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Fertilizer Usage and Technical Efficiency of Rice Farms under Tropical Conditions: A Data Envelopment Analysis (DEA)

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ABSTRACT This study employed an output-oriented DEA approach to evaluate the impact of fertilizer usage on the technical efficiency of rice farms in Kogi state, Nigeria. Results suggest that rice farms with fertilizer could expand output potentially by 74 percent and 61 percent as compared to 77 percent and 66 percent for rice farms without fertilizer under constant returns to scale and variable returns to scale respectively. This can be achieved without altering the quantities of inputs used. Furthermore, the corresponding average scale efficiency of 77 percent and 79 percent for rice farms with and without fertilizer respectively suggests that by operating on an optimal scale, a further increase in output can be realized beyond the projected values by as much as 23 percent and 21 percent correspondingly. Thus, rice farmers should be encouraged to adopt optimum fertilizer rate in order to achieve increase in rice production. This can be accomplished through education, proper execution of fertilizer price subsidy as well as early distribution of fertilizer to farmers.

INTRODUCTION

Rice is one of the major staple crops in Nigeria and the fourth major cereal in Nigeria after maize, sorghum and millet (Babafada 2003). It is grown virtually in all the agro-ecologies of Nigeria with over 4.0 million hectares of land suitable for rice cultivation, but only about 2.0 million hectares is currently being cultivated (Abubakar 2003). Its production in the country rose from 2.4 million metric tonnes in 1994, to 3.9 million metric tonnes in 2005 (CBN 2006). In spite of the increase in production of about 1.8 percent, the demand for rice surpasses supply (Adeoye 2003; Ojehomon et al. 2004). Consequently, the country has been importing to bridge the supply-demand gap. Considering its vast agricultural land and suitable ecology, Nigeria is endowed to produce enough rice to satisfy domestic demand and has the potential to export to other countries (Babafada 2003). However, domestic rice production has not increased sufficiently to meet the increased demand despite the various policy measures put in place to facilitate production. Thus, the inability of the Nigeria rice sector to match the domestic demand have raise a number of important questions both in policy circle and among researchers (Okuruwa et al. 2009). According to Okuruwa et al. (2009), the issue of efficiency of the rice farmers in the use of resources is central to explaining why domestic rice production lags behind the demand for the commodity in Nigeria. Since increased productivity is directly related to production efficiency, it is very important to raise productivity of the farmers. In order to increase productivity, Nigeria agriculture needs to embrace the used of fertilizer, improve seeds and crop protection products given that land expansion is limited (Ayinde et al. 2009). Given the importance of fertilizer in enhancing productivity, the Nigerian government over the years has embarked on several policies to encourage the use of fertilizer. Notwithstanding the various reforms and policy introduced by the federal government to encourage the use of fertilizer, farmers are yet to adopt the optimum fertilizer rate (Ayinde et al. 2009). In view of the fact that increase output and productivity are directly or indirectly related to fertilizer use, the study becomes of essence, as it would examine the impact of fertilizer on technical efficiency in rice production among rice farmers. This would then provide significant insight for policy formulation. While considerable efforts have been directed at examining productive efficiency of farms in Nigeria (Ojo 2004; Ogundari and Ojo 2005), little attention has been given to measuring the impact of specific input use such as fertilizer which constitutes a major part of crop production in Nigeria.

Thus, the main objective of this paper is to analyze the impact of fertilizer usage on the technical efficiency of rice farms in Kogi state, Nigeria. The specific objec-tives of the study are: (i) evaluate the technical efficiency levels of rice farms with and without fertilizer; and (ii) evaluate the scale efficiency levels of rice farms with and without fertilizer.

METHODOLOGY

Analytical Framework

In this study, the Data Envelopment Analysis (DEA) method was chosen because of its ability to readily produce rich information on technical and scale efficiency. DEA is a non-parametric mathematical programming technique that presents a particularly suitable way to decompose efficiency into pure technical and scale aspects and therefore facilitates the examination of economies of scale. The DEA technique does not require a specific functional or distributional form, and can accommodate scale issues. A large number of studies have extended and applied the DEA technology in the study of efficiency worldwide. DEA models can be either output or input oriented. The input-oriented model measures the quantities of inputs that can be reduced without any reduction in the output quantity produced. On the other hand, output-oriented model measures the degree to which output quantity can be increased without any change in the quantities of inputs used. However, the relative range of the efficiency scores remains the same whether input-oriented or output-oriented method is employed. The output oriented models can be either constant returns-to scale (CRS) or variable returns-to-scale (VRS). This study used both constant returns to scale (CRS) and variable returns to scale (VRS) models with output orientation, in which the ability to produce maximum output from given quantities of input is the main goal.

Technical Efficiency

Technical efficiency is the ability of a firm to produce the maximum possible output from a given combination of inputs and technology. Technical efficiency may be split into pure technical efficiency and scale efficiency, in other words, the nature of technical inefficiencies can be due to the inefficient implementation of the production plan in converting inputs to outputs (pure technical inefficiency) and/or due to the deviation of the decision making units (DMUs) from the most productive scale size (scale inefficiency). Following Coelli et al. (1998), the linear programming models for the output oriented measure of technical efficiency under the assumption of constant returns to scale for the rice farms is given as:

$$\begin{aligned}&\min_{\phi,\lambda} \phi,\\ &\text{st} - \phi y_i + Y\lambda \geq 0,\\ &x_i - X\lambda \geq 0,\\ &\lambda \geq 0 \quad \text{.......... (1)}\end{aligned}$$

It is assumed that the constant returns-to-scale (CRS) model specified in equation (1) is only appropriate where all rice farms are operating at an optimal scale. Where this assumption does not hold, scale effects will confound the measures of technical efficiency (Coelli et al. 1998). Therefore, following Banker et al. (1984), the CRS model was reformulated by imposing a convexity constraint, to equation (1) $N_1 2\ \lambda = 1$. The specification is given below:

$$\begin{aligned}&\min_{\phi,\lambda} \phi,\\ &\text{st} - \phi y_i + Y\lambda \geq 0,\\ &x_i - X\lambda \geq 0,\\ &N_1 \lambda = 1\\ &\lambda \geq 0 \quad \text{.......... (2)}\end{aligned}$$

Where $N_{1,}$ is a vector (n x 1). $1 \leq \phi < \infty$ and ϕ - 1 is the proportional increase in output that could be realized by the ith farm with input quantities held constant. It will be obtained for each rice farm. Y and X are output and input, respectively. Banker et al. (1984) recommended the use of variable returns to scale (VRS) that decomposes technical efficiency into pure technical efficiency and scale efficiency. Pure technical efficiency is calculated relative to the variable returns to scale assumption. The measure of technical efficiency obtained in the model with variable returns is also named as 'pure technical efficiency', as it is free of scale effects. Where yi is a vector (m x 1) of rice output of the ith farm, xi is a vector is a vector of (k x 1) of inputs of the ith farm, Y is the rice output matrix (n x m) for n farms, X is the rice input matrix (n x k) for the n farm. Note that $1/\phi$ defines an output-orientated technical efficiency score that varies between zero and one (Coelli et al. 1998).

Scale Efficiency

Once there are variations between the values of efficiency scores in the CRS and VRS models, scale inefficiency is established, indicating that the return to scale is inconsistent, that is, it can be increasing or decreasing (Färe and Grosskopf 1994). Scale inefficiency occurs if the firms do not operate at constant returns to scale. Therefore, it is important for firms to operate at CRS for optimal production. In measuring scale efficiency**,** constant returns to scale (technical efficiency), and variable returns to scale (pure technical efficiency) were first estimated. Scale efficiency was then estimated by dividing a CRS estimate of technical efficiency by a VRS estimate of technical efficiency. The scale efficiency (SE) of the *i*th rice farm is given as:

$$SE_i = TE_i^{CRS}/TE_i^{VRS} \quad (3)$$

Where TE_i^{CRS} is technical efficiency for the model with constant returns to scale and TE_i^{VRS} is technical efficiency for the model with variable returns to scale. Scale efficiency can vary between zero and one in value. A scale efficiency score of one indicates that the firm is operating at an optimal scale that is CRS. As mentioned earlier, scale inefficiency is usually a result of increasing or decreasing returns to scale (Sharma et al. 1996). So to find out whether a rice farm is operating in an area of increasing returns to scale or decreasing returns to scale, an additional linear programming is introduced, that is, the convexity constraint in equation (2), $N_1\lambda = 1$, is replaced with $N_1\lambda \leq 1$ for the case of non-increasing returns and $N_1\lambda \geq 1$ for the case of non-decreasing returns. The models were estimated using the DEAP version 2.1 with output orientation option to obtain the efficiency levels for the rice farms.

Data Set and Variables

Data for this analysis comes from a cross sectional survey of rice farms conducted in Kogi state (Ataboh 2007). Output (Y) represents rice production (kg/ha) and inputs; x1, x2, x3, x4 and x5 representing farm size (hectare), cost of labour (Naira), cost of fertilizer (Naira), cost of seeds (Naira), and cost of pesticides (Naira) respectively. The outline of output and inputs used in rice production among different categories of rice farms, that is, rice farms with fertilizer and rice farms without fertilizer in Kogi state is presented in Table 1. The mean output of rice realized by rice farms with fertilizer was 4035.03 kg/ha as compared to 2450.7kg/ha for rice farms without fertilizer (Table 1). The higher output from rice farms with fertilizer could be attributed to higher levels of inputs used by this category of farms.

RESULTS AND DISCUSSION

Technical Efficiency Scores

Employing the out-oriented DEA under constant returns to scale (CRS) and variable returns to scale (VRS) models, technical efficiency and scale efficiency for each rice farm were estimated. The summary statistics for technical efficiency under constant returns to scale (CRS), technical efficiency variable returns to scale (VRS) and scale efficiency are presented in Table 2 for rice farms with and without fertilizer respectively. The mean technical efficiency (CRS), technical efficiency (VRS) and scale efficiency for rice farms with fertilizer were 0.26 (26%), 0.39 (39%) and 0.77 (77%), respectively. On the other hand, the mean technical efficiency (CRS), technical efficiency (VRS) and scale efficiency for rice farms without fertilizer were 0.23 (23%), 0.34 (34%) and 0.79 (79%), respectively. These results suggest that rice farms with fertilizer could potentially expand output by 74 percent and 61 percent as compared to 77 percent and 66 percent for rice farms without fertilizer without altering the input quantities used. These results thus show that fertilizer does have an impact on the efficiency of rice output. Furthermore, the corresponding mean scale efficiency of 77 percent for rice farms with fertilizer and 79 percent for rice farms without fertilizer suggests that by operating on an optimal scale a further increase in output can be achieved beyond their projected value by as much as 23 percent and 21 percent respectively. This implies that there is room for additional increase in domestic rice output from existing hectares

Table 1: Summary statistics of variables used in the analysis

Variables	*Rice farms with fertilizer (n=100)*				*Rice farms without fertilizer (n=100)*			
	Mean	*Std. Dev.*	*Min*	*Max*	*Mean*	*Std. Dev.*	*Min*	*Max*
Y	4035.03	3313.7	300	30000	2450.7	2250.9	220	21000
x1	206.7	284.3	13.8	2100	166.7	166	10.3	1472.7
x2	35531	29581.6	3000	250000	25406.5	16845.9	5000	100000
x3	14402.5	8720.5	5000	55000	0.0	0.0	0.0	0.0
x4	11677	14370.5	1000	125000	7141	6155.4	1000	50000
x5	10244.5	11853.2	700	79500	3169	1606.9	950	6600

Note: n = Number of farms

Table 2: Summary statistics of efficiency measures and number of efficient rice farms

Efficiency measure	*Efficient farms*	*Mean*	*Std. Dev.*	*Min*	*Max*
Rice Farms With Fertilizer					
Technical efficiency (under CRS)	5	0.26	0.23	0.02	1
Technical efficiency (under VRS)	17	0.39	0.32	0.02	1
Scale efficiency (SE)	8	0.77	0.25	0.12	1
Rice Farms Without Fertilizer					
Technical efficiency (under CRS)	2	0.23	0.16	0.01	1
Technical efficiency (under VRS)	12	0.34	0.28	0.01	1
Scale efficiency (SE)	6	0.79	0.2	0.12	1

if efficiency of rice production is enhanced. This observation is in agreement with Ataboh (2007) and Okuruwa et al. (2009). Although the above results show that rice farms with fertilizer were more efficient, the technical and scale efficiency scores did not differ much from the corresponding estimates for rice farms without fertilizer. This could probably be attributed to under utilization of fertilizer by the rice farmers. This is in agreement with Ayinde et al. (2009) who reported that farmers in Nigeria are yet to adopt the optimum fertilizer rate. Thus, embracing the use of fertilizer alone may not be the key to increasing rice production levels in Nigeria if farmers are not encourage to adopt the optimum fertilizer rate. This can be accomplished through farmers' education as some studies on farming performance have shown (Llewelyn and Williams 1996; Dhungana et al. 2004).

In addition, it was observed that only 5 rice farms with fertilizer under CRS assumption were efficient. However, when the assumption of CRS was relaxed and the VRS model was estimated, the impact on technical efficiency was more evident as the number of efficient farms rose to 17 (Table 2). This improvement from the VRS model was mainly due to the inclusion of scale efficiency, which the CRS model did not take into account (Murthy et al. 2009). As regards to scale efficiency, only 8 farms were found to be efficient.

Returns to Scale

This section reports on the nature of scale with which the sampled rice farms operated. This is important because in addition to knowing the number of efficient rice farms, degree inefficiency and optimal scale of operation, it is also vital to know how many farms (with and without fertilizer) are operating under increasing returns to scale (IRS), decreasing returns to scale (DRS) or constant returns to scale (CRS). Using DEA every rice farm was evaluated, given its size level to determine its scale measures. This type of analysis according to Anderson et al. (2002) would be useful to each farm as they could determine the implications for expansion. The number of farms operating under constant, increasing, and decreasing returns to scale is shown in Table 3.

Table 3: Distribution of rice farms according to returns to scale

Farms	*Type of returns*			
	IRS	*CRS*	*DRS*	*Total*
Rice farms with fertilizer	15	12	73	100
Rice farms without fertilizer	42	7	51	100

Under rice farm with fertilizer, 15 farms were found operating with IRS or sub-optimal scale. This implies that production scale of these farms could be increased by decreasing costs, given that they were performing below optimum. On the other hand, 73 farms were operating with DRS or supra-optimal scale that is the farms were operating above the optimum scale, suggesting that these farms could increase their technical efficiency by reducing their production levels. Similarly only 12 farms were found operating with CRS or optimal scale (Table 3). Out of the 100 rice farms without fertilizer, 42, 7 and 51 farms were operating under IRS, CRS, and DRS respectively.

Given that majority of the rice farms with and without fertilizer were operating under IRS and DRS suggests that rice farms in general were scale inefficient, since scale inefficiency is usually due to the presence of either IRS or DRS. This is in agreement with Sharma et al. (1999). Although in the short run, farms may operate with increasing returns to scale (IRS) or decreasing returns to scale (DRS), in the long run however, rice farms must shift towards constant returns to scale (CRS) to be efficient in order to achieve the desired increase in rice production in Nigeria.

CONCLUSION

Data envelopment analysis was employed to evaluate the impact of fertilizer usage on the technical efficiency of rice farms in Kogi State, Nigeria. Results indicated that rice farms with fertilizer were more technically efficient than rice farms without fertilizer. Suggesting that rice farms with fertilizer could potentially expand output by 74 percent and 61 percent as compared to 77 percent and 66 percent for rice farms without fertilizer, without altering the input quantities used. Furthermore, the corresponding mean scale efficiency of 77 percent for rice farms with fertilizer and 79 percent for rice farms without fertilizer suggests that by operating on an optimal scale a further increase in output can be achieved beyond the planned value by as much as 23 percent and 21 percent respectively. Meaning that additional increase in domestic rice output from existing hectares is still possible if the technical efficiency of rice farms in Nigeria is enhanced. Consequently, in order to realize the desired increase in rice production in Nigeria as well as enhanced efficiency, rice farmers should be encouraged to adopt optimum fertilizer rate. This can be accomplished through proper implementation of fertilizer price subsidy, early distribution of fertilizer to farmers and educating farmers on the proper use of fertilizer through agricultural extension agents. This will go a long way in increasing fertilizer usage as well as the level of efficiency and productivity of rice farm in the study area.

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