
Fertilizers & chemicals	8371	10286	11794	8716
Total	18088^{a}	22829^{b}	36326^{c}	25006^{b}
Yield (kg/ha)	7122^{a}	6495^{b}	6344^{b}	6265^{b}
Cropped area (ha)	2.1^{a}	3.4^{ab}	6.2^{c}	3.6^{b}
Number of farmers	30	44	56	45

Different letters (a, b and c) show significant difference among groups at 5% level of significance.

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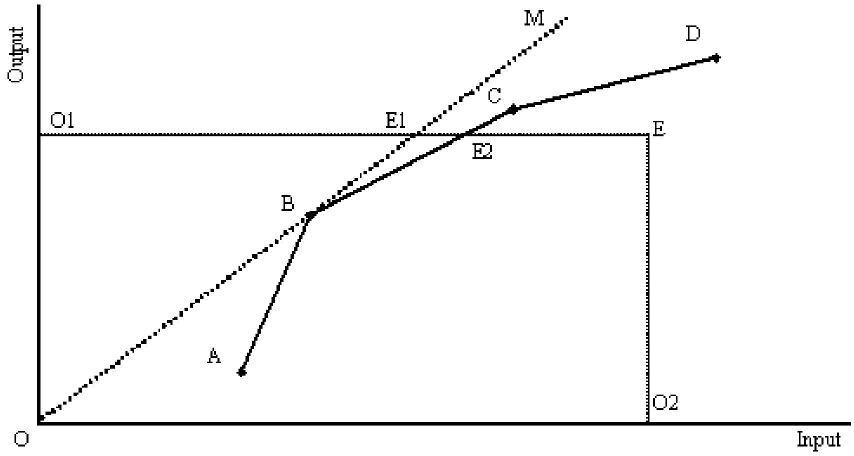

Figure 1. Input-oriented CCR(Charnes, Cooper and Rhodes) and BCC(Banker, Charnes and Cooper) models (one input-one output).

employed the Cobb-Douglas production function for evaluating the same data set. The *RTS* value was obtained by summing up all regression coefficients ($\sum_j \beta_j$) engaged in the equation. It is clear that all farmers follow a *RTS* condition. Technical efficiency has been calculated by the following equation:

$$TE_i = exp(\frac{u_i - u_{max}}{\sum_j \beta_j})$$

where, u_i is the error term in estimation of production of i^{th} farmer, u_{max} is the maximum positive error term and j is the number of regression coefficients.

RESULTS AND DISCUSSION

Return-to-scale

The information on whether a farmer operates at *IRS*, *CRS* or *DRS* is particularly helpful for redistributing resources, and thus enables him to attain the higher yield levels. Table 2 shows the frequency distribution of *RTS* among inefficient (projected) farmers, who have been projected on the BCC model, as well as efficient farmers. Most of the efficient farmers (58.5% operation-wise and 63.8% source-wise) followed the *CRS* portion of the frontier, while projected (inefficient) farmers laid on the *IRS* portion (55.5% operation-wise and 64.1% source-wise). Zone 5 had the highest number of *CRS* efficient farmers (88.8%) as compared to others for operation-wise energy inputs, followed by zone 2 (81%), zone 3 (67.9%) and zone 4 (11.1%). However, zone 5 had the least number of efficient farmers (19.1 %). It is clear that zone 2 had less inefficient farmers (11.2%) with 88.8% of the *IRS* condition. The *CRS* inefficient farmers had more of a share in zone 5 (62.9% of total). Source-wise pattern was almost different. While zone 2 had the highest share of the efficient farmers in operation-wise energy inputs, zone 3 had the same situation in source-wise with the share of 38.6%, and 58.8% of efficient farmers followed the *CRS* pattern. Thus, farmers in zone 5 accordingly exhibited lower efficiency compared with farmers in other zones. A few among efficient and inefficient farmers (except in zone 5) laid on the *DRS* portion and practiced more inputs, but could not necessarily obtain the proportionate value of output. It is interesting to note that the *IRS* efficient farmers still had unstable position due to low *SE* with respect to *CRS* efficient ones.

Manes and Singh (2003) reported that all paddy growers in different agro-climatic zones obeyed *CRS* when *RTS* was measured

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Table 2: Frequency distribution of return-to-scale of efficient and inefficient rice growing farmers in different zones.

	Efficient farmers				Inefficient farmers				
	IRS [a]	*DRS* [b]	*CRS* [c]	Total	*IRS*	*DRS*	*CRS*	Total	Grand total
Zone	Operation-wise								
2	4	-	17	21	8	-	1	9	30
3	9	-	19	28	14	-	2	16	44
4	5	19	3	27	16	7	6	29	56
5	1	1	16	18	7	3	17	27	45
Total	19	20	55	94	45	10	26	81	175
	Source-wise								
2	-	3	7	10	10	1	9	20	30
3	6	1	10	17	26	-	1	27	44
4	2	2	14	18	28	5	5	38	56
5	2	5	6	13	11	15	6	32	45
Total	10	11	37	58	75	21	21	117	175

[a] Increasing Return-to-Scale; [b] Decreasing Return-to-Scale, [c] Constant Return-to-Scale.

by parametric frontier function. The *RTS* values were 1.042, 1.023 and 0.972 for zones 2, 3 and 4, respectively. A variation can be seen among these values, however it was reported that this variation did not differ statistically from unity at the 5% level of significance. The DEA classified efficient and inefficient (projected) DMUs into different *RTS* groups. DEA gave more precise response to assessing the *RTS* conditions for redistributing the energy sources among farmers.

Technical, Pure Technical and Scale Efficiencies

Table 3 shows the frequency distributions of *TE* and *PTE* for different agro-climatic zones. About 23.3% of farmers in zone 2 acted as CCR efficient DMUs and increased to 33.3% when measured by the BCC efficient frontier (source-wise). One-third of farmers had *TE* in the range of 0.9-1.0 for using source-wise energy inputs and 23.3% were efficient. In the BCC model nearly 53.3% of farmers had efficiency in the range of 0.9-1.0 and 27% were efficient. It was observed that most of the farmers in zones 2 and 4 followed the same pattern of energy use and accumulated near the BCC efficient frontier. Zone 2 was more efficient (operation-wise) than others due to a higher number of efficient farmers. The share of efficient farmers were 56.7% and 70% in CCR and BCC models, respectively. It is obvious that the majority of farmers were efficient in both models. The frequency distribution of efficiencies for operation-wise and source-wise energy inputs showed that farmers technically applied energy inputs in operations more efficiently than source-wise. It can be concluded that farmers distributed the energy inputs among operations more homogeneously than depleting the energy from different energy sources.

Table 4 reveals the average *TE*, *PTE* and *SE* of farmers. Operation-wise *SE* showed that farmers in zone 3 lost energy more than in other zones due to the inappropriate size of farms. Low *TE* in zone 3 pertained to low *SE* (inappropriate size of farms), whereas for farms in zone 5 it was related to low *PTE* (inappropriate technical use of energy). Consequently, for optimization purposes the techniques are accordingly different. For instance, farmers in zone 3 need to schedule a long-term program for improving farm sizes and then redistribute the energy,

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Table 3: Frequency distribution of technical and pure technical efficiency of rice growing farmers in different zones.

Zone	Efficiency	Efficiency scores range < 0.6	0.6 - 0.7	0.7 - 0.8	0.8 - 0.9	0.9 - 1	Efficient	Total
				Operation-wise				
2	Technical	-	-	-	3	10	17	30
	Pure technical	-	-	-	-	9	21	30
3	Technical	-	1	2	9	13	19	44
	Pure technical	-	-	-	4	12	28	44
4	Technical	-	-	4	14	19	19	56
	Pure technical	-	-	2	7	19	28	56
5	Technical	-	1	10	12	6	16	45
	Pure technical	-	-	8	13	6	18	45
				Source-wise				
2	Technical	-	-	3	10	10	7	30
	Pure technical	-	-	-	4	16	10	30
3	Technical	-	2	18	9	5	10	44
	Pure technical	-	-	2	12	13	17	44
4	Technical	-	-	9	17	16	14	56
	Pure technical	-	-	-	23	15	18	56
5	Technical	-	1	15	14	9	6	45
	Pure technical	-	-	11	16	5	13	45

whereas farmers in zone 5 need only to redistribute the energy. Similarity, source-wise low *TE* of farmers in zones 3 and 5 was due to both low *PTE* and *SE* in zone 3 and low *PTE* in zone 5.

Manes and Singh (2003) worked out that farmers in zones 2, 3 and 4 had an average parametric source-wise *TE* of 0.947, 0.901 and 0.823, respectively. The results in Table 4 reveal that the mean value of source-wise *TE* (DEA approach) has a different trend, so that a very weak correlation (r= 0.0083) was obtained between parametric and non-parametric sets of *TE* pairs. In addition, different *TE* rating trends were observed for farmers these two methods as shown in Table 5. It can be concluded that decision making for optimizing and redistributing the energy inputs is accordingly different. Singh (2001) and Manes and Singh (2003) concluded that *TE* was independent of farm size under the crop for different zones. Results in Table 4 showed that there were variations among *SE* of farmers in different zones, and differences were significant at a 1% level of significance. It means that the size of farms had an effect on the *TE* scores. This difference between parametric and non-parametric methods may refer to precise decomposition of *TE* by the DEA method.

Table 4: Technical, pure and scale efficiency of rice growing farmers in different zones.

Efficiency	Zone2	Zone 3	Zone 4	Zone 5
		Operation-wise		
Technical (CCR)	0.97±0.04	0.93±0.08	0.92±0.08	0.89±0.10
Pure technical (BCC)	0.98±0.02	0.97±0.04	0.96±0.05	0.91±0.10
Scale	0.98±0.02	0.95±0.05	0.97±0.04	0.98±0.03
		Source-wise		
Technical (CCR)	0.91±0.07	0.85±0.11	0.90±0.09	0.85±0.10
Pure technical (BCC)	0.95±0.05	0.94±0.06	0.93±0.06	0.88±0.10
Scale	0.95±0.05	0.91±0.08	0.96±0.04	0.97±0.04

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Table 5: Technical efficiency rating (%) of framers in different agro-climatic zones (source-wise).

Zone	Efficiency	Efficiency scores range				
		< 0.6	0.6 - 0.7	0.7 - 0.8	0.8 - 0.9	0.9 - 1
		Non-parametric (DEA)				
2	Technical	-	-	10	33.3	56.7
3	Technical	-	4.5	40.9	20.5	34.1
4	Technical	-	-	16.0	30.4	53.6
		Parametric				
2	Technical	-	-	-	3.4	96.6
3	Technical	-	-	-	56.4	43.6
4	Technical	-	4.1	34.7	49.0	12.2

CONCLUSIONS

Farmers in zone 2 had the highest *TE* (0.91) followed by zones 4 (0.90), zones 3 and 5 (each 0.85). The value of *SE* was highest in zone 5 (0.97) followed by zone 4 (0.96), zone 2 (0.95) and zone 3 (0.91). A low *TE* score may be influenced by *PTE* (inappropriate amount of energy inputs in zone 5), by *SE* (inappropriate farm size in zone 3) or by both of them. This is the merit of the DEA approach to decompose the *TE* into *PTE* and *SE*. However, there was no correlation between *TEs* measured by the parametric and non-parametric (DEA) approaches. Also, in contrast to the parametric method on which a *CRS* condition was assigned to all efficient production function; DEA exhibited the merit of variable *RTS*. About 58.5% and 63.8% of the efficient farmers followed *CRS* in operation-wise and source-wise energy inputs, respectively, whilst 55.6% and 64.1% of inefficient farmers correspondingly had *IRS* for operational and source-wise energy inputs. It is a powerful tool for enhancing the decision makers of managers while optimizing the systems.

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مقایسه دو روش پارامتری و غیر پارامتری راندمان مصرف انرژی در تولید شلتوک

س. م. نصیری و س. سینگ

چکیده

برای تعیین تابع تولید دو روش پارامتری و غیر پارامتری معمول و مرسوم است. تابع پارامتری کب-داگلاس روش شناخت شده ای برای تعیین کارایی و بازگشت به مقیاس است. مطالعه حاضر کارایی و بازگشت به مقیاس برنج کاران در چهار منطقه ایالت پنجاب هند را با استفاده از روش غیر پارامتری تحلیل پوششی داده ها محاسبه نمود. نتایج این پژوهش با نتایج حاصل از روش پارامتری که قبلا با داده های مشابه گزارش شده بود مورد مقایسه قرار گرفت. نتایج نشان داد که کشاورزان منطقه ۲ با داشتن متوسط کارایی منبع محور ۰/۹۱ نسبت به سایر مناطق از راندمان بالایی برخوردار بودند. کشاورزان منطقه ۴ (۰/۹۰)، منطقه ۳ و ۵ (هرکدام ۰/۸۵) در رتبه های بعدی قرار گرفتند. مقدار راندمان مقیاسی نشان داد که ۳ درصد انرژی هنگام استفاده از منابع انرژی توسط زارعین در منطقه ۵، چهار درصد در منطقه ۴، پنج درصد در منطقه ۲ و نه درصد در منطقه ۳ بهدر رفته است. همچنین بین کارایی منبع محور برنج کاران در دو روش پارامتری و غیر پارامتری همبستگی مشاهده نشد. نتایج روش غیر پارامتری نشان داد که به ترتیب ۵۵/۶ درصد و ۶۴/۱ درصد از زارعین کم کارا در آزمونهای عملیات محور و منبع محور دارای بازگشت به مقیاس صعودی بودند. این در حالی است که بازگشت به مقیاس ثابت برای این دسته از زارعین باروش پارامتری گزارش شده بود.

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