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Technical efficiency of catfish production in Oyo State, Nigeria. A case of freshwater culture systems using Data Envelopment Analysis (DEA) approach

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Target Audience*: Fish farmers*

Abstract

Nigeria is the highest fish consumer and offers the largest market for fish and fisheries products in Africa, fish as food is the main source of animal protein to this teemed population. Although domestic fish production is on increase despite this, the country still experiences short fall due to rapid growing human population. This study therefore estimates the technical efficiency and factors responsible for inefficiency of catfish production in freshwater culture systems using data envelopment analysis (DEA). The result shows that estimated inefficiency coefficients for age and household size ($p<0.05$); experience, farm size and extension service ($p<0.1$) were statistically significant. This agrees with the priori expectation that technical efficiency should increase with increase in these parameters. Furthermore, all inputs used by catfish farmers in production processes indicated slacks but at different degree. Fish feed, being the most important input in fish production, constitute more than half of production cost thus, farmers in the study area could operate on the production frontier by reducing their feed input levels by 7.33% and 8.25%, for concrete tanks and earthen ponds respectively. However, Research Institute and University should come up with a well-defined, nutritionally complete and affordable feed for catfish production and disseminate same to farmers. Also, subsidy programme should be introduced to reduce production costs, increase farmers' income and provide enough animal protein to the teeming population at affordable price.

Key words: *Concrete tank; earthen pond; fish farming; slack variables*

Description of Problem

Aquaculture is one of the sub-sectors in the fisheries sector which is experiencing rapid growth. By the year 2030, this sub-sector has the potential to contribute about 109 million metric tons largely to the world fish production and based on this, it is projected that this sub-sector would account for about 50% of the world fish production, providing approximately two third of fish consumed worldwide (1). To achieve this, the sub-sector must engage in efficient use of resources such as feed, labour, fish seed, culture systems, etc which will result to an increase in fish output keeping other practices such water pollution, fish diseases and losses under control (2).

Nigeria is the most populous country in Africa with over 200 million people and largest economy in Africa with GDP of US$376.284bn in 2018 (3). Nigeria is the major fish consumers and offers the largest market for fish and fisheries products in Africa (4). The main source of animal protein to this teeming population is fish, as a result of this, fisheries sector in Nigeria is saddled with the responsibility of providing food security to the fast-increasing population (5). Nigeria has aquaculture potential which constitutes 75% of 923,768 km^2 of the land mass and 14 million hectares of inland water. Since 2005, domestic fish production has been on increase; despite the increase, fish supply is still unable to meet up with demand of fish due to rapid human population. The situation has widening demand-supply gap which has led to huge importation of fish to augment local production (5). In 2019, the Minister of Agriculture, Chief Audu Ogbeh stated that $60 million was spent to augument this deficit (6).

Fish farming is an aspect of aquaculture but at time the two are used simultaneously because output from aquacultural production is from fish farming (7). Fish farming could either be water base or land base (concrete or earthen ponds, vats (wooden or fibre glass) and plastics tank). A lot of challenges are hindering production of land base culture systems, which has continued to limit growth of this sector. Nigeria has the largest economy in Africa this has made her to compete seriously for land for industries, leading to greater scarcity and hence high land prices or rental rates, thereby making it difficult for small-scale fish farmers to expand their farms (8). Moreover, in Nigeria price of commodities is on the high side this has not left livestock feed out. Prices of feed have escalating over time, thus forcing fish farmers to reduce the use of pellet feed and opt for household food waste and animal offal to feed fish, this has reduced the quality and quantity of fish produced resulting to low profit margin at the end of production cycle (8). However, these may contribute directly or indirectly to technical inefficiency. Factors such as the farmer's age, experience, household size, educational level, and frequency of contact with extension workers may be responsible for the technical inefficiency at farm level. To increase farmer's income, it is imperative to improve the technical efficiency (optimal use of inputs) resulting into lower production costs per unit and higher returns to fish farmers. This study aims to estimate the technical efficiency and determine the factors responsible for inefficiency of freshwater culture systems.

Materials and Methods

Study Area

This study was carried out in Ibadan/Ibarapa Zone; one of the four Agricultural Zones in Oyo State, Nigeria, with 14 Local Government Areas (LGAs). The other Zones are Oyo with 4 LGAs, Ogbomosho with 5 LGAs and Saki with 13 LGAs.

Sampling Procedure and Data Collection

Multistage sampling technique was employed to select respondents in the study area. In **stage I**, purposive sampling technique was used to select 7 LGAs from the selected agricultural zone. In **Stage II**, twenty-five (25) registered homestead catfish farmers were selected using simple random sampling technique from the selected LGAs to give a total number of one hundred and seventy-five (175) homestead catfish farmers. At the end of questionnaire administration, thirteen (13) copies of administered questionnaire were discarded as a result of non-response and inadequate information and data from One hundred and sixty-two (162) respondents were used for the analysis. The valid responses consisted of 94 and 68 decision-making units (DMUs) for concrete tanks and earthen ponds respectively.

Primary data for the study were obtained from a cross-section of homestead catfish farmers using a structured questionnaire.

Location of fish farmers were gotten from the State Catfish Farmers Association with the assistance of the zonal headquarters of Oyo State Agricultural Development Programme. Data collected included demographic characteristics such as age, sex, marital status, household size, educational level, household size, and fishing experience; inputs used for catfish production per production cycle; fixed input, variable input, and the output of catfish production. Before the commencement of this study, a pilot study was conducted to validate the research instrument (questionnaire) and all the necessary changes and adjustments were effected.

Data Description and OLS

Table 1 showed the description of variable used in this study. The output represents the total quantity of fish produced per production circle measured in kilogrammes (kg). For this study, the optimal measure of output is the quantity index based on the prices of cultured specie. However, data on the prices of each single fish could not be gotten, thus total fish production was used as a proxy for output (10, 11, 12). Stocking density, feed, labour (family and hired workers) and other costs were used as the inputs. Number of fingerling stocked was used to determine the stocking density. Feed is considered as the most expensive inputs in fish farming business (13) and is assessed in kilogramme (kg), fish farmers were asked about the quantity (kg) of feed used throughout the production cycle. Labour unit was measured according as man day (14). This was estimated by the number of hours spent (family and hired workers) on the farm using man-days as the unit. The rule of thumb is that eight working hours is equivalent to one day (1 man-day for single adult, 0.75 man-day for adult female and 0.50 man-day for child of less than 18years) (15, 16). Other cost includes purchase/rent of farm land, maintenance and repair of implements and drugs which was measured in Naira (USD 1 = ₦ 464).

Technical Efficiency Determinants

Men have the likelihood of increasing technical efficiency in catfish production than their female counterpart (8). This is attributed to the fact that fish farming is strenuous and energy consuming (5). Also, men are easily motivated to adopt recent innovation whereas some women are risk taker a times (5). Age and experience are incorporated in the model to investigate whether they have any influence on technical inefficiency. Elderly farmers are expected to have accrued more experience overtime and hence demonstrate more technical efficiency. On the other hand, age may influence older farmers not to adopt new/improved technology whereas; young farms are likely to adopt new/improved technology, making them to be more technically efficient. Household size is believed to have more influence on technical efficiency, farmers with large families may have better helping hands in assisting in some farm operations, especially in developing countries (Nigeria) resulting in efficient use of resources. Education is projected to influence technical efficiency positively. Farm size and extension services are expected to influence technical efficiency positively, the bigger the farm the better the technical know-how.

Table 1. Description of variables in the Data Envelopment Analysis (DEA) and OLS model

Variable	Description	Unit
Output	Total quantity of fish produced	Kg
Number of fish stocked	Fingerlings stocked in the farm	Number
Feed	Total quantity of feed utilized (imported or local feed)	15Kg (bag)
Labour	Labour used	Man-days
Other costs	Costs incurred from other inputs	Naira (₦)
Technical efficiency determinants		
Gender	Represent the gender of fish farmer/manager (male = 1, female = 0)	Dummy
Age	Represents age of fish farmer/manager	Year
Experience	Represents number of years the farmer/manager spent in fish farming	Year
Household size	Number of the fish farmer family	Number
Educational level	Level of education of fish farmer/manager	Years spent in school
Farm size	Number of ponds	Number
Extension services	Extension visits to fish farm in the last three years (1 = yes; otherwise)	Dummy

Naira (US$ 1 = ₦ 464.0)

Slack variable analysis identifies the efficiency of the use of resources; it helps one (farmer) to know the best level of resources to be used to achieve a maximum level of output and the level of resources and output slacks. It also allows one to analyse resource efficiency and output efficiency (5, 17). The data was tested for normality distribution before the OLS regression analysis was carried out, dummy variables were not included. No multicollinearity was detected among the variables using variance inflatory factors (VIF) and tolerance test; the data are well fitted for OLS regression analysis

Concepts and Measures of Efficiency

Efficiency is considered as estimation of the production frontier based on distance function. The concept of technical efficiency is the ability to produce maximum output from a given set of inputs (18, 19). As proposed by Farrell, there are two types of efficiency for the input-oriented problem and they are as follows:

1. Technical efficiency (TE) which is measured as the ratio between the observed output and the maximum output, under the assumption of fixed input.
2. Allocative or price efficiency (AE) refers to the ability to combine inputs and outputs in optimal proportions in the light of prevailing prices and is measured in terms of behavioural goal of the production unit like, for example, observed optimum cost or observed optimum profit.

$$Efficiency = \frac{weighted\ sum\ of\ input}{weighted\ sun\ of\ outputs} \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

Two different approaches can be used to measure efficiency: The Stochastic Frontier Analysis (parametric approach) and Data Envelopment Analysis DEA (non-parametric approach). Several authors have used DEA, since its ingestion in several fields especially in fields like banking, transportation, education, agriculture, manufacturing (15). DEA allows one to calculate the efficiency scores, the input and output slack values, and to identify the production units which are fully efficient. The efficiency score is determined by optimizing DEA model either in constant returns or in variable returns. In addition, DEA model can be optimize following the production unit objective's orientation. The input-oriented DEA models consider the possible (proportional) input reduction while maintaining the current levels of outputs. The output-oriented DEA models consider the possible (proportional) output augmentation while keeping the level of inputs. However, these standard DEA models do not take account of slacks in the "objective function". An additive DEA model was developed which considers a possible input decrease as well as output increase simultaneously (21). However, it does not measure the intensity of inefficiency, as well as standard models (22). In this respect, (22) proposed a slack based model (SBM) that optimize the input and output slacks and provide a pure measure of efficiency. Thus, DEA input-oriented model was adopted for the study to estimate technical efficiency. The model is expressed as follows:

min $\theta_i \lambda_j$

st:

$$Y_{\mathrm{rj}} - \sum_{\mathrm{j=1}}^{\mathrm{n}} Y_{\mathrm{rj}}\lambda_j \leq 0, r = 1.\dots\dots\dots\dots\dots.., s$$

$$\theta_{\mathrm{i}} x_{ik} - \sum_{\mathrm{j=1}}^{\mathrm{n}} X_{\mathrm{kj}}\lambda_j \geq 0, k = 1.\dots\dots\dots.., m$$

$$\sum_{\mathrm{j=1}}^{\mathrm{n}} \lambda_j = 1$$

$\lambda_{\mathrm{j}} \geq 0, j = 1, \dots\dots, n\dots\dots$ adapted from (15)

where θ_i denotes the technical efficiency of the i-th fish farm, this i-th fish farms uses m inputs set X_{ik} (m represents stocking density, feed (kg), labour, costs incurred from other inputs) to produces s output set λ_j (s represents different types of fish products); m is the number of inputs (i = 1. . .m); s is the number of outputs (r = 1. . .s); n is the number of fish farms (j = 1. . .n); λ_j is a nonnegative vector that permits the construction of a production possibility set for j DMU; Yrj is a vector of output level; X_{kj} is a vector of observed inputs (23).

Results and Discussion

The minimum and maximum technical efficiency scores were estimated as 0.427 and 0.981 for concrete tanks system and 0.514 and 0.971 for earthen pond system as shown in Table 2. On average, the technical efficiency score of catfish farmers in the study area was estimated at 0.812 and 0.855 for concrete tanks and earthen ponds culture systems respectively. This finding is relatively similar to the findings of (24, 25, 17, 14, 26, 27). This suggests that the least technically efficient catfish farmer could increase his technical efficiency by additional 57.0% and 49.0% for concrete tanks and earthen ponds culture system respectively, while the best technically efficient catfish farmer given available technology and inputs could improve production by an additional 2.0% (concrete tanks) and 3.0% (earthen ponds) on the frontier. Also, the average technical efficiency of both culture systems indicated that catfish farmer in the study area could increase their technical efficiency by additional 19.0% and 15.0% respectively for maximum production. However, less than 10.0% of the catfish farmers have technical efficiency score lower than 0.70. This implies that most of the catfish farmers in the study area operate close to the production frontier.

Table 2: Distribution of technical efficiency of freshwater culture systems

Efficiency score	Culture systems			
	Concrete tanks		Earthen ponds	
	Frequency (94)	Percentage	Frequency (68)	Percentage
< 0.5	1	1.06	-	-
0.5 – 0.59	2	2.13	1	1.47
0.60 – 0.69	5	5.32	2	2.94
0.70 – 0.79	13	13.8	9	13.2
0.80 – 0.89	24	25.5	39	57.4
0.90 – 1.00	49	52.1	17	25.0
Mean	0.81		0.85	
Standard deviation	0.17		0.09	
Minimum	0.43		0.51	
Maximum	0.98		0.97	

***Source*:** Computed from survey data

Table 3 show the slack variable of freshwater culture systems. The findings estimate the percentage of fish seed slacks for freshwater culture systems to be 0.235 for concrete tanks and 0.141 for earthen ponds. This implies that fish seed inputs could be reduced by 0.23% and 0.14% without changing the output levels for concrete tanks and earthen ponds respectively. Based on these findings, the stocking density needs no or little adjustment. The estimated percentages of feed slacks for concrete tanks and earthen ponds were 7.3 and 8.253. This implies that fish farmers in the study area could operate on the production frontier by reducing their feed input levels by 7.33%, and 8.25%, respectively. During the course of the study, it was observed that almost all the fish farm in the study area operate on small scale level having common limitation of inadequate access to quality feed resulting total or partial dependent on locally formulated feed. However, poor feeding practice could increase production costs, deplete water quality parameter thereby reducing the dissolved oxygen content, subsequently resulting into low feed intake and high mortality rate leading to financial loss. Percentages labour slacks was 0.384 and 0.428 for both culture systems, implies that labour input needs no or little adjustment. This could be attributed to total dependence of family labour which is one of the characteristics of small-scale farming.

Table 3: Slacks variable of freshwater culture systems

Input slacks (%)	Culture system	
	Concrete tanks	Earthen ponds
Fish seed	0.235	0.141
Feed used	7.34	8.25
Labour	0.384	0.428
Other costs	5.46	6.13
Total	13.4	14.9

***Source*:** Computed from survey data

Technical Inefficiency Analysis

The estimated inefficiency parameters were presented in Table 4. It showed that the estimated coefficients for gender, age, experience, household size, educational level, farm size and extension service were -0.00251, 0.000917, -0.00616, -0.00917, -0.0367, -0.00385 and -0.00786 respectively. In this study inefficiency was used as dependent variable, hence variables with negative coefficient (sign) had positive impact on technical efficiency. The estimated coefficient of age shows significant impact on technical efficiency. This implies conservative nature of older fish farmers making them to become less willing to adopt improved innovations resulting into low technical efficiency in production. However, the coefficient of education implies that fish farmers with higher educational qualification tend to be technically efficient to their counterpart with low educational qualification, but this relationship was statistically insignificant as a result of mode operation (small scale). The coefficient of catfish farmers' experience was found to be negative and statistically significant ($p < 0.05$). This implies that experienced farmers are more technically efficient. Experienced farmers are believed to have acquired skills over time. This finding was similar to the study of (28) conducted in Cross River State who reported that farming experience was also a significant determinant of technical inefficiency. The findings agree with the *a priori* expectation that technical efficiency should increase with increase in years of experience. Furthermore, the coefficient of household size was negative and statistically significant ($p < 0.05$), implies that the larger the household size better the input efficiency usage. Also, farm size was statistically significant ($p < 0.1$) with negative coefficient; this implies that technical efficiency increases with increase in farm size.

Table 4: Determinants of technical inefficiency in freshwater catfish farming

Variables	Coefficient	Standard error	*t*-value	*p*-value
Gender	-0.00251	0.00154	-1.63	0.42
Age	0.000917	0.00035	2.59	0.07
Experience	-0.00616	0.00213	-2.89	0.03
Household size	-0.00917	0.00715	-1.28	0.01
Educational level	-0.0367	0.0207	-1.77	0.78
Farm size	-0.00385	0.0651	-0.0531	0.09
Extension services	-0.00786	0.0038	-2.06	0.02

***Significant at 1%, **Significant at 5%

***Source*:** Computed from survey data

Conclusion and Application

1. This paper examined the technical efficiency of catfish production using four variables (inputs), out of these variables (fish seed, fish seed labour and other cost) fish feed and other cost had highest degree of slack.
2. Fish feed, being the most important input in fish production, constitute more than half of production cost thus, farmers in the study area could operate on the production frontier by reducing their feed input levels thus, research institute and university through extension workers in collaboration with farmer's

association and other relevant agencies should come up with a well-defined feed (feed formula) for fish production in relation to intend culture system.

3. Also, fish farmers should be educated on feeding regime to curb wastage and mortality due to over feeding.

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