



Farmers' efficiency under irrigated and rainfed production systems in the derived savannah zone of Nigeria

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Abstract

The gap between food demand and supply has increased concerns over food production in Nigeria. Improving the resource-use efficiencies of farmers is considered a viable solution to this challenge. In addition, irrigated agriculture is being promoted to increase output and provide productive employment for farmers during the dry season. This study determined and compared the technical efficiencies of farms under irrigated and rainfed crop production systems in the derived savannah zone of Nigeria; with a view to identify factors influencing inefficiency in these systems. The farm level data obtained were analyzed by employing the stochastic production frontier model. The results showed that for farms under irrigated and rainfed systems, increase in farm size, family labour and fertilizer application will increase output levels. In addition increase in hired labour and irrigation water will increase output under irrigated system. The mean technical efficiency of farms under irrigated and rainfed systems was 0.84 and 0.67 respectively. This implies that there is potential for improvement in efficiency under both systems; although more for rainfed system. Age, literacy status and years of farming affect the level of efficiency under both systems. Under irrigated system, ownership of water pump and residency status are also contributory factors. It is suggested that size of farms should be increased along with improved access to adult education and institutional credit. Irrigated farming should be encouraged because it can provide employment and improved incomes particularly during off-season.

Key words: Technical efficiency, irrigation, rainfed, production system, Nigeria.

Introduction

Nigeria is faced with the challenge of providing adequate food supply for its teeming population. The goal of increasing food production and reducing food imports has elicited many programmes and policies at various levels of government. Rainfed agriculture is widely practiced by farmers in the country; however, following the drought in the early 70s, the Federal Government initiated program to develop irrigated agriculture. The first was the establishment of the River Basin Development Authorities (RBDAs) in the early seventies and by the late 1980s; the development of small-scale irrigation systems in *fadama*¹ land areas commenced. In 1993, the Federal Government in collaboration with the World Bank and state governments started a new programme referred as the National Fadama Development Project. The programme is being implemented by States' Agricultural Development Projects and is to improve *fadama* infrastructure and introduce the low cost-petrol driven pumps to farmers. This to assist them to assess both surface and ground water for irrigation during the dry season and also supplement rainfall in the rainy season for food production all the year round.

Several authors have opined that increase in factor productivity and input efficiency is imperative for increasing production¹⁻³. This will offer solution to the food deficit problem particularly due to rapid population growth resulting in increased pressure on naturally endowed resources while traditional fallow periods are diminishing at a faster rate. This paper assesses and compares

the technical efficiency of farms under irrigated and rainfed production systems. The effects of the selected socioeconomic characteristics of farm households on individual technical efficiency are also investigated so as to identify factors that lead to inefficiencies.

Theoretical Framework

The efficiency of a firm refers to its success in producing as large an amount of output as possible from given set of inputs. Maximum efficiency is attained when it becomes impossible to reshuffle a given resource combination without decreasing the total output. Farrell⁴ has proposed that the efficiency of a firm consists of two components, namely technical and allocative efficiency components. According to Farrell⁴, technical efficiency is the ability to produce a given level of output with a minimum quantity of inputs under a given technology. It indicates the gains that can be obtained by improving resource management. The production frontier can be viewed as a firm's locus of maximum outputs from various sets of input combination. In this regard, it is possible that a firm, within its scale of operation, is not close to the frontier. On the other hand, there may be firms whose outputs are close to the frontier, given their levels of inputs. A measure of how close a firm is to the maximum output level as defined by the frontier, given its inputs level, is the measure of its technical efficiency. Allocative efficiency measures the degree of success in achieving the best combination of different inputs in producing a specific level of output, having regard to the relative

¹ *Fadama* is the Hausa word for low lying seasonally flooded areas in the river plains. *Fadama* farming is dry season farming carried out usually between the months of November and April every year.

prices of these inputs. When input price ratios are considered, there is only one point out of the several points on a technically efficient isoquant, which represents allocative efficiency. This is the point at which the price ratio line is tangent to the efficient isoquant. At this point, the amount of each input being used to produce the specified level of output is the minimum possible at the given prices of the inputs. It is the least-cost point. Economic or total efficiency is the product of technical and allocative efficiency.

Efficiency Measurement

Several empirical studies have been conducted on efficiency using different efficiency measures. They include those using the profit function ⁵, the production function ⁶, the mathematical programming ^{7, 8} and the production frontier function ⁸⁻¹⁰. Recently, the efficiency frontier has been more relatively used. Empirical studies of productive efficiency have used a wide variety of approaches in modeling the frontier production function including parametric and non-parametric techniques and deterministic and stochastic techniques. Given the alternative empirical tools available, the choice as to the best method is unclear ¹⁰. However, recent agricultural production efficiency studies have adopted the use of the stochastic parametric methodology ⁹⁻¹¹.

The stochastic production frontier was specified by Aigner *et al.* ¹² and by Meeusen and Van den Broeck ¹³. The major feature of the stochastic production frontier is that the disturbance term is composed of two parts, a symmetric and a one-sided component. The symmetric (normal) component, V_i , captures the random effects due to measurement error, statistical noise and other non-systemic influences outside the control of the firm. It is assumed to have a normal distribution. The one-sided (non-positive) component U_i captures randomness under the control of the firm. Its distribution is assumed to be half normal or exponential. The frontier is stochastic in that its placement is allowed to vary randomly across firms. The stochastic frontier function is specified as:

$$Y_i = F(X_{ij}; \beta) + v_i - \mu_i \quad i = 1, 2, \dots, N$$

- Y_i = Output of the i^{th} firm in unit/hectare
- X_{ij} = Vector of actual j^{th} inputs used by the i^{th} firm in unit/hectare
- β = Vector of production function parameters to be estimated
- V_i = Random variability in production that cannot be influenced by the firm
- U_i = Deviation from maximum potential output attributable to technical inefficiency

Direct estimates of the parameters can be obtained by either the maximum likelihood method or the corrected ordinary least squares (COLS) method, given suitable distributional assumptions for the error terms. The maximum likelihood estimator has, however, been found to be asymptotically more efficient than the COLS estimators ¹⁴, which explains the preference for it. The stochastic frontier model is adopted as the analytical tool in this paper.

Study Area and Data

The study was carried out in the derived savannah zone of Kwara state. The state is one of the thirty six states in Nigeria with an average annual rainfall ranging between 1000 and 1500 mm. The state's vegetation is made up of rainforest in the south, the derived

savannah in the middle and the Guinea savannah to the north. The state is essentially agrarian with rainfed farming being practiced by natives only while irrigated farming is practiced by few natives and migrant farmers from the drier states in northern Nigeria. Data was collected by means of structured questionnaire, and a multistage sampling technique was used to obtain the required sample. The state sixteen local government areas are stratified into four zones by the state's Agricultural Development Project (KWADP). The two zones in the derived savannah formed the sample frame for the study. The second stage of sampling involved the selection of villages in these zones where farmers participate in the *fadama* project and the last stage was the selection of farmers that were interviewed. In all, 130 responses of farmers under *fadama* and 104 from rainfed production systems were used in the analysis.

Data were collected on farm household characteristics, resource endowments, input and output variables. The input variables include land, family labour and hired labour, capital and water. The major farm outputs are vegetables under irrigation and grains and tubers under rainfed systems. The outputs of vegetable were converted into their grain equivalents ².

Empirical Model

The stochastic production frontier was used to measure the technical efficiencies under each production system. The approach developed by Jondrow *et al.* ¹⁵ and employed by Seyoun *et al.* ¹⁶ had been modified and used in this study. The empirical model is as specified in Equation 1 for farms under *fadama* irrigation production system. The technical efficiency for individual farm is computed as an index and the mean technical efficiency for each production system is determined. The factors that influence the technical inefficiency of the different production systems were identified and the parameters of the variables were estimated using the Coelli and Battese ¹⁷ inefficiency model. The inefficiency model is stated in Equation 2 for farms under *fadama* irrigation production system.

The stochastic frontier production function is:

$$\ln Y_i = \ln \beta_0 + \sum_{j=1}^m \beta_j \ln X_{ij} + v_i - \mu_i \dots\dots\dots 1$$

- where,
- Y_i = Farm output in grain equivalent on farm i
- X_i = Vector of inputs used measured in units
- X_1 = Farm size in hectares
- X_2 = Family labour in standard-days
- X_3 = Hired labour in standard-days
- X_4 = Other production costs (seeds, agro-chemicals) in Naira
- X_5 = Quantity of fertilizer used in kilograms
- X_6 = Quantity of water used in cubic metres
- v_i = Random variability in production that cannot be influenced by the farmer
- μ_i = Deviation from maximum potential output attributable to technical inefficiency
- β = Vector of production function parameters to be estimated
- $i = 1, 2, 3 \dots n$ farms.

¹ Grain equivalent is the standard conversion unit by which output of different crops are compared.

$j = 1, 2, 3 \dots \dots m$ inputs

The inefficiency model is stated as:

$$\mu_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \dots + \delta_5 Z_5 \dots \dots \dots 2$$

where,

μ_i = Technical inefficiency effect of the i^{th} farm

Z_1 = Age of the farmer in years

Z_2 = Years of irrigation farming

Z_3 = Dummy variable for education

(1 for having formal education, 0 otherwise)

Z_4 = Dummy variable for ownership of water pump

(1 for owning water pump, 0 otherwise)

Z_5 = Dummy variable for residency status

(1 for resident, 0 otherwise)

δ = Parameters to be estimated

For farms under rainfed production system, the variables in the model are as defined for *fadama* production system. However, water variable is not included in the model since rain is the source of water supply. The variables in the inefficiency model are age of the farmer in years, years of rainfed farming and dummy variable for formal education (1 for having formal education, 0 otherwise). The residency status becomes irrelevant for this production system because migrant farmers do not cultivate tubers and grains, due to the gestation period of these crops and the fact that they would have returned to their home base to participate in rainfed farming before they could harvest these crops.

The β and the δ coefficients are unknown parameters to be estimated along with the variance parameters σ_s^2 and γ . The sigma squared (σ_s^2) and gamma (γ) coefficients are the diagnostic statistics that indicate the relevance of the use of the stochastic production frontier function and the correctness of the assumptions made on the distribution form of the error term. The sigma squared (σ_s^2) indicates the goodness of fit and correctness of the distributional form assumed for the composite error term. The gamma (γ) indicates that the systematic influences that are unexplained by the production function are the dominant sources of random errors. The statistical significance of gamma shows that in the specified model, there is the presence of a one-sided error component (V_1). This implies that a traditional response function estimated by the ordinary least square cannot adequately represent the data, and the use of a stochastic production frontier function estimated by the maximum likelihood estimation

procedures is therefore appropriate. The parameters of the models were obtained by the maximum likelihood estimation method, using the computer programme, FRONTIER version 4.1.¹⁸

Results and Discussion

Socio-economic characteristics of farmers: The socio-economic characteristics of farmers are presented in Table 1. In both production systems the highest percentage of farmers is within the age bracket of 41 and 50 years with a mean age of 47.37 years and 50.12 years of *fadama* irrigation rainfed farming respectively. Although the mean ages are significantly different at 10 percent, the farmers are still relatively young and economically active. This is consistent with the findings of Amaza¹⁹. He found out that the mean age of farmers is 49.6 years in Gombe state of Nigeria. In both systems, male farmers outnumber the female ones. However, there are more female involved in rainfed farming than in irrigated farming. In both systems, about half of the farmers have formal education although the mean years of schooling is higher for rainfed farmers than those under irrigated farming and it is significantly different at 10 percent. Average family size is close to ten, which shows that there is opportunity of employing the available family labour for farm work. Farmers under rainfed system are, however, more experienced in farm activities than those under irrigation. Over 70% of farmers in both systems practice farming as primary occupation and are members of cooperative societies. All the farmers under rainfed system are resident farmers of the study area but only 36.92% are residents under irrigated system while others are immigrants.

Resource use patterns of farmers: The predominant system of land tenure under irrigated system is leasehold representing 66.15%. It is more diverse under rainfed system; with about 52% of farmers' cultivating inherited land, 27% on leased land and about 16% on borrowed land. The tenural system is related to the types of crops cultivated. Short-gestation crops are common under leasehold arrangements while longer gestation crops are mostly cultivated on inherited land.

Farms under rainfed system are generally larger than those under irrigated system ($P < 0.01$). The mean farm size under irrigated system is 0.45 hectares and 1.28 hectares under rainfed system. This result conforms to the findings of Ajibefun²⁰ about rainfed farmers in Ondo state. The study reported the mean farm size to be 1.36 hectares. In irrigated system, the labour use per hectare is more than in rainfed system ($P < 0.01$). The average labour use per hectare is 233.33 standard-days in irrigated system and 93.31 standard-days in rainfed system. This confirms that irrigated system is more labour intensive. The average cost incurred on seeds and agrochemicals is ₦4,009 and ₦2,650 per farm on irrigated and rainfed systems respectively. The higher cost incurred under irrigated system ($P < 0.10$) is due to the intensive system of farming under irrigation. The average quantity of fertilizers used is 1.57 bags in irrigated system and 1.00 bags in rainfed system. All farmers under irrigated system use fertilizer while only 56% of the farmers under rainfed system use fertilizer.

Table 1. Summary statistics of the socioeconomic characteristics and level of resource use of irrigated and rainfed production systems.

Variable	Irrigated		Rainfed		t-value of mean difference
	Mean	Standard deviation	Mean	Standard deviation	
Farm size (hectares)	0.45	0.27	1.28	0.78	5.46 ^{xxx}
Labour use per hectare (standard days)	233.33	60.38	95.31	42.52	6.11 ^{xxx}
Seeds and agrochemicals (Naira)	4009.17	2157.54	2650.09	1198.91	3.85 ^{xxx}
Fertilizer (50 kg)	1.57	0.84	1.00	0.61	2.97 ^{xxx}
Irrigation water (cubic metres)	2332.8	1099.05			
Farmers' age (years)	47.37	9.94	50.12	7.53	1.98 ^x
Years of formal schooling	3.96	2.72	4.52	3.80	2.25 ^x
Years of farm experience	16.68	11.53	25.57	10.96	3.01 ^{xxx}

-statistics showing statistical difference between the two systems: ^{xxx} significant at 1% level, ^{xx} significant at 5% level, ^x significant at 10% level.

Table 2. Maximum likelihood estimates of parameters of Cobb-Douglas stochastic frontier production function for farms under *fadama* irrigation production system.

Variable	Irrigated			Rainfed	
	Parameter	Coefficient	Standard error	Coefficient	Standard error
Stochastic frontier					
Constant	β_0	-4.320 ^{xxx}	0.812	-2.351 ^{xxx}	0.864
Farm size	β_1	0.428 ^{xxx}	0.132	0.392 ^{xxx}	0.115
Family labour	β_2	0.218 ^{xxx}	0.037	0.184 ^{xxx}	0.050
Hired labour	β_3	0.019 ^s	0.012	0.026	0.052
Other production inputs	β_4	0.044	0.038	0.386 ^{xxx}	0.099
Fertilizer	β_5	0.026 ^s	0.015	0.047 ^s	0.028
Irrigation water	β_6	0.275 ^{xxx}	0.138		
Inefficiency model					
Constant	δ_0	0.247	0.762	-1.218	1.037
Age	δ_1	0.049 ^{xxx}	0.017	0.054 ^{xxx}	0.014
Years of farming	δ_2	-0.031	0.027	-0.093 ^{xxx}	0.027
Dummy for formal education	δ_3	-0.928 ^{xxx}	0.369	-0.004 ^{xx}	0.225
Dummy for ownership of pump	δ_4	-0.539 ^{xxx}	0.259		
Dummy for residency status	δ_5	1.690 ^{xxx}	0.53		
Variance parameters					
Sigma squared	σ^2	0.288 ^{xxx}	0.064	0.193 ^{xxx}	0.046
Gamma	γ	0.954 ^{xxx}	0.013	0.555 ^{xxx}	0.133

^{xxx} significant at 1% level, ^{ss} significant at 5% level, ^s significant at 10% level.

The stochastic frontier model and resource use efficiency: The maximum likelihood estimates of parameters of the stochastic frontier model for farms under the two systems are presented in Table 2. The table contains the estimation of the parameters of the stochastic frontier production function, the inefficiency model and the variance parameters of the stochastic frontier model. The variance parameters for the two functions are statistically significant at the 1% level. This justifies the specification of a stochastic frontier production function and indicates that the inefficiency variables are significant in explaining the technical inefficiency of the farmers. Generally, the estimated coefficients for all the production inputs represent their elasticities as is typical of a Cobb-Douglas production function. They all have positive signs in both systems which shows that increase in input will lead to increase in output and vice versa. The magnitudes of the coefficients are less than one which implies that output is inelastic to changes in these inputs.

The estimated coefficients of farm size are 0.428 and 0.392 for irrigated and rainfed systems respectively. They are statistically significant at 1% level. A percentage change in input will result in 0.43 and 0.39% change in output in irrigated and rainfed systems respectively. This finding agrees with that of Onyenweaku ⁶. He found positive and inelastic production elasticities with respect to farm size which were statistically significant in irrigated and unirrigated farms. The coefficients for the family labour is 0.218 and 0.184 for irrigated and rainfed system respectively and are statistically significant at 1% level. Output is inelastic with respect to family labour under both systems but more under rainfed system. Rainfed farming is not an intensive system of farming and its labour requirement is lower than in irrigated farming. This allows for the family labour supply to be in excess. This may lead to workers having idle time and also more than enough people doing the work required for lesser number of people. The coefficient of hired labour for irrigated system is 0.019 and it is

0.026 for rainfed system. Only the coefficient for farms under irrigated system is statistically significant at 10%. The coefficient signifies that hired labour is highly inelastic. These results show that family labour remains the major source of labour supply in both systems and supplemented by hired labour. The estimated coefficients of other production inputs under irrigated system are not statistically significant. Under the rainfed system, the coefficient is 0.386 and it is significant at 10%. An increase of 1% in other production inputs will lead to an increase of 0.386% in output. The coefficients of fertilizer are 0.026 and 0.047 for irrigated and rainfed systems respectively. The low values of these coefficients indicate that crop production is highly inelastic with respect to fertilizer in both systems. The coefficient of irrigation water is 0.275 and it is statistically significant at 1% level.

Technical efficiencies of farmers: The farm specific efficiency indices are given alongside the estimates of the parameters of the function. The frequency distributions of the technical efficiencies in the two systems are given in Table 3. The results show the variation in the technical efficiencies of farms under the two systems. None of the farms has efficiency index of one, which shows that no farm operated on the efficiency frontier, leaving a gap to technical inefficiency. In irrigated system, the distribution of the technical efficiency of farms shows a wide gap between the most efficient farm (0.98) and the least efficient farm (0.44) which shows that inter-farm variation is high. The mean efficiency is 0.84 which shows a high level of technical efficiency on an average farm. The percentage of farms with efficiency indices above 0.80 is 73.07% while that below 0.50 is 3.08% indicating that a large percentage of the farms has high technical efficiency. Under rainfed system, the most efficient farm has an index of 0.96 while that of the least efficient farm is 0.21. The mean technical efficiency is 0.67. Only 33.66% of the farms have efficiency indices above 0.80 while about 15.38% have efficiency indices below 0.50.

We tested the hypothesis of equality of technical efficiency in the two systems using analysis of variance. The result shows statistically significant differences at the 5% level of significance.

Table 3. Frequency distribution of technical efficiencies of farms under irrigated and rainfed production systems.

Technical efficiency	Irrigated		Rainfed	
	Number of farms	Percentage of farms	Number of farms	Percentage of farms
≤ 0.50	4	3.08	16	15.38
0.51 - 0.60	4	3.08	4	3.85
0.61 - 0.70	5	3.85	16	15.38
0.71 - 0.80	22	16.92	33	31.73
0.81 - 0.90	45	34.61	25	24.04
0.91 - 1.00	50	38.46	10	9.62
Total	130	100	104	100

Sources of inefficiency: The Schumpeterian theory of economic development suggests that technical efficiency is influenced by technical knowledge and understanding, as well as by the socio-economic environment within which the farmer must take

decisions²¹. The signs on the coefficients in the inefficiency model are interpreted in the opposite way. A negative sign means that the variable increases efficiency and vice versa. In irrigated system, results reveal that older farmers are more inefficient than the younger ones and illiterate farmers are more inefficient than literate farmers. Farmers who do not own pumps and residents are also more inefficient than migrants. Under rainfed system, the sources of inefficiency include the older age of farmers, fewer years of farm experience and illiteracy.

Conclusions and Policy Implications

The socio-economic analysis reveals that the farmers are still young and economically active; with more males than females in both systems. However, there are more males under irrigated system than in rainfed one. About half of the farmers has formal education with a significantly higher number of years of schooling under rainfed system. About 70 percent practice farming as their primary occupation, although farmers under rainfed system have significantly higher years of farm experience. All farmers under rainfed system are residents while only 36 percent under irrigated are residents. Although smaller plots of land are cultivated under irrigated system than under rainfed system, resources are intensively used under irrigated system.

The stochastic frontier analysis reveals that increases in farm size, family labour and fertilizer will increase output levels in both systems. In addition, increases in hired labour and irrigation water will increase farm output under irrigated system. The mean technical efficiency under irrigated system is 0.84 and 0.67 under rainfed which reveals that there are potentials for improving production of farms under the two systems, but higher ones under rainfed system. Investigation of factors influencing inefficiencies reveals that the age of farmers, their level of education and their experience in farming affect their level of efficiency. In irrigated farming, migrants were more efficient than residents and ownership of water pumps enhances efficiency.

The policy thrust of this study is that farmland cultivated should be increased to increase output under both systems. Presently under irrigated farming, surface water is commonly used for irrigation but there is a need to access ground water for farming as land close to surface water will not be adequate to increase farm size and output. This can be achieved by installing tube wells instead of wash bore. The procurement of fertilizer can be improved on by the provision of institutional credit to farmers. This will also enhance the adoption of micro-irrigation technologies such as the water pump. Most of the farmers belong to cooperative societies; an on-lending loan scheme will ease the accessibility of credit to farmers, judicious use of the loan and efficient loan recovery. Adult literacy classes should be organized to improve the literacy level of the farmers. Irrigated farming is labour intensive and can provide a means of reducing unemployment in the country. A revitalization of the farm settlement scheme should be embarked upon with better monitoring. Irrigated farming can be made more attractive to women through sensitization programmes and improving their accessibility to inputs.

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