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Statistical Analysis of Technical Efficiency of Smallholder Pearl Millet Farmers in North-western Nigeria: A Stochastic Frontier Approach

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Abstract:
Millet is a prominent staple food among households in northern Nigeria; hence the bulk of its production is from the region. This study examined the technical efficiency of smallholder pearl millet farmers in north-western Nigeria. Using a sample of 430 smallholder farmers in the Kano and Jigawa states, the data for the study were collected during the 2015/2016 cropping season. Stochastic frontier analysis and least square regression were used to estimate the technical efficiency of millet farmers and to examine its determinants, respectively. The results obtained from the stochastic frontier analysis show substantial technical inefficiency among smallholder pearl millet farmers. The results reveal that all the six production variables used in the model: farm size, fertilizer, manure, labour, seed, and agrochemical, had a positive technical relationship with pearl millet output and were statistically significant. The elasticity of production, with a value of 1.83, showed that the pearl millet farmers were operating at an increasing return to scale. The result also reveals an average TE of 82 percent. The best practicing and the least technically efficient pearl millet farmers had technical efficiencies of 96 and 64 percent, respectively. In addition, in the OLS models, farmers' socio-economic factors such as farm size of farmers, type of seed planted, household size, education, access to credit, and extension contact were found to determine technical efficiency. Results of the study revealed a need for strong policies towards ensuring an efficient means of accessing farmland, labour, and improved pearl millet varieties access. Policies should also be formed to ensure easy and timely access to credit to pearl millet farmers and strengthen the extension programs for effective extension services delivery in the study area.

Keywords: *Statistical analysis, technical efficiency, stochastic frontier, pearl millet, north-west*

1. Introduction

Pearl millet is an important cereal that makes up about two-thirds of the total cereal production in Africa, and it is regarded as one of the world's four most essential cereal crops (millet, rice, maize, and sorghum). Its ability to withstand stress and thrive in hot regions has made it quite popular in hot regions and especially across many African countries, which account for about 55 percent of the global total pearl millet production and also take up 59 percent of the total global area under pearl millet cultivation (Bhagavatula *et al.,* 2013). Within Africa, more than 13.63 million hectares are put to use, accounting for about 74 percent of the total area cultivated in Africa, and 28 percent of the world's total production is in West Africa. According to FAO (2013), Nigeria, as one of the most important millet-producing countries in the world, produces almost half (40 percent) of total African millet production. The northern part of Nigeria provides an ideal agro-ecological condition for the production of pearl millet, and the bulk production of this crop is from north-eastern and north-western regions, which contributes a greater proportion of the national production.

In recognition of the crucial role millet plays in the regions' food security, the Nigerian government, in 1975, established 'Lake Chad Research Institute (LCRI)', mandated to facilitate research in millet production in the country by way of developing improved technologies. Over the years, the agency has made appreciable achievements through the release of improved varieties such as LCIC MV-1 (SOSAT – C88) and LCICMV-3 (Super SOSAT) with potential yields of 3.0 – 4.0 tones ha^{-1} (LCRI, 2018). Other concerted efforts, such as with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to promote millet production, have been in existence since 2008. However, despite the aforementioned government's efforts, millet production in Nigeria has witnessed a decline in the last decade. FAO (2018) listed the main factors undermining crop production in Nigeria to include:

- Reliance on rain-fed agriculture,
- Smallholder land holdings,
- Low productivity due to poor planting material,
- Low fertilizer application, and
- A weak agricultural extension system, amongst others

To worsen the situation is the menace of religious sects ravaging the north-eastern parts of the country, which make farming activities almost impossible in the region, further increasing the demand for pearl millet in the region. Empirical evidence has indicated that Nigeria's average pearl millet yield is lower than the potential expected yields, making studying efficiency in pearl millet production worthwhile. For instance, the potential yield, as presented by (ICRISAT 2014; LCRI, 2018), is 2.5-4.0 tons ha^{-1} of millet per hectare has never been achieved in the country; the yield per hectare in Nigeria has been ranging from 1-1.5 tons ha^{-1}. Inefficient practices by smallholder farmers can impede the socio-economic and overall agricultural development of a population (Dewbre & Battisti, 2008). In order to increase farm productivity in pearl millet, the availability of resources must be complemented with efficient use. It is, therefore, very important, if not necessary, to study efficiency in pearl millet production, which will go long a long way in determining the direction of resource adjustment that could lead to higher productivity. To this end, this study estimated the technical efficiency of pearl millet smallholder farmers in Northwest Nigeria and their determinants in addition to the farmers' production elasticity.

2. Materials and Method

2.1. Study Area

The study was carried out in the Northwest Area of Nigeria, with seven states that made up the North-western region. These include: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara states, with Kano state being the most populous (40 percent of the total population in the region) (NPC, 2006).

2.2. Sampling Procedure and Method of Data

Primary data were used for this study and collected with the aid of a structured questionnaire. Multi-stage random sampling was used for this study. In the first stage, simple random sampling was used to select two states (Kano and Jigawa) from the north-western states. In the second stage, systematic random sampling was used to select 300 pearl-millet farmers from the total population of 1,102,711 pearl-millet farmers in Kano state, such that 1,102,711 was divided by 300 to get 3,676, and a number was randomly selected between 1 and 3,676, and the number picked happened to be farmer 2,940th which was considered as the starting number for selecting the sample size for the state. The next sampling units were farmers numbered 6,616, 10292, 13,968, and so on to 1,102,064, which winded up with 300 farmers from Kano state. In the third stage, a systematic sampling procedure was used to select 200 pearl millet farmers from a total population of 735,141 pearl-millet farmers from Jigawa state such that 735,141 was divided by 200, which gave 3,676 and a number between was randomly selected from 1 and 3676 and it happened to be 1,835 which was taken as starting number for the sampling. The next sampling units for Jigawa state were farmers numbered 5,511, 9,187, 12,863, and so on to 733360, which gave the 200 sampled farmers and eventually added up to 500 farmers sample size. However, a total number of 430 valid questionnaires were retrieved.

2.3. Analytical Techniques

Stochastic frontier analysis (SFA) and multiple regressions were used to analyse the data.

2.4. Model Specification

According to Battese and Coelli (1977), the stochastic frontier production function has the advantage of estimating the farms' discrete technical efficiency and its determinants concurrently. It is implicitly expressed in equation (4) as follows.

$$Y_i = f(x_i, \beta)e^{\emptyset}, i = 1, \dots, N \quad (4)$$

Where:
Y_i is the output produced by the i^{th} farm,
X_i is a vector of inputs used by the i^{th} farm, and
β is a vector of parameters to be estimated,
ϕ is the random error term, which can be decomposed as:

$$\emptyset_i = v_i + u_i \quad (5)$$

V_i in the above equation corresponds to the random component representing factors that are beyond the control of the farmer and left out independent variables (Aigner *et al.,* 1977) assumed to be independently and identically distributed (id). As a result, V_i is distributed $N(0, \delta_V^2)$ and is independent of the U_i. On the other hand, U_i represents a random variable that accounts for technical inefficiency in production and is assumed to be independently distributed, truncated at zero, and normally distributed with mean μ and variance ($[N(\mu, \delta_u^2)]$) where the inefficiency effects are exhibited in terms of other variables (Battese & Coelli, 1995) and expressed in equation (6) as below:

$$u_i = Z_i\delta + E_i \quad (6)$$

Where:

Z_i is a vector of independent variables related to the technical inefficiency effects,

δ is a vector of unknown parameters to be estimated, and E_i stands for unobservable random variables, which are assumed to be identically distributed.

The stochastic production frontier of the technically efficient farmer would represent the maximum achievable output (Y_i^*) as follows:

$$Y_i = f(X_i, \beta)exp(V_i) \quad (7)$$

This can, therefore, be used to estimate the technical efficiency of all other farms in relation to this technically efficient farm. Consequently, the technical efficiency (TE_i) of the i[th] farm is presented in equation (8):

$$TE_i - \frac{Y_i}{f(X_i, \beta)exp(V_i)} \quad (8)$$

Where:

TE_i may be conceptualized as the ability of a producer i[th] farm to produce relative to a maximum yield using a given amount of input and available technology. From the above equation, we can discern that TE is the ratio of observed output to maximum feasible output in an environment characterized by exp(v_i).

The estimation of the stochastic production frontier function may be observed as a variance decomposition model, which can be expressed in equation (9) as:

$$\delta^2 = \delta_u^2 + \delta_v^2 \quad (9)$$

Where:

δ_u^2andδ_v^2respectively are the variances of the parameters symmetric (v) and one-sided (u) error terms. The variance ratio parameter γ_i, which relates the variability due to technical inefficiency (u) to the total variance (δ^2) (Jondrow *et al.,* 1982), can be calculated as in equation (10) as:

$$\gamma = \frac{\delta_u^2}{\delta^2} = \frac{\delta_u^2}{\delta_u^2 + \delta_v^2} \quad (10)$$

As it is apparent from the discussion above, the parameter γ is an indicator of the relative variability of the two sources of variations which takes the value between zero and one, i.e., 0≤ $\gamma \leq 1$. Hence, if γ is nearer to zero, the symmetric error term dominates the variation between the frontier maximum attainable level of output and the observed level of output. Put differently, a value of γ close to zero denotes that the difference between the observed and the maximum achievable levels of output is dominated by random factors outside the control of the farmer, while the bigger the value of γ is, the more the production is subjugated by variability stemming from technical inefficiency.

2.5. Specification of the Empirical Model

A two-stage technique was employed in this study (Battese & Coelli, 1995; Kitila & Alemu, 2014). The stochastic frontier production function was first used to analyze the technical efficiency of pearl millet farmers, and then, the OLS regression model was used in the second stage to analyze determinants of TE. The simple notion behind the MLE principle is to select the parameter estimates to maximize the probability of obtaining the data (Ali & Khan, 2014). The production function is specified in Cobb-Douglas functional form in equation (11) as below:

$$lnY_i = \beta_0 + \beta_1 lnX_{1i} + \beta_2 lnX_{2i} + \beta_3 lnX_{3i} + \beta_4 lnX_{4i} + \beta_5 lnX_{5i} + \beta_6 lnX_{6i} + V_i - U_i \quad (11)$$

Where:

- Ln = the natural logarithm
- Y_i = Quantity of Pearl millet output (kg)
- X_1 = Farm Size (hectares)
- X_2 = Fertilizer (Kg)
- X_3 = Manure (ox-cart)
- X_4 = Labour (man-day)
- X_5 = Seeds (kg)
- X_6 = Agrochemicals (litres)
- V_1 = Stochastic component of error term not under the control of farmers
- β_0 = Intercept
- β_1 - β_6 = Parameters to be estimated
- i = number of farms

2.6. OLS Estimation of Technical Efficiency Determinant of the Farmers

It is a well-known fact that most researchers used the Tobit regression model to investigate determinants of TE in the second-stage. However, Since TE scores are fractional in nature and not generated by a censoring procedure, this

approach has been extremely criticized for producing inconsistent estimation, hence contextually inappropriate (Banker and Natarajan, 2008).
The model is expressed in the equation as:

$$\Psi_{TE} = \propto_0 + \propto_1 Z_{Age} + \propto_2 Z_{Fsize} + \propto_3 Z_{Edu} + \propto_4 Z_{Exp} + \propto_5 Z_{SedTyp} + \propto_6 Z_{Coop} + \propto_7 Z_{Crdt} + \propto_8 Z_{Ext} + \propto_9 Z_{HHsize} + \propto_{10} Z_{Distmkt} \quad (12)$$

Where:

- $\Psi_{TE,}$= represents the technical efficiency of the i^{th} farmer.
- Z_A =age of the farmer (years)
- Z_{Fsize} =Farm size (hectare)
- Z_{Edu} = educational level of farmers (years)
- Z_{Exp} = Farming experience (years)
- Z_{SedTyp} =Type of seed planted (Improved=1, Recycled=0)
- Z_{Coop} = Cooperative membership (member=1, otherwise=0)
- Z_{Crt} = Access to credit (Access=1, otherwise=0)
- Z_{Ext} = visits by an extension agent (number)
- Z_{HHsize} = Household size (number of persons)
- $Z_{Distmkt}$ =Agrochemicals (Kilometres)

2.7. Modeling Framework and Concept of Efficiency

Production efficiency is either measured by parametric or by non-parametric methods. Literature on efficiency measures has been shaped by the seminal work of Farrell (1957) for non-parametric approaches and by Aigner et al. (1977) for parametric approaches. The principle behind efficiency measures involves a comparison of the observed output with the potential (attainable) output. However, the potential output is not known in practice and thus must be estimated.

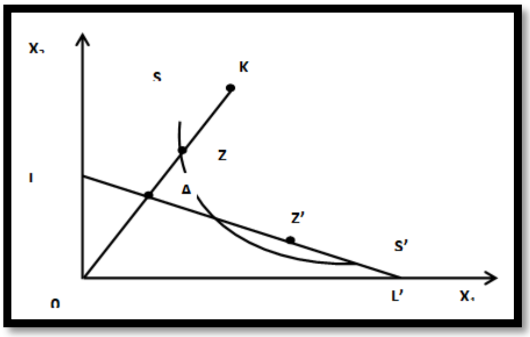

Figure 1: Input-oriented Measures for Technical, Allocative, and Economic Efficiencies

Originally, the input-oriented efficiency concept, which is adopted in this study, was introduced by Farrell (1957). Farrel (1957) defined 'efficiency' in three related terms, and the graphical illustration of his definitions is presented in figure 1 above. He illustrated the firm using two factors of production, X_1 and X_2, to produce a single output Z by considering CRS frontier function. In order to show the input-oriented efficiency and allocative efficiency concepts, he used a convex Isoquant curve, as shown in figure 1.

The fundamental aim of analyzing input-oriented efficiency is to address the question of how much quantity of factors of production needs to be proportionally reduced to achieve the same level of output as before. A fully technically efficient firm could be represented by the set of production points along the curve SS', and Z* is an allocative efficient farm (Slope = ratio of the price of X_1 and X_2). LL* signifies the iso-cost line (where SS* is tangential to the iso-cost line), as shown in figure 1.

In a condition where the firm uses a factor of production represented by point K to produce a single output level, the technical inefficiency level of the firm could be represented by the distance ZK, which is exactly equal to the proportion by which the factor of production could be reduced to attain technically efficient production level. Hence the technical efficiency of firms in the case of input-oriented efficiency is commonly measured by the ratio: $TE = OZ/OK$, which is equal to 1− (ZK/OK), where ZK/OK is the technical inefficiency portion of the firm. For a technically efficient firm, the ratio of ZK/OK is zero, and the ratio of OZ/OK is equal to one.

The value of firm efficiency is always found between 1 and 0. If the TE score is one, it indicates that the firm is technically efficient, which is represented by point Z in figure 1 as it lies on the isoquant curve. Therefore, all farmers that produce along the isoquant are 100 percent technically efficient. Thus, technical (TE), allocative (AE), and economic (EE) efficiencies of farm P can be measured by the ratios:

$$TE = {}^{OZ}/_{OK} \quad (1)$$

$$AE = {}^{OA}/_{OZ^*} \quad (2)$$

$$EE = {}^{OZ}/_{OK}\, X\, {}^{OA}/_{OZ} = {}^{OA}/_{OK} \quad (3)$$

An efficient farm is indicated by a score of 1, and a measure of inefficiency is 1, the relative efficiency value or the distance from the inefficient point to the frontier.

3. Result

3.1. Production Variables and Factors Hypothesized to Explain TE Inefficiency in Pearl Millet Production in North-western Nigeria

Table 1 shows the Summary Statistics & Expected Signs of the Variables per Hectare used in Technical efficiency **(TE).** The production variables in the estimation of efficiency were farm size, fertilizer, manure, labour, seed, and agrochemicals, while the socio-economic variables that were hypothesized to be associated with the technical efficiency of pearl millet farmers include the age of farmers, size of farm cultivated by farmers, education, farming experience, type of seed sown by farmers, and cooperative membership, access to extension service, access to credit, household size and distance to market. The hypothesized variables, their description, and expected signs are shown in table 1.

Variables	Units	Mean	S.D.	Min.	Max.	Expected Sign
Farm size	Hectare	2.53	1.25	0.50	6.00	+
Fertilizer	Kilogram	213.30	98.34	44.00	467.50	+
Manure	Ox-cart	36.00	21.98	3.60	99.00	+
Labour	Man-days	86.00	39.03	21.00	185.00	+
Seed	Kilogram	75.56	37.62	16.00	160.00	+
Agrochemicals	Litre	3.48	1.67	1.00	8.00	+
Age	Years	39.00	11.40	20.00	77.00	-
Education	Years	10.30	5.64	0.00	18.00	+
Experience	Years	10.70	7.10	1.00	33.00	+
Type seed sown	1=improved, 0=traditional or conventional					+
Co-operative	1=yes, 0=No					+
Access to Credit	1=yes, 0=No					+
Extension Contact	1=yes, 0=No					+
Household size	No. of Persons	7.00	6.83	1.00	30.00	+/-
Dist. to Market	Kilometres	7.93	8.19	0.00	50.00	-

Table 1: The Summary Statistics & Expected Signs of the Variables Per Hectare Used in Technical Efficiency (TE)

3.2. Technical Efficiency Distribution of Pearl Millet Farmers in North-western Nigeria

Table 2 shows the frequency distribution of the stochastic production frontier model in Cobb-Douglass functional form of stochastic production frontier was used to estimate the technical efficiency of pearl millet farmers in the study area. The stochastic frontier model permits for technical inefficiency and that random shock beyond the control of the farmer can have an effect on output. The average technical efficiency for the 430 randomly sampled pearl millet farmers was 82 percent, with minimum and maximum technical efficiency of 64 percent and 96 percent, respectively. The maximum technical efficiency of 96 percent reveals that none of the sampled pearl millet farmers reached the frontier threshold.

Attaining an estimated average technical efficiency of 82 percent for the pearl millet production indicates that the farmers were cultivating at about 18 percent further down the frontier level, thus, revealing a substantial inefficiency among pearl millet farmers in the study area. Conversely, in the short-run, farmers, on average, could decrease inputs (farm size, fertilizer, manure, labour, seed, and agrochemicals) by 18 percent to achieve the output they are currently getting if they use inputs efficiently by adopting a superior improved technique and technology to attain the technical efficiency of 100 percent. The results further indicate that for the average farmer in the sample to attain the technical efficiency of his/her most efficient peers, he/she could achieve about 14.58 percent {1–(0.82/0.96) x 100} cost savings. Similarly, the least technically efficient farmer will have 33.33 percent {(1– 0.64/0.96) x 100} cost savings to become the most efficient farmer.

This estimate of technical efficiency is analogous to the findings of other studies recently reported. For example, Iliyasu *et al.* (2016), Shavgulidze *et al.* (2017), Yang *et al.* (2017), Vasanthi *et al.* (2017), Tefaye and Beshir (2016), Koirala *et al.* (2016), and Bwala *et al.* (2015) have estimated mean technical efficiency levels of 79 percent in Malaysia, 81 percent in Georgia, 81.7 percent in China, 82 percent in India, 79 percent in Ethiopia, 79 percent in the Philippines, and 82 percent in Nigeria, respectively.

Technical Efficiency	No. of Farmers	Percentage	Min	Mean	Max
0.61-0.70 0.71-0.80	8 166	1.9 38.6	0.64	0.82	0.96
0.81-0.90	229	53.3			
0.91-.99	27	6.3			
1.00	0	0.00			
Total	430	100.00			

Table 2: Technical Efficiency Distribution of Pearl Millet Farmers in North-western Nigeria

3.3. OLS Parameter Estimates of Average Production and Maximum Likelihood (ML) Parameter Estimates of SPF for Smallholder Pearl Millet Farmers

Table 3 shows that the OLS and ML estimates of production function parameters are based on equation (11) discussed in the previous page. The ordinary least square (OLS) model yields the estimates of the average (traditional) production function, whereas the Maximum Likelihood (ML) function provides estimates stochastic production frontier. The coefficient parameters across the models showed a level of similarities which confirms that the frontier function represents a neutral upward shift of the traditional (average) production function. The results correspond to the findings of Bravo-Ureta and Pinheiro (1997). Furthermore, the two models' parameter estimates are positive and statistically significant. The analysis also reveals that the coefficient of determination (R^2) of 0.68, indicating that about 68 percent of the variation in pearl millet output was explained by inputs (farm size, fertilizer, manure, labour, seed, and agrochemicals) included in the OLS model. The F-ratio (506.50) is significant at a 1 percent level, meaning that the OLS regression model is of good fit.

The result of the maximum likelihood estimates of the Stochastic Frontier of pearl millet production function is presented in table 3. The sigma-square was 0.7813 ($p<0.05$), attesting to the good fit of the model. Gamma (ɣ) is also a measure of the level of inefficiency in the variance parameters and ranges between 1 and 0. For the Cobb-Douglas model used in the study area, it is estimated to be 0.458 ($p<0.05$) or approximately 46 percent. This establishes the fact that inefficiencies exist in the sampled pearl millet farmers and indicates that 46 percent of the total variation in pearl millet output is due to a small percentage of technical inefficiency in the study area, suggesting that a greater percentage was due to random shocks (flood, pests and diseases, weather) beyond the control of the pearl millet farmers.

Therefore, the result of the diagnostic statistic validates the appropriateness and correctness of the stochastic parametric production function and the maximum likelihood estimation model employed. Since our focus is on ML estimates, the interpretation and discussion in this study are only on the coefficients obtained from stochastic frontier function analysis of technical efficiency.

The estimated coefficient for farm size (0.372) was positive and statistically significant at 1 percent. This implies that a 1 percent increase in farm size will *ceteris paribus* lead to an increase of 0.5415 percent in output. This increase is inelastic because a 1 percent increase in the input leads to a less than 1 percent increase in the output. This result is not at variance with those obtained by Sibiko *et al.* (2013), Wassie (2014), and Lubadde *et al.* (2016) but varied from one observed by Haji (2007), Ng'ombe and Kalinda (2015), and Mugambi *et al.* (2015) who found a coefficient of farm size to be significant but negative indicating inverse relation of farm size with technical efficiency.

The production elasticity of output with respect to the quantity of fertilizer was 0.219, positive and statistically significant at 1 percent level. This implies that a 1 percent increase in the amount of fertilizer applied on the farm will increase output by 0.1355 percent *ceteris paribus*. Similar results were found by Abedullah *et al.* (2007). Essilfie *et al.* (2011), Alwarritzia *et al.* (2015), and Ali and Jan (2017); but contrary to Ambali (2012), Jordan (2012), and D onkoh *et al.* (2013) that found that fertilizer had a negative influence on technical efficiency in their respective studies. According to these researchers, the negative effect of an adequate quantity of fertilizer application indicates that improved performance is independent of fertilizer applied by farmers.

Variables	**OLS Estimates**	**t-ratio**	**ML Estimates**	**t-ratio**
Constant	5.510 (0.255)	21.623***	2.077 (0.086)	23.999***
$\ln X_1$=Farm size	0.566 (0.255)	10.139***	0.372 (0.042)	8.783***
$\ln X_2$=Fertilizer	0.095 (0.056)	2.222**	0.219 (0.034)	6.535***
$\ln X_3$=Manure	0.146 (0.043)	4.289***	0.109 (0.045)	2.444**
$\ln X_4$=Labour	0.146 (0.034)	3.055**	0.729 (0.233)	3.125***
$\ln X_5$=Seed	0.060 (0.048)	1.992**	0.206 (0.036)	5.591***
in agrochemicals	0.031 (0.017)	1.823*	0.198 (0.077)	2.588***
R^2	0.68			
F-Statistic	506.504***			
Sigma-squared(δ^2)			0.781	
gamma (ɣ)			0.458	
Log-likelihood Function			43.58	
Sample Size (n)	430		430	

Table 3: OLS and ML Parameter Estimates Based on a Sample of Pear
**** and ** Stand for Significant at 1 Percent and 5 Percent Levels, Respectively,*
^{Ns}=Not Significant. Values in Parenthesis Are Standard Error

3.4. Elasticity of Production (EP) and Return to Scale (RTS)

Table 4 shows the results of the production elasticities for the inputs in the Cobb-Douglas frontier function. The estimated elasticity of production of farmers in the study area shows increasing return to scale (IRS). All the inputs' elasticities are inelastic, that is, one percent (1%) increase in each of these inputs results in less than one percent increase in output (yield). The RTS parameter computed from the summation of the coefficients of estimated inputs is 1.83 (which means an increase in all inputs combined by 1% increases pearl millet yield by 1.083). This stage is usually characterized by inefficiency as it exhibits increasing returns to scale. At this stage, in the short run, an increase in the input would yield more than the proportionate increase in the output (Florence *et al.,* 2018).

Variables	Coefficient
LnFarmsize	0.372
LnFertilizer	0.219
LnManure	0.109
LnLabour	0.729
LnSeed	0.206
LnAgrochemicals	0.198
RTS	1.8327

Table 4: Elasticity of Production (EP) and Return to Scale (RTS)

3.5. Comparison between the Efficient, Average, and Least Efficient Farmers in Terms of Inputs Used Per Hectare

Table 5 shows that the quantities of inputs used by the most technically efficient farmers in the sample to produce an average output of 2,301.52 kg $^{ha-1}$ were fertilizer (110kg $^{ha-1}$), manure (45 ox-cart $^{ha-1}$), labour (40 Man days $^{ha-1}$), seed (40.00 kg $^{ha-1}$) and agrochemicals (1.00 litre $^{ha-1}$). In contrast, an average efficient farmer in the sample used fertilizer (77.85Kg $^{ha-1}$), manure (14.43 ox-cart/ha), Labour (32 man^{-days} $^{ha-1}$), seed (27.79 kg $^{ha-1}$), and agrochemicals (1.24 litre ^{ha1}) to produce 1230.66kg ^{ha1} of output. Similarly, the least technically efficient farmer in the sample made use of fertilizer (312 Kg $^{ha\ 1}$), manure (20 ox^{-cart} $^{ha-1}$), labour (48 man^{-days} $^{ha-1}$), seed (88 kg $^{ha-1}$), and agrochemicals (4.00 litre $^{ha-1}$) to cultivate an average pearl millet output of 1235.52kg $^{ha-1}$.

These results imply that fertilizer, manure, Labour, and seed were under-utilized, while agrochemical was over-utilized by the average technically efficient farmer in the sample. Therefore, for the average technically efficient farmer to attain the technical efficiency of their most efficient counterpart in the sample, they should increase the use of fertilizer, manure, labour, and seed by 32.85kg ha^{-1} (42.20 percent), 30.57 ox-cart ha^{-1} (211.85 percent), 8 man-days (23.49 percent) and 12.21 kg ha^{-1} (43.94 percent) of the quantity being used, respectively. However, agrochemicals were over-used, and their use should be reduced by 0.24 liters ha^{-1} (19.94 percent) to ensure efficient pearl millet production.

In the same vein, compared to the most technically efficient farmer, the less technically efficient farmer in the group over-utilized fertilizer, labour, seed, and agrochemical while under-utilizing manure. So, since the utilization of these inputs has exceeded their optimum level as used by the most technically efficient farmer. In order to achieve optimal resource allocation in pearl millet production, it is necessary to reduce their use by 202kg ha^{-1} (64.74 percent), 8 man-days ha^{-1} (16.67 percent), 48kg ha^{-1} (54.55 percent), and 3 liters ha^{-1} (75 percent) from the levels currently used by farmers, respectively. Moreover, the least efficient farmers should increase the use of manure by 25 ox-cart ha^{-1} (125 percent) since this particularly was found to be lower than its optimum level compared to the most efficient farmer. The findings are similar to the results reported by Coelli *et al.* (2002), where fertilizer and labour were found to be highly over-utilized by rice farmers in Bangladesh.

	Efficient Farmer	**Average Efficient Farmer**			**Least Efficient Farmer**		
Variable	**Quantity of Inputs Used**	**Quantity of Inputs Used**	**Deviation from Optimality**	**% Deviation from Optimality**	**Quantity of Inputs Used**	**Deviation from Optimality**	**% Deviation from Optimality**
Farm size	1Ha	1Ha	1Ha	1Ha	1Ha	1Ha	1Ha
Fertilizer	110Kg	77.85Kg	32.85Kg	42.2	312 Kg	-202 Kg	-64.74
Manure	45 Ox-cart	14.43 Ox-cart	30.57 Ox-cart	211.85	20 Ox-cart	25 Ox-cart	125
Labour	40M/days	32 M/days	8 M/days	23.49	48 M/days	-8 M/days	-16.67
Seed	40Kg	27.79Kg	12.21 Kg	43.94	88 Kg	-48Kg	-54.55
Chemicals	1 Litre	1.24 Litre	-0.24 Litre	-19.35	4 Litre	-3 Litre	-75.00
Output	2301.52Kg	1230.66Kg	1070.86 Kg	87.02	1235.52	1066.00 Kg	86.28

Table 5:1 Comparisons between the Efficient, Average, and Least Efficient Farmers in Terms of Inputs Used Per Hectare

4 Conclusions and Recommendations

4.1. Conclusions

Stochastic production and OLS models were used in this study to estimate the technical efficiency of smallholder pearl millet farmers in north-western Nigeria.

Both socio-economic and demographic factors determining technical efficiency levels were also explicated. The results reveal that the average technical efficiency was 82 percent, ranging from 64 to 96 percent. This indicates that the farmers were cultivating at about 18 percent further down the frontier level, which means they are operating close to the frontier. The implication is that; although the average pearl millet farmers in north-western Nigeria are considerably technically efficient, full efficiency was not attained. Therefore, the null hypothesis that pearl millet farmers in the area are fully efficient is rejected. Hence, there is evidence of inefficiency among farmers in producing pearl millet in the study area. The return to scale value indicates that the production of pearl millet in the study area was on stage I of production.

The factors that have been identified as contributing positively towards improving technical efficiency include: farm size, farming experience, cooperative membership, and extension contact, while the age of farmers and distance of farm to market affected the technical efficiency negatively. That means young farmers, with more experience and contacts with extension staff, cultivate a larger farm size that is located close to the market and belonging to cooperative societies are more likely to be efficient.

4.2. Recommendations

Finally, well-designed policies aiming at increasing resource productivity can positively impact pearl millet production. Farmers' socio-economic variables must be considered while creating policies that aim to increase efficiency since there is a link between these two factors (efficiency and socio-economic factors). These policies should be very critical components of programs that would enable smallholder pearl millet producers to be more efficient in the north-western region of Nigeria.

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