

THE RESOURCE USE EFFICIENCY OF CONVENTIONAL AND ORGANIC DATE FARMS IN SAUDI ARABIA: A DATA ENVELOPMENT ANALYSIS APPROACH.

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ABSTRACT

The present study applied the Data Envelopment Analysis (DEA) models to evaluate conventional and organic date farms resource management of Saudi farmers using 126 and 94 rural date farmers at conventional and organic farms respectively. Technical, assuming variable return to scale, and cost efficiencies among the respondents varied substantially ranging between 0.08 and 0.54, for Technical Efficiency, and ranging between 0.20 and 0.15 for Cost Efficiency at conventional and organic date farms respectively. A mean scale efficiency of 0.39 and 0.27 are estimated for conventional and organic date farms. The study showed that some of the decision-making units have scale inefficiency, suggesting that the decision-making units are not all operating at the optimal scale. Most of the respondents operated very far away from the efficiency frontier. The overall technical inefficiency among the respondents resulted more by scale inefficiency compared to pure technical inefficiency. Allocative inefficiency is worse than technical inefficiency, implying that the low level of overall economic efficiency is the result of higher cost (allocative) inefficiency and scale inefficiency (operating at less than optimal scale size). Solving allocation and scale problems is critical for improving date farm resource use efficiency of Saudi date farmers.

Key words: Data Envelopment Analysis, Technical Efficiency, Cost Efficiency, Scale Efficiency.

INTRODUCTION

The performance of the date farms in this study was evaluated in terms of the productivity and efficiency of the date farmers. Production efficiency means attainment of a production goal without waste (Ajibefun and Daramola 2003). Efficiency is concerned with relative performance of the processes used in transforming given input into output (Ohajianya and Onyeweaku 2001). The measurement of efficiency is important because it is a success indicator and performance measure by which production units are evaluated. Furthermore, the ability to quantify efficiency provides decision makers with a control mechanism with which to monitor the performance of the production system or units. Production efficiency can be measured technically, allocatively and economically. These three measures of production efficiency give general overview of the conventional and organic date farmer's overall performance in resource utilization in the production process. Technical efficiency is the ability of a farmer to produce on the maximum possible frontier. A production process may be inefficient, in the sense that it fails to produce maximum output from a given bundle of inputs. Technical inefficiency results in over-utilization of inputs (Hazarika and Subramanian 1999). Allocative efficiency is the farmer's ability to produce a given level of output using the cost minimizing input ratios. Invariably, a farm is considered to be allocatively efficient in the use of a

given factor if the farm is able to equate the marginal value product (MVP) of the factor to the factor price (P). A production process may be allocatively inefficient in the sense that the marginal revenue product (MRP) of input might not be equal to the marginal cost of that input. Allocative inefficiency results in utilization of inputs in the wrong proportions, given input prices. Economic efficiency is the farmer's ability to produce a predetermined quantity of output at minimum cost given the available technology. Economic efficiency is the ability of farmer to maximize profit (Adeniji 1988; Ohajianya and Onyenweaku 2001). Economic efficiency is the product of technical and allocative efficiency. It indicates the costs per unit of output for a firm which perfectly attains both technical and price efficiencies. Technical and allocative efficiencies are necessary and, when they occur together, sufficient conditions for achieving economic efficiency (Yotopoulos and Lau 1973). This study uses the constant returns to scale and variable returns to scale data envelopment analysis models. The cost approach data envelopment analysis model has the advantage of allowing simultaneous estimation of the technical efficiency, allocative efficiency and economic efficiency of individuals (Coelli 1996). The use of the variable returns to scale specification permits the calculation of technical efficiency devoid of scale efficiency effects (Coelli 1996). The data envelopment analysis (DEA) model offers a flexible approach with a considerable scope for the use of diverse data (real and monetary) (Ready *et al.*

2004). Furthermore, DEA is deterministic and permits the choice between the constant return to scale (CRTS) specifications and the variable return to scale (VRTS) specifications depending on whether all decision making units (DMU's) are operating at the optimal scale and otherwise respectively. Using multiple stage data envelopment analysis model, Gorman and Ruggiero (2008) evaluated the US state performance. They found that most states are technically efficient, but nearly half are operating at less than optimal scale size. Using a variant of data envelopment analysis, slack based measure (SBM), Kuah *et al.* (2010) assessed quality management efficiency. They observed that data envelopment analysis is suitable to measure quality management efficiency and give improvement suggestion to the inefficient quality management. Several studies have been conducted on the analysis of farm efficiency. For example, Ajibefun (2002), using the stochastic frontier production function, analysed policy issues in technical efficiency of Nigerian small scale farmers. Ater and Umeh (2003) applied a stochastic frontier production function to analyse poverty reduction among dry season Fadama enterprises in Nigeria. Ajibefun and Daramola (2003) applied stochastic frontier production function and cost function for the analysis of determinants of technical and allocative efficiency of micro-enterprises in Nigeria. Asogwa *et al.* (2007) applied stochastic frontier production function for technical efficiency analysis of Nigerian cassava farmers as a guide for food security policy. Asogwa *et al.* (2011) applied stochastic frontier production function and cost function for technical and allocative efficiency analysis of Nigerian rural farmers and its implication for poverty reduction. Of all these studies, none has focused on the application of DEA for the analysis of farm efficiency. The CRTS assumption is only appropriate when all DMU's are operating at an optimal scale. Imperfect competition, constraints on finance, etc. may cause a DMU to be not operating at optimal scale. Banker *et al.* (1984) suggested an extension of the CRTS DEA model to account for variable returns to scale (VRTS) situations. The use of the CRTS specification when not all DMU's are operating at the optimal scale will result in measures of technical efficiency (TE) which are confounded by scale efficiencies (SE). The use of the VRTS specification will permit the calculation of TE devoid of these SE effects. The focus of this paper therefore, is to develop a model to evaluate farmers' resource management (efficiency) by using Data Envelopment Analysis (DEA).

The broad objective of this study is to develop a model to evaluate date farmers' resource management efficiency, at conventional and organic date farms, by using Data Envelopment Analysis (DEA).

METHODOLOGY

Farm level data were collected on 225 rural date farmers in Kingdom of Saudi Arabia. Data are collected from 6 Regions based on two different technologies, one for conventional and the other for organic date farms. There were 126 conventional date farms and 94 organic date farms. Production resources were categorized into five groups: land, water, labor, organic fertilizer, and chemical fertilizer. Land was measured in hectares, water was measured in cubic meters, human labor was measured in man (worker), Chemical fertilizer was measured in kilogram's, and organic fertilizer was measured in cubic meters. The unit prices of the resources were measured in Saudi Rials (USD=3.75SR).

The data collected were analyzed using the Data Envelopment Analysis Program (DEAP) by (Coelli, 1996). The Technical and cost efficiencies with constant returns to scale (CRTS) and variable returns to scale (VRTS) DEA models were used for data analysis.

Model Specification

Data Envelopment Analysis (DEA): Before presenting the model, the relevant concepts are presented below:

Overall Technical Efficiency (OTE): This is related to a given farm operating in constant return to scale (CRTS). Overall technically efficient farms fall on the frontier. The overall technical efficiency can be disaggregated into two measures *viz.*, pure technical efficiency and scale efficiency.

Pure Technical Efficiency (PTE): This concept arises when a given farm is operating under variable returns to scale (VRTS). A decision-making unit (farm) which is identified as technically not efficient on CRTS frontier can become technically efficient, if it falls on the VRTS frontier. This unit falling on VRTS frontier is technically efficient, even that it works with less than its full capacity.

Scale Efficiency (SE): A decision-making unit, date farm, is said to be scale efficient if it operates under constant returns to scale, utilizing its full capacity.

Input Congestion: This implies overutilization of resources. This is found in variable returns to scale date farms.

The DEA Model: Given the CRTS assumption, the best way to introduce DEA is via the *ratio* form. For each decision-making unit (DMU) one would like to obtain a measure of the ratio of all outputs over all inputs, such as $u'y/v'x$ where u is an $M \times 1$ vector of output weights and v is a $K \times 1$ vector of input weights. To select optimal weights one specifies the mathematical programming problem:

$$\max_{u,v} (u'y/v'x_i),$$

$$\begin{aligned} & \text{st } u'y_j/v'y_j = 1, j=1,2,\dots, N, \\ & u, v \geq 0. \end{aligned} \quad (1)$$

This involves finding values for u and v , such that the efficiency measure of the i -th DMU is maximized, subject to the constraint that all efficiency measures must be less than or equal to one. One problem with this particular ratio formulation is that it has an infinite number of solutions. To avoid this one can impose the constraint $v'x_i=1$

$$\begin{aligned} & \max_{u,v} (u'y_i), \\ & \text{st } v'x_i = 1, \\ & \mu'y_j - v'x_j = 0, j=1,2, \dots, N, \\ & \mu, v \geq 0, \end{aligned} \quad (2)$$

where the notation change from u and v to μ and v reflects the transformation. This form is known as the *multiplier* form of the linear programming problem. Using the duality in linear programming, one can derive an equivalent *envelopment* form of this problem:

$$\begin{aligned} & \min \theta, \\ & \text{st } -y_i + Y\theta = 0, \\ & x_i - X\theta = 0, \\ & \theta \geq 0, \end{aligned} \quad (3)$$

where θ is a scalar and X is a $N \times 1$ vector of constants. This envelopment form involves fewer constraints than the multiplier form ($K + M < N + 1$), and hence is generally the preferred form to solve. The value of θ obtained will be the efficiency score of the i -th DMU. It will satisfy

$\theta = 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient DMU, according to the Farrell (1957) definition. Note that the linear programming problem must be solved N times, once for each DMU in the sample. A value of θ is then obtained for each DMU. The CRTS linear programming problem can be easily modified to account for VRTS by adding the convexity constraint: $N1' = 1$ to (3) to provide:

$$\begin{aligned} & \min \theta, \\ & \text{st } -y_i + Y\theta = 0, \\ & x_i - X\theta = 0, \\ & N1' = 1 \\ & \theta \geq 0, \end{aligned} \quad (4)$$

where θ is a scalar and X is a $N \times 1$ vector of constants, whereas $N1$ is an $N \times 1$ vector of ones. The value of θ obtained will be the efficiency score of the i -th Decision Making Unit (DMU). It will satisfy $\theta = 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient DMU, according to the Farrell (1957) definition. One would then run the following cost minimization Data Envelopment Analysis:

$$\begin{aligned} & \min \sum_{i=1}^n w_i x_i^*, \\ & \text{st } -y_i + Y\theta = 0, \\ & x_i^* - X\theta = 0, \\ & N1' = 1 \\ & \theta \geq 0, \end{aligned} \quad (5)$$

where w_i is a vector of input prices for the i -th DMU and x_i^* (which is calculated by the LP) is the cost minimizing

vector of input quantities for the i -th DMU, given the input prices w_i and the output levels y_i . The total cost efficiency (CE) or economic efficiency of the i -th DMU would be calculated as:

$$CE = w_{i2} x_i^* / w_{i2} x_i. \quad (6)$$

That is, the ratio of minimum cost to observed cost. One can then calculate the allocative efficiency residually as:

$$AE = CE/TE. \quad (7)$$

Note that the product of technical efficiency and allocative efficiency provides the overall economic efficiency. Note that all three measures are bound by zero and one.

Calculation of Scale Efficiency: Many studies have decomposed the technical efficiency (TE) scores obtained from a CRTS DEA into two components, one due to scale inefficiency and one due to "pure" technical inefficiency. This may be done by conducting both a CRTS and a VRTS DEA upon the same data. If there is difference in the two TE scores for a particular DMU, then this indicates that the DMU has scale inefficiency (SE). The scale inefficiency can be calculated from the difference between the VRTS TE score and the CRTS TE score. Thus,

$$TE_{I, CRTS} = TE_{I, VRTS} \times SE_i. \quad (8)$$

RESULTS AND DISCUSSION

Table (1) shows the differences among five input use at both conventional and organic date farms. Date farms are classified in three categories based on farm area. The main characteristics of date farms can be summarized as following, see table (1).

For conventional and organic date Farms, average farm area were 44 and 23 hectares respectively, using 668 and 367 thousand cubic meters each year, and hire 18 and 13 worker at each farm respectively. Note that conventional date farms using both organic and chemical fertilizer, while organic date farms use only organic fertilizers. Differences in input use among date farms with area greater than 30 hectares, 30-10 hectares, less than 10 hectares for both conventional and organic date farms are shown in table (1).

The result in Table (2) shows that majority of the respondents (76%) operated within a technical efficiency range of 0.50 and less than 1.00, for conventional date farms (CDF), while it was 53% at organic date farms (ODF). The implication of this result is that majority of the respondents are not technically efficient in the use of production resources, especially at ODF. This can result to an equi-proportionate over utilization of inputs (input congestion), and hence low productivity, low output and low income. Furthermore, technical efficiency among the CDF varied substantially ranging between 0.189 and 1.00, with a mean technical efficiency of 0.774, and that range was 0.119 and 1 with

average 0.543 at ODF, (Table 2). This result suggests that the farmers are not utilizing their production resources efficiently, indicating that they are not obtaining maximal output from their given quantities of inputs. In other words, technical efficiency among the respondents can be increased, on average, by 22.6 and 45.7 percent, at CDF and ODF respectively, through better use of available resources, given the current state of technology and farmer skills. This would enable the farmers obtain maximum output from their given quantities of inputs, and hence increase their farm incomes. This validates claim by Asogwa *et al.* (2011), in similar case, that Nigerian rural farmers are not obtain maximum output

from their given quantity of inputs.

Based on date farm size, average technical efficiency were 76%, 72%, and 81% at large, medium, and small CDF respectively. Last estimates were 45%, 44%, and 12% at ODF respectively. It means that small date farms, less than 10 hectares, were the most technical efficient ones at CDF, and the least efficient ones at ODF. The importance of last results is that small date farms are 54% and 60% of total numbers of CDF and ODF respectively. So farmers of small ODF need to improve the use of inputs to increase efficiency. The results would be explained by date farmers experience, which is less at ODF if compared with CDF.

Table 1. Statistics of input data based on date farm type and area

Farm area statistics	Conventional Date Farms					Organic Date Farms			
	Farm inputs					Farm inputs			
Area (hectares)	Water (m3)	Labor (worker)	Chemical Fertilizer. (kg)	Organic Fertilizer (m3)	Area (hectares)	Water (m3)	Labor (worker)	O-Fert. (m3).	
Date farm area >30 hectares									
Average	198	2734264	48	487	1499	108	1481375	21	1281
Max	1200	16480320	174	1250	7000	200	3143200	53	5000
Mini	35	88400	1	45	0	35	369380	6	34.56
Date farm area 10-30 hectares									
Average	14	248216	19	249	4877	16	261749	22	2525
Max	30	710760	60	540	34482.7	30	950800	98	15000
Mini	10	85600	2	22	0	10	59640	2	500
Date farm area <10 hectares									
Average	5	155596	7	342	3147	4	133668	7	4154
Max	9	4209700	51	8750	32000	9	2766000	53	20000
Mini	0.3	13126	1	10	0	0.1	9794	1	200
All farms									
Average	44	668429	18	344	3313	23	367092	13	3310
Max	1200	16480320	174	8750	34482.7	200	3143200	98	20000
Mini	0.3	13126	1	17	0	0.1	9794	1	34.56

Source: study data

Table 2. Technical and Cost Efficiency range distribution and date farm numbers

Efficiency Rate	Conventional Date Farms (CDF)				Organic Date Farms (ODF)			
	Technical Efficiency		Cost Efficiency		Technical Efficiency		Cost Efficiency	
	No. of Farms	% Farms	No. of Farms	% Farms	No. of Farms	% Farms	No. of Farms	% Farms
100%	66	52	2	2	12	13	2	2
50%>100%	30	24	2	2	38	40	3	3
10%>50%	31	24	100	78	44	47	47	50
<10%	0	0	23	18	0	0	42	45
sum	127	100	127	100	94	100	94	100

Source: Study results

An allocative efficiency range of 0.006 and 1, with an average of 0.282 and 0.273 at both CDF and

ODF respectively. Application of this result is that majority of the respondents are not allocatively efficient

in the use of production resources. This can result to the utilization of inputs in the wrong proportions, given input prices, and hence higher costs of input combination and reduced return to capital. Furthermore, allocative efficiency among the respondents varied widely ranging between 0.155 and 0.337, at large and small CDF respectively, with a average allocative efficiency of 0.282 (Table 2). While it range between 0.077 and 0.365 at ODF respectively with an average of 0.273. This result suggests that the date farmers are not able to equate the marginal value product (MVP) of the input to the input price (P) as they allocate the inputs of production for production, with large date farms if compared with small date farms. This results indicating that they are utilizing the inputs in the wrong proportions, given input prices. In other words, about 73 percent of resources are inefficiently allocated, at both CDF and ODF, relative to the best-practiced farms producing dates. This implies that allocative efficiency among the respondents could be increased by 73 percent in the area through better utilization of resources in optimal proportions given their respective prices and given date farm area and the current state of technology. This would enable the farmers equate the marginal revenue product (MRP) of input to the marginal cost (MC) of the input, thereby improving farm income.

Cost efficiency range of 0.20 and 0.15, on average, at CDF and ODF respectively, see Table 3. Small date farms, less than 10 hectares, have cost efficiency, on average, 0.24 and 0.23, while it were 0.13 and 0.03 at large date farms, greater than 30 hectares, for CDF and ODF respectively. The implication of this result is that large date farms are not cost efficient in the use of production resources, if compared with small date farms. This can result to higher costs per unit of output for a large date farm and hence the inability of the farmer to maximize profit. Furthermore, cost efficiency among the respondents varied widely ranging between 0.004 and 1, with a mean economic efficiency of 0.13 at large ODF (Table 3). This result suggests that the farmers in the study area are not able to minimize the cost of production. In other words, 87.13 percent of production costs were wasted relative to the best practiced farms producing dates and facing the same technology in the study area. The implication is that overall economic efficiency among the respondents could be increased by 87.3 percent in the area through the reduction in production costs that would occur if production were to occur at the allocatively and technically efficient points, given the current state of technology. This would enable the date farmers to minimize production costs, and hence maximize income and profit.

Majority of the respondents (81%) operated within a scale efficiency range of 0.005 and less than 1 at CDF, and it was 85% at ODF, (Table 3). The implication of this result is that majority of the respondents are not

scale efficient. Furthermore, scale efficiency among the date farm sizes and farm technology, CDF or ODF, are varied substantially. This result suggests that the farmers are operating in less than optimal scale size. In other words, scale efficiency among the respondents, at CDF and ODF, can be increased by 61 and 73 percent respectively by operating in optimal scale size, given the current state of technology. This would enable the date farmers operate in optimal scale size, and hence increase their farm productivity and incomes. The average level of overall allocative efficiency (AE) and overall cost efficiency (CE) are estimated at 28 percent and 20 percent at CDF, and 27 percent and 15 percent at ODF. These results generally highlight the relative inefficiency that characterizes the ODF was less than that of CDF from the cost of production, while they are close at allocative efficiency. The overall technical inefficiency among the respondents resulted more by scale inefficiency compared to pure technical inefficiency, which can direct policy makers to search and adopt the optimal date farm size. The results further indicate that allocative inefficiency is worse than technical inefficiency, which implies that the low level of overall cost efficiency is the result of higher cost (allocative) inefficiency and scale inefficiency. So, Date farms are operating at less than optimal scale size. This suggests that solving allocation and scale problems is critical for improving date farm resource management, or efficiency of date farmers. This corroborates Kuah *et al.* (2010), who observed that data envelopment analysis is suitable to measure DMU' s efficiency and give improvement suggestion to the inefficient DMU. The effect of a marginal increase in technical, scale and allocative efficiency on total cost efficiency could be substantial. Any improvement in date farms productivity would lead to increase in returns to the date farmers from agricultural activity using traditional technique as CDF, or the other technique of ODF. Such increase in farmer incomes would lead to rapid development of agriculture sector, as long as dates are the most important crop at the Kingdom of Saudi Arabia.

The study showed that some of the decision-making units have scale inefficiency, suggesting that the decision-making units are not all operating at the optimal scale. Most of the respondents operated very far away from the efficiency frontier. The overall technical inefficiency among the respondents resulted more by scale inefficiency compared to pure technical inefficiency. Allocative inefficiency is worse than technical inefficiency, implying that the low level of over- all economic efficiency is the result of higher cost (allocative) inefficiency and scale inefficiency (operating at less than optimal scale size). Solving allocation and scale problems is critical for improving farm resource management.

Table 3. Efficiency estimation of NDF and ODF based of farm area

Conventional Date Farms (CDF)									Return To Scale
	area>30	No. of farms	%	CRSTE	VRSTE	Scale Eff.	Allocative Eff.	Cost Eff.	
average	198			0.616	0.758	0.809	0.155	0.127	6 CRS
max	1200	24	19	1.000	1.000	1.000	1.000	1.000	14 IRS
mini	35			0.014	0.227	0.017	0.006	0.004	4 DRS
Area 10-30									
average	14			0.290	0.720	0.417	0.260	0.158	3CRS
max	30	34	27	1.000	1.000	1.000	0.757	0.757	31IRS
mini	10			0.029	0.254	0.067	0.071	0.023	
area<10									
average	5			0.168	0.807	0.226	0.337	0.239	1CRS
max	9	68	54	1.000	1.000	1.000	1.000	1.000	53IRS
mini	0.3			0.005	0.189	0.005	0.008	0.005	
Average for all	44	126	100	0.286	0.774	0.389	0.282	0.195	
Organic Date Farms (ODF)									Return To Scale
	area>30	No. of farms	%	CRSTE	VRSTE	Scale Eff	Allocative Eff.	Cost Eff.	
average	108			0.281	0.454	0.564	0.077	0.033	1 CRS
max	200	14	15	1.000	1.000	1.000	0.208	0.084	13 IRS
mini	35			0.034	0.133	0.162	0.022	0.005	
Area 10-30									
average	16			0.110	0.435	0.275	0.171	0.070	1 CRS
max	30	24	25	0.327	0.836	0.785	0.407	0.180	23 IRS
mini	10			0.014	0.203	0.033	0.037	0.014	
area<10									
average	4			0.110	0.612	0.186	0.365	0.207	56 ICR
max	9			1.000	1.000	1.000	1.000	1.000	
mini	0.1	56	60	0.007	0.119	0.010	0.007	0.007	
Average for all	25	94	100	0.135	0.543	0.265	0.273	0.146	

CRSTE= Constant Return to Scale Technical Efficiency, VRSTE= Variable Return to Scale Technical Efficiency, CRS= Constant Return to Scale, IRS= Increasing Return to Scale, DRS= Decreasing Return to Scale.

Source: results of study data using DEAP.

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