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Comparative Resource Use Optimization Among Selected Irrigated Maize Farmers In The North Western States Of Nigeria: A Dea Approach

Ajiboye Abiodun
Department of Agricultural Economics and Extension Services
Ekiti State University PMB 5363, Ado Ekiti. Ekiti State, Nigeria

Osundare F. Olayinka
Department of Agricultural Economics and Extension Services
Ekiti State University PMB 5363, Ado Ekiti. Ekiti State, Nigeria

ABSTRACT

The study examined resource use optimization in 240 irrigated maize farms sampled from four states of North-western Nigeria. Data Envelopment Analysis (DEA) was employed to obtain three types of optimality – optimal, sub optimal and super optimal output levels. The results show that there were substantial scale inefficiencies in all the four states. This implies that most of the farms should be larger than their present sizes in order to achieve higher production given, the available factor mix.. The results also showed that if all farms were using the same technology, then it would be expected that return to scale would increase for farms with a relatively low outputs and decreasing return to scale farms with a relatively high outputs .Constant return to scale would be expected for farms with output levels equal to the mean output .The mean output of the suboptimal scale is larger than the mean output of the optimal as well as super optimal scales for Kebbi State. In the remaining three states, and the pooled data, the mean outputs of the super – optimal scale were large than the mean outputs of the optimal and sub-optimal scales. Farms that are characterized by constant return to scale can change scale of operation only by proportionately increasing or decreasing input-output combinations. Those that were characterized by increasing return to scale can gain efficiency by increasing production and become scale efficient. On the other hand, those found to be operating in the decreasing return to scale range, would need to reduce scale of operation to gain efficiency improvements.

Key words: Water, Resource, Optimization, DEA, Return to scale, Efficiency

INTRODUCTION

Like many other economies of the sub-Saharan African nations, Nigeria share in the episode of the vicious interaction among food shortage, severe poverty and unsustainable use of agricultural water resources. Past policies of successive government in Nigeria have directed towards addressing the lingering water-food security nexus the country is experiencing. The imbalance in the supply of food especially cereals and population explosion in the country is not unconnected with the problem associated with the irrigation sector of the nation.

Aggravating this is the scarcity of water which has now become a colossal challenge in many countries. Irrigation system, being a major consumptive user of water resources, experience a lot of pressure to release water for the availability of other end-users and discover avenues in which performance can be improved (Malano et al., 2004). It is no longer a new knowledge that water is becoming increasingly scarcer both in terms of quality and quantity. This is especially for irrigation purposes. It is pertinent also to note that without irrigation, the feeding of the world's growing population, as a result of increases in the agricultural yield and output would not have been possible. It is estimated that 250 million hectares of land currently under irrigation, is nearly five times the size of irrigated land that existed at the beginning of the twentieth century (Rosegrant et al., 2002).

Over the last four decades, irrigated areas have increased rapidly, helping to boost agricultural output and feed a growing population. Irrigation uses the largest fraction of water in almost all countries .Globally, 70 percent of freshwater diverted for human purposes goes to agriculture, and irrigation water demand is still increasing because the area being irrigated continues to expand. In some countries, the expansion of surface water use appears to be approaching the physical limit, and groundwater abstractions are increasingly exceeding rates of replenishment. Meanwhile, industrial and domestic water demand has been increasing rapidly as a result of increasing economic development and urbanization. In some Countries and regions, water is already being transferred out of irrigation and into urban industrial uses, putting additional stress on the performance of the irrigation sector (Rosegrant and Ringler, 2000).

Although the achievements of irrigation in ensuring food security and improving rural welfare have been impressive, past experience also indicates problems and failures of irrigated agriculture. In addition to large water use and low efficiency, environmental concerns are usually considered the most significant problem of the irrigation sector. Environmental problems include excessive water depletion, water quality reduction, water logging, and salinization.

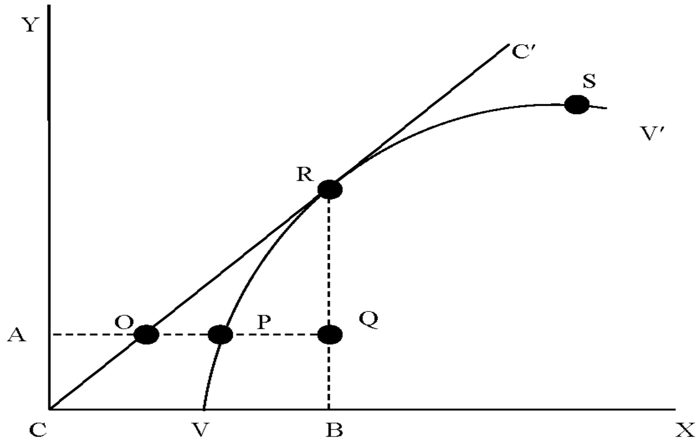
Contributing to the aforementioned challenge is the need to cater for the food need of the rapidly growing human populace.

A pragmatic approach therefore needs to be adopted in order to gear efforts to accelerating food production. One of these approaches is the small-scale irrigation schemes adopted by many peasants, especially in the savannas of the northern Nigeria. As such this study looks at the optimality of resource use by the small scale irrigation farmers in the study area. The objective of this study is to examine resource use optimality in irrigated maize farms in selected states of north western NJigeria.

CONCEPTUAL FRAMEWORK TRANSPARENT OBJECTIVITY

This section discusses conceptual issues related to types and components of DEA efficiency measures. The discussion in this section strongly follows the work of Coelli et al. (2008). The figure below is an hypothetical situation that demonstrates some concepts of efficiency measures by using six decision making units (DMUs) which could also be referred to as firms. These are represented by points O, P, Q, R, and S. Each DMU is assumed to employ a composite input, X, in the production process to produce a composite output, Y.The CC′, represents constant returns to scale (CRS). The slope of this line is a constant, i.e., a unit increase in the composite input leads to equal one unit increase in the level of output at all points along the line CC′ The fact that points O and R lie on the line CC′ indicate that these farms are fully efficient and they operate under conditions of CRS.

Figure 1. Efficiency analysis



Adapted from Ayele G and W. M. Beatrice (2015)

On the other hand, the curve VV′ represents variable returns to scale (VRS) production function. Unlike the CRS case, a unit increase in the level of input use leads to variable quantities of increments in output under VRS (along the curve VV′). DMUs P, R, and S are fully efficient firms producing with, increasing returns to scale (IRS), CRS, and decreasing returns to scale (DRS) respectively.

Point Q denotes an inefficient DMU by both the CRS and VRS criteria. The level of its technical inefficiency can be measured by using an input or output oriented DEA approaches.

For the CRS case, the value of the technical efficiency score remains the same regard-less of whether input or output oriented method is applied. This means Θ = AO/AQ = BQ/BR. This means that either the level of output can be increased from O to R keeping the quantity of input at the same level, B, or, alternatively, the level of input can be reduced from B to a point below O to produce the same level of output, A. For the VRS, given that change in the level of input use causes variable changes in the level of output along the curve VV′, the output and input oriented methods yield different technical efficiency scores. It should be noted that for fully efficient DMU, Θ = 1, but for all inefficient DMUs, Θ < 1. The difference between 1 and Θ (or 1-Θ) indicates the proportion by which the DMU can increase output without any change in the amount of input used. For the same level of output, we obtain different technical efficiency scores for the CRS and the VRS. For instance, for point Q, the output oriented technical efficiency scores for the CRS TE and VRS TEV at output level A are given as CRSTE = AO/AQ and VRSTE = AP/AQ.

The distance between the CRS line and the VRS curve (OP) is caused by differences in scale efficiency (SE). The latter is given by the ratio of the CRSTE to VRSTE, i.e. SE = CRSTE / VRSTE = (AO/AQ)/(AP/AQ) = AO/AP. It follows that the CRS technical inefficiency can be decomposed into 'scale inefficiency', OP, and 'pure inefficiency', PQ. If SE = 1, then the farm is scale-efficient; its combination inputs and outputs is efficient both under CRS and VRS (BIELIK and RAJČÁNIOVÁ, 2004). In other words, if the technical efficiency scores for the CRS and VRS are equal, it means the farm is operating at optimal scale. On the other hand, if SE < 1, then the farm is scale-inefficient or operating at a suboptimal scale. In other words, the farm is too small or too large.

The SE scores do not indicate whether or not the DMU is operating at the IRS or DRS ranges. This can be specified by solving for a DEA with non-increasing returns to scale (NIRS). In the context of the diagram above, the NIRS case is given by a locus of points represented by CORSV′. The relevant returns to scale along the NIRS locus is obtained by the NIRS based scale efficiency scores (SEI) as ratios of the CRSTE scores and the NIRS technical efficiency scores (TEI), i.e., SEI = CRSTE / TEI. If SEI = 1, then the DMU is operating at IRS range of the VRS curve. However, if SEI < 1, then the DMU is operating at DRS range. This means that, in the context of Figure 1, any point up to and including R is considered as an IRS range but any point beyond R, such as S, denote a DRS range.

MODEL SPECIFICATION AND DATA

Model Specification

Data envelopment analysis (DEA) was used in this study. The DEA model could be input –oriented or output –oriented under either the assumption of Constant Return to Scale CRS or Variable Return to Scale VRS specifications .Our study focused on the input orientation because our interest is to analyse how input is used efficiently. According to Coelli (1996), the best way to introduce DEA is via the *ratio* form. For each DMU, a measure of the ratio of all outputs over all inputs could be obtained, such as $u'y_i / v'x_i$, where u is an M x l vector of output weights and v is a K x l vector of input weights. To select optimal weights the following mathematical programming problem is specified:

$$\max_{uv}\ (u'y_i / v'x_i),$$
$$\text{s.t}\quad u'y_i / v'x_i \leq 1, \quad j= \ l, 2,.........\ N,$$
$$u, v \ \geq \ 0. \qquad (1)$$

The aim is to determine the values of u and v that will maximized the efficiency index of the i-th DMU. The condition is that all efficiency measures must be less than or equal to unity. One problem with this particular ratio formulation is that it has an infinite number of solutions. To avoid this, one can impose the constraint $v'x_i = 1$, which provides:

$$\max_{\ ,v}(\ , y_i),$$
$$\text{st} \quad v'x_i = 1,$$
$$\ ' y_j - v'x_j \quad 0,\ j = 1,2,\ldots.N,$$
$$\ , v \quad 0, \qquad (2)$$

Where the notation change from u and v to μ and v reflects the transformation. Using the duality in linear programming, the equivalent envelopment form of this problem is: wellness vestige iota carriage harness mastery

$$\text{Min}_{\ ,}\quad ,$$
$$\text{st} \quad - y_i + Y \quad 0,$$
$$x_i - X \quad 0,$$
$$0, \qquad (3)$$

where θ is a scalar and λ , is a N xl vector of constants. This envelopment form involves fewer constraints than the multiplier form (K+M <N+l), and hence is generally the preferred form to

solve. The value of θ obtained will be the efficiency score for the i-th DMU. It will satisfy θ ≤ 1 , with a value of 1 indicating a point on the frontier and hence a technically efficient DMU.

An extension of the CRS DEA to VRS model can be made (Banker, Charnes and Cooper(1984). This will permit the calculation of TE devoid of these Scale effects.

This is done by adding the convexity constraint: N1 'λ,=l to equation (3) to provide:

$$\begin{aligned} &\min_{,} \quad , \\ st \quad & -y_i + Y \quad 0, \\ & x_i - Y \quad 0, \\ & N1' = 1 \\ & 0, \end{aligned} \qquad (4)$$

Where NS is an Nxl vector of ones.

Given the price information of the six explanatory variables namely water, land, labour, fertilizer seed and herbicide, the allocative efficiency (AE) and Economic Efficiency (EE) will be calculated. For the case of VRS cost minimization, the input-orientated DEA model can be obtained .This will involve running the following, cost minimization DEA

$$\begin{aligned} &\min_{,xi^*} w_i' x_i^*, \\ st \quad & y_i + Y \quad 0 \\ & N1' = 1 \\ & 0 \end{aligned} \qquad (5)$$

Where w_i is a vector of input prices for the i-th DMU and x* 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 economic efficiency of the i-th DMU will be calculated as the ratio of minimum cost to observed cost.

$$EE = \frac{w_i' x_i^*}{w_i' x_i} \qquad (6)$$

One can then calculate the allocative efficiency residually as

AE = EE/TE. (7)

As noted earlier, the VRS technical efficiency scores would not distinguish between cases where the DMU is operating with the increasing returns to scale or decreasing returns to scale. The NIRS specification distinguishes between areas of the IRS and DRS ranges of the VRS.

DATA

The study was carried out in four states in North Western Nigeria. The region was chosen due to its agroclimatic nature and prevalence of irrigation agriculture relative to other regions in the country. The four states are: Kano ,Sokoto, Zamfara and Kebbi. The basic data required for the analysis of this study was primary. The data was collected from farmers who practice irrigation in the study area. The data was sourced through the use of structured questionnaire which comprised various questions pertaining to the socio-economic characteristics, farming activities, value and volume of output of the participating farmers. A multi-stage sampling method which involved four stages was used. The sampling method involved a purposive selection of four states in the north western Nigeria, based on the predominance of irrigation farming in the region. A total of twelve local government areas, three in each state were selected for the interview and a village from each of the local government areas was systematically chosen followed by the selection of the farmers through a random sampling process. A total of 20 farmers were selected in each village. This amounted to a total of 240 respondents. Information were gathered on the irrigation schemes, household and enterprise characteristics, farm activities, quantities and costs of inputs used in production (capital, variable and overhead), quantities and values of output, a reasonable estimate of the quantity of water consumed.The survey was carried out in 2008.

RESULTS AND DISCUSSION

Table1: Descriptive Statistics of Sampled Farmers in the four States

Variables	Mean
Age (years)	40.3
Household size (Actual)	5
Education (years)	5.67
Farm experience (years)	14.13
Market distance (km)	1.22
Farm size (Ha)	1.44
Hired labour (Mandays)	4
Percentage that used fertilizer	86.47
Fertilizer (Kg)	124
Pesticide (Liters)	5.04

Table 1 shows that the mean age of respondents in the study area was 40 years; while an average farmer had a farm size of 1.44 Ha to show that the scale of operation was a small one. Years of formal education was approximately 6 which indicated that most of the farmers had an average of primary school education. The mean household size was 5 people, suggesting a not-too-large family size, which was indicative of the need for hired farm labour demand in the study area of which the mean size was 4. Farm experience was 14 years, indicating that the farmers were not new entrants and hence should have enough motivation to use fertilizer. Finally, market distance to farmers' homesteads was 1.4 Km which means that farmers should not have difficulty due to transportation in accessing fertilizer on their irrigation farms.

Table 2. Distribution of efficiency estimates from the pooled data

Efficiency Indices	CRS						VRS					
	TE		AE		EE		TE		AE		EE	
	No of farms	% of farms	No of farms	% of farms	No of farms	% of farms	No of farms	% of farms	No of farms	% of farms	No of farms	% of farms
<10	0	0	01	0.42	08	3.33	0	0	03	1.25	60	25
10-19	0	0	18	7.5	59	24.58	05	2.08	34	14.17	112	46.67
20-29	04	1.67	36	15	83	34.58	28	11.67	66	27.5	47	19.58
30-39	24	10	57	23.75	44	18.33	47	19.58	72	30	11	4.58
40-49	43	17.91	42	17.5	30	12.50	46	19.17	38	15.83	07	2.92
50-59	45	18.75	32	13.33	05	2.08	39	16.25	18	7.50	01	0.42
60-69	46	19.17	26	10.83	05	2.08	28	11.67	04	1.67	01	0.42
70-79	29	12.08	10	4.17	0	0	21	8.75	03	1.25	0	0
80-89	09	3.75	07	2.92	0	0	09	3.75	01	0.42	0	0
90-99	12	5.0	03	1.25	01	0.42	05	2.08	0	0	0	0
100	28	11.67	08	3.33	05	2.08	12	5.0	01	0.42	01	0.42
Total	240	100	240	100	240	100	240	100	240	100	240	100
Mean	63		45		28		52		33		17	

Table 2 gives the frequency distribution of all the four states CRS and VRS efficiency estimates obtained by the 2 – stage DEA methods, as pooled together. The average overall technical efficiencies are 0.63 and 0.52 for the CRS and VRS respectively .Substantial inefficiencies occurred in the farming operation of the sampled farm households in all the states. Under the prevailing conditions, about 11.67% and 5.0% of farms were identified as fully technically efficient under the CRS and VRS specification respectively. The observed difference between the CRS and VRS measures further indicated that some of the farmers did not operate at an efficient scale and improvement in the overall efficiencies could be achieved if the farmers adjusted their scales of operation.

The average allocative efficiencies and economic efficiencies under the CRS and VRS specifications are respectively 0.45, 0.28 and 0.33. 0.17. This wide difference could also be attributed to the different management practices embarked upon by the farmers.

The lowest technical efficiency score falls within the 20 – 29 group under the CRS scale specification while the lowest TE score falls within the 10 – 19 group under the VRS specification. This shows that the TE scores under the CRS were higher than those obtain under the CRS specification. The results revealed that the irrigated farmers did not use resources in an efficient manner

Table 3. Distribution of Scale Efficiency (SE)

Efficiency Indices	States								Total	
	Kebbi		Sokoto		Zamfara		Kano		Pooled	
	N0 of farms	% of farms	N0 of farms	% of farms	N0 of farms	% of Farms	N0 of farms	% of farms	N0 of farms	% of farms
20-29	0	0	1	1.67	0	0	0	0	0	0
30-39	0	0	4	6.67	4	6.67	0	0	0	0
40-49	0	0	12	20	6	10	0	0	0	0
50-59	3	5	17	28.33	10	16.67	1	1.67	13	5.42
60-69	8	13.33	7	11.67	3	5	6	10	44	18.33
70-79	7	11.67	7	11.67	5	8.33	15	25	54	22.5
80-89	6	10	5	8.33	6	10	9	15	54	22.5
90-99	17	28.33	2	3.33	18	30	21	35	63	26.25
100	19	31.67	5	8.33	8	13.33	8	13.33	12	12
Total	60	100	60	100	60	100	60	100	240	100
Mean	87		62		76		86		81	

The average scale efficiency indices for Kebbi, Sokoto, Zamfara and Kano states are respectively 87%, 62% 76%, and 86%, with Sokoto state demonstrating the highest scale inefficiency and Kebbi state operating at the lowest scale inefficiency. However, the results show that there are substantial scale inefficiencies in all the four states. This implies that most of the farms should be larger than their present sizes in order to achieve higher production given, the available factor mix. The issue of large scale inefficiencies had been identified by early researchers. Binam et al (2003), observed a large scale in efficiency for coffee farmers in Ivory Coast, Abay et al. (2004) reported it for tobacco farmers in turkey. Shafiq and Rehman ,(2000) found large scale inefficiencies for cotton farmers in Pakistan .In the case of irrigation farms, Stiljn et.al. (2007) found an average of 60% scale inefficiencies among small scale irrigation households in Ethiopia. This according to them was significant with nearly all farms operating at increasing returns to scale. On the other hand, Haji (2006), found that scale inefficiencies were nearly absent in more traditional farming systems and Alene et al. (2006) arrived at similar conclusion for inter cropping in southern Ethiopia.

Table 4. Distribution of optimal, sub optimal and super optimal outputs

State/scale	Number of farms	% of farms	mean Outputs	Output Range
Kebbi				
optimal	19	31	2161.05	880-4940
Sub-optimal	40	66.67	2900	2900
Super-optimal	01	1.67	1697.25	480-3700
Sokoto				
Optimal	05	8.33	2140	900-3500
Sub-optimal	54	90	1355.56	780-2300
Super-optical	01	1.67	3000	3000
Zamfara				
Optimal	08	13.33	2202.38	1000-3200
Sub-optimal	45	75	1429.30	700-3200
Super-optimal	07	11.67	2974	1726-3892
kano				
optimal	08	13.33	1762.5	1300-3000
Sub-optimal	47	78.33	1522.34	1000-3500
Super-optimal	05	8.35	24.90	500-3200
Pooled				
optimal	12	5	2285.75	900-3500
Sub-optimal	207	86.25	1513.84	480-3800
Super-optimal	21	8.75	3013.43	2000-4940

The pure technical efficiency or VRS scores do not distinguish between types of returns of scales. The following criteria can be employed to establish the distinctions

i. If CRSTE = VRSTE, then it is CRS
ii. If CRSTE < VRSTE and SE = NIRS, then it is DRS
iii. If CRSTE < VRSTE and SE ≠ NIRS, then it is IRS

In this con-text, it is important to explain why most farms were characterized by IRS, suggesting the farms can increase their efficiency by increasing their scale of operation. Does this mean increasing the number of animals?

The classification into optimal, suboptimal and Super-optimal outputs on a state-by-state basis is reported in Table 4.16 above. In terms of economies of scale, 19 farms were characterized by constant return to scale, 40 farms had increasing return to scale and only 1 farm was characterized by decreasing return to scale among the Kebbi state irrigation households. In Sokoto State, 5 farms were characterized by constant return to scale, 54 farms by increasing return to scale and only 1 farm by decreasing return to scale. In Zamfara state, 8 farms operated under the constant return to scale, 45 farms were characterized by increasing return to scale, 7 farms were characterized by decreasing return to scale. In Kano states, 8 farms were characterized by constant return to scale, 47 by increasing return to scale and 5 farms by decreasing return to scale. For the pooled result, 12 farms were characterized by constant return to scale, 207 by increasing return to scale and 21 farms by decreasing return to scale.

If all farms are using the same technology, then it would be expected that return to scale would increase for farms with a relatively low outputs and decreasing return to scale farms with a relatively high outputs .Constant return to scale would be expected for farms with output levels equal to the mean output .The mean output of the suboptimal scale is larger than the mean output of the optimal as well as super optimal scales for Kebbi State. In the remaining three states, and the pooled data, the mean outputs of the super – optimal scale were large than the mean outputs of the optimal and sub-optimal scales. The results indicates that the super optimal output levels overlap a substantial portion of the optimal and sub-optimal outputs, while for Kebbi state, the sub-optimal output value overlaps that of optimal and super optimal values. Farms that are characterized by constant return to scale can change scale of operation only by proportionately increasing or decreasing input-output combinations. Those that are character-ized by IRS can gain efficiency by increasing production and become scale efficient. On the other hand, those found to be operating in the DRS range, would need to reduce scale of operation to gain efficiency improvements.

RECOMMENDATIONS

The study is designed to familiarize farmers' attention with an area in crop production where resource use efficiency has been neglected over the years. The need to use irrigation water more efficiently is paramount in the face of gradual change in climate which results in delayed planting periods and its associated problems. Hence the augmenting role of irrigation in cushioning the risks involved in rain-fed farming due to rainfall shocks and the increase in population pressure on the available water resources is a factor that justifies the need to use resources more efficiently in irrigation shemes in the area.

The empirical evidences in this study show that there are scale inefficiencies in the selected north western states of Nigeria. This implies that the farms should be larger than their present sizes for higher production within the available factor mix. There is therefore the need to invigorate farm mechanization in conjunction with all other modern farming methods for the expansion of cultivated areas.

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