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SUSTAINABLE TECHNICAL EFFICIENCY: EVIDENCE FROM VEGETABLE (WATERLEAF: *TALINUM TRIANGULARE*) PRODUCTION IN SOUTHERN NIGERIA

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Abstract. This study defined sustainable technical efficiency from a set of efficiency indices generated from the maximum likelihood estimation of the stochastic production functions fitted on data collected from waterleaf farms in the Uyo agricultural zone of Akwa Ibom State, southern Nigeria. A multi-stage random sampling method was employed to choose two hundred respondents. A structured questionnaire was administered to the respondents to obtain the necessary data for the study. The empirical results revealed an average technical efficiency of 52.23% while the sustainable technical efficiency averaged 87.77% among waterleaf farmers in the zone. Determinants of Sustainable technical efficiency were identified using the Logit and Tobit models. The results of the two models were consistent and in line with the inefficiency model. Findings revealed that farmers' age, number of female farmers, household size, farm size, farming experience, access to extension services, membership in social organization, land ownership status and non-farm income earned by farmers positively affected the sustainable technical efficiency of waterleaf farmers in the zone. On the other hand, farmers' education, farming experience, cost of labour and value of post-harvest losses negatively affected sustainable technical efficiency. To achieve sustainable technical efficiency in waterleaf production, it is recommended that membership in social organizations should be intensified among waterleaf farmers. Also, land development is critical for the sustainability of waterleaf production in the zone. In addition, female beneficiaries should be the major target of any government intervention in waterleaf production. Training-based on-farm demonstrations, focus group discussion, advocacy and talks are preferred instead of a curriculum or formal education for waterleaf farmers in the State.

Keywords: waterleaf, technical efficiency, sustainable, vegetable, Akwa Ibom State

INTRODUCTION

Waterleaf (*Talinum triangulare*) is among the popular vegetable crops widely grown and consumed in the southern region of Nigeria (Udoh, 2005; Udoh and Akpan, 2007; Akpan et al., 2018; Akpan et al., 2019a and Akpan, et al., 2019b). Its production has enormous economic benefits to resource-poor farmers. Crop production serves as a means of complementing family income and is a reliable livelihood option for a good number of unemployed people, especially women in the region (Udoh and Akpan, 2007 and Akpan et al., 2019b). Production of waterleaf has the advantage over other vegetable crop enterprises in terms of lower set-up cost, short gestation period and high demand all year round (Udoh and Akpan 2007; Akpan et al., 2013). The medicinal qualities of the crop have been reported by several researchers (Mensah et al., 2008 and Ikewuchi et al., 2017). The crop is rich in carbohydrates, steroids, protein, fat, oil, minerals, crude fibre etc. (Aja et al., 2010 and Amusat et al., 2018).

Waterleaf production requires farm resources that are relatively scarce and have competing needs (Udoh, 2005 and Udoh and Akpan, 2007). The majority of the waterleaf farmers in the region are resource-poor (Udoh, 2005; Akpan et al., 2019c and Akpan et al., 2020). Due

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to the competing needs of farm resources by other crop enterprises and high population density, as well as rapid urbanization (Akpan and Ebong, 2021) in the region, optimum efficiency in farm resource management by waterleaf farmers is the key to sustainable production. Currently, waterleaf is an integral part of urban agriculture, and its production has become one of the most highly preferred livelihood activities among unemployed women in the southern region of Nigeria (Udoh and Etim 2008; Nya et al., 2010; Akpan et al., 2010; Uko et al., 2019 and Akpan, 2020). The sustainability of small-scale farm enterprises like waterleaf production is critical and is necessitated by the need to meet the dietary requirement of the teeming consumers and also achieve food self-sufficiency in the southern region (Akpan et al., 2019c and Olugbire et al., 2021). This is because the bulk of food produced in the country is derived from small-scale farm enterprises. Predicated on the above fact, the federal government of Nigeria in recent times has directed most of its farm-level policies and programmes toward increasing the technical efficiency of small-scale farm enterprises in a sustainable manner (Akpan et al., 2011; Akpan et al., 2017 and Oke et al., 2021).

Achieving sustainable technical efficiency is more than just optimizing farm resource use. It takes into consideration the economic, environmental, political and social, as well as cultural hindrances affecting farm production today and in the future (Brundtland, 1987). Hence, sustainable technical efficiency hinges on efficient management of farm resources at all times. According to Borza (2014), it offers workable options to eradicate poverty and hunger while improving the environmental performance of agriculture. As noted by Aye and Mungatana (2011) and Bulagi (2020), the improvement of agricultural productivity, amidst the various negative externalities, is the only effective strategy to address food security in rural communities.

Based on the increasing importance of the waterleaf crop, especially in the southern region of Nigeria, it is obvious that its sustainable production is paramount and should occupy the pivotal position around which policies on vegetable production revolve in the region. It is against this background that the current efforts by the waterleaf farmers in the region need to be re-assessed to identify factors that would promote sustainable production.

Attempts by researchers to study the productivity of waterleaf farmers in the southern region of the country have focused mainly on the technical efficiency and production analyses, as well as costs and returns without due consideration of the aspect of sustainable production. For instance, Udoh and Akpan (2007) estimated the stochastic production function of waterleaf in Akwa Ibom State and found significant inelastic contributions of farm size, planting materials, labour, fertilizer and farmyard manure to waterleaf production. Input-output relationship exhibited increasing returns to scale. In addition, the mean technical efficiency index of 0.65 was discovered while farmers' ages, household size and contact with the extension agents were significant in explaining variations in the technical efficiency indices of waterleaf farmers. Also, Udoh and Etim (2008) estimated the technical efficiency of urban-based waterleaf farmers in Akwa Ibom State. The results revealed an increasing return to scale and mean efficiency index of 0.82 units, while farming experience and education were important variables affecting technical efficiency. In a similar vein, Enete and Okon (2010) worked on the profitability of waterleaf production in Akwa Ibom State. The findings showed a high profitable index of 0.78 among farmers and also identified the use of poultry manure, larger household size, increased farmers' education and capital accumulation as the key factors affecting the output of waterleaf in the State. Recently, Uko et al. (2019), Akpan (2020) and Akpan and Monday (2021) established a positive relationship between farm inputs utilization and output of waterleaf in the humid tropical rainforest belt of Nigeria.

As observed, there is scanty literature on waterleaf enterprise productivity and the old literature needs to be updated. The waterleaf enterprise is an evolving enterprise with a great future, therefore more studies are needed to design an appropriate policy path for its sustainability in the region. Guided by this fact, this study was developed as a deviation from the usual technical efficiency study but rather focused on the sustainable technical efficiency and its determinants among waterleaf farmers in the Uyo agricultural zone of Akwa Ibom State in the southern region of Nigeria. Hence, the study specifically estimates the indices of sustainable technical efficiency and identified factors that influence it among waterleaf farms in the southern region of Nigeria.

RESEARCH METHODOLOGY

The study was conducted in the Uyo agricultural zone of Akwa Ibom State, southern Nigeria. The zone consists of the following local government areas as shown in figure 1: Uyo, Uruan, Ibesikpo Asutan, Itu and Ibiono Ibom Local government areas. Crops widely grown in the zone are leafy vegetables, cassava and garden egg. Others include maize, yam, pepper, plantain and cucumber. Some households grow cash crops such as oil palm, rubber and cocoa.

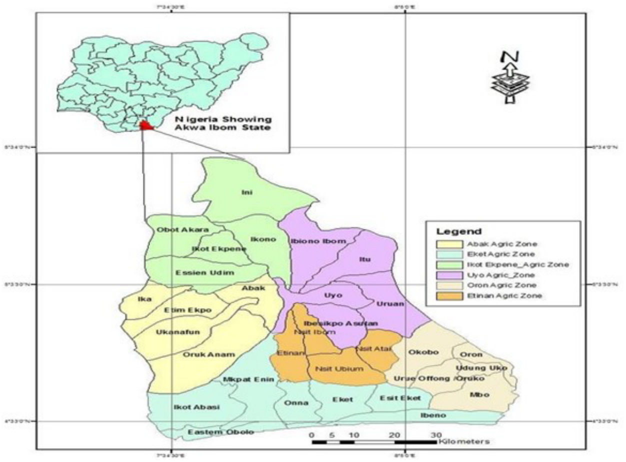

Fig. 1. Map of Akwa Ibom State showing the six agricultural zones
Source: retrieved from Akwa Ibom State government.

Sample size selection

The study employed Cochran (1963) formula to derive a representative sample size from a large population of waterleaf farmers in the study area. The equation is specified as thus:

$$S_n = \frac{z^2 P(1-P)}{D^2} \tag{1}$$

where:

S_n – is the required sample size
Z – is the 95% confidence interval (1.96)
P – is the expected proportion of waterleaf farmers in the total farm population in the study area (about 85%)
D – is the absolute error or precision at 5% type 1 error.

The sample size is derived as shown in equation 2.

$$S_n = \frac{(1.96)^2 0.85(1-0.85)}{(0.05)^2} = 196 \tag{2}$$

The representative sample was increased to 200 waterleaf farmers for convenience and proportional sampling.

Sampling techniques

The Uyo Agricultural Zone was chosen purposefully from the total of six agricultural zones in the State. The primary reason was the large population of waterleaf farmers and consumers in the zone. A multi-stage sampling technique was used in the study. The first stage was the purposive selection of four out of five local government areas (Uyo, Ibesikpo Asutan, Itu and Uruan local government areas) in the zone. The reasons were to obtain an even spread of the respondents and captured areas noted for intense production in the zone. The second stage involved randomly selecting two clans from each local government area. A total of eight clans were randomly picked for the study. The following clans were selected: Etoi and Offot clans in Uyo local government area; Ibesikpo and Asutan Ekpe clans in Ibesikpo local government area: Itu and Itam clans in Itu local government area; southern and central Uruan clans in Uruan local government area. The third stage focused on a random selection of twenty-five waterleaf farmers from each clan. A total of two hundred waterleaf farmers were selected and used for the study. The study used primary information from waterleaf farmers in the study area. The social, economic and production data were obtained from the waterleaf farmers using a structured questionnaire. The information gathering was complemented by the use of personal interviews conducted with key informants in the study area.

Theoretical framework and analytical techniques

The study is based on the theory of production with emphasis on resource use efficiency and the concept of production frontier analysis. The resource use efficiency concept is derived from the production theory and is based on the assumption that output is a function of the level of inputs and the efficiency of the producer in using those inputs. The production frontier assumes that the boundary of the production function is defined by the best practice firms. Therefore, it indicates the maximum potential output for a given set of inputs. The difference between the observed output and the potential output is generally attributed to a combination of inefficiency and random error.

Citing Battese and Coelli (1995), stochastic production frontier (SPF) is defined as:

$$Y_j = f(X_j - \beta)\exp(V_j - U_j) \tag{1}$$

where:

Y_j – is the output of *j* firm
Xj – is a vector of factor inputs
V_j – is the stochastic error term and
U_j – is a one-sided error representing the technical inefficiency of firm *j*.

Both V_j and U_j are assumed to be independently and identically distributed with constant variance and zero means. Technical efficiency (TE) of a firm using SPF is given as:

$$\begin{aligned} TE = \frac{Y_i}{Y_i^{\square}} &= \frac{\text{Observedoutput}}{\text{Fronteroutput}} = \\ &= \frac{f(X_j - \beta)\exp(V_j - U_j)}{f(X_j - \beta)\exp(V_j)} \exp(U_j) \end{aligned} \tag{2}$$

Implicitly, it is shown as thus:

$$\begin{aligned} \text{Log}WAL = \delta_0 + \delta_1\text{Log}FAM + \delta_2\text{Log}HOL + \\ + \delta_3\text{Log}HRL + \delta_4 Log\text{FER} + \delta_5\text{Log}WED + \\ + \delta_6\text{Log}CAP + \delta_7\text{Log}MAU + (V_1 - U_1) \end{aligned} \tag{3}$$

where:

WAL – output of waterleaf measured in (kg)
FAM – land size of farmer measured in hectare
HOL – household labour (mandays)
HRL – hired labour (mandays)
FER – quantity of fertilizer (kg)
WED – waterleaf stem cultivated (kg)
CAP – depreciation value of farm asset as a proxy of farm capital (Naira)
MAU – quantity of manure measured in kg
$(V_i - U_i)$ – composite error term
$\delta_0 - \delta_7$ – parameters for estimation.

Technical inefficiency and factors influencing it among waterleaf farmers

The stochastic frontier production specified in equation 3 was used to generate indices of the technical efficiency and determinant of technical inefficiency simultaneously using a single-stage maximum likelihood estimation procedure. The interpretation of determinants of technical efficiency was the opposite of the result on the determinants of technical inefficiency. Implicitly, the determinants of technical inefficiency are specified as thus:

$$\begin{aligned} INE = \beta_0 + \beta_1 AGE + \beta_2 EDU + \beta_3 GEN + \beta_4 EXP + \\ + \beta_5 HHS + \beta_6 FAS + \beta_7 EXT + \beta_8 SOC + \beta_9 TIC + \\ \beta_{10} LOW + \beta_{11} LAC + \beta_{12} SPT + \beta_{13} INC + u_i \end{aligned} \tag{4}$$

where:

INE – technical inefficiency
AGE – age of the farmers (years)
EDU – education level of the farmer in years
GEN – gender (dummy 1 for female farmers and 0 for male farmers)
EXP – farming experience (years)
HHS – household size (Number)
FAS – farm size (ha)
EXT – access to agricultural extension agent (number of times being visited in a year)
SOC – membership in a social organization (number of years)
TIC – amount of ticket paid in the market (naira)
LOW – land ownership (dummy 1 for yes and 0 for no)
LAC – labour cost (naira)
SPT – quantity of waterleaf spoilt or stolen measured in naira
INC – income from non-farm sources (naira).

Measuring sustainable farm-level technical efficiency

The technical efficiency indices generated from the stochastic production function consist of various farm-level efficiencies. However, not all farm-level technical efficiency indices can be considered as being sustainable. Hence, for this study on waterleaf farmers, we proposed a range of technical efficiency that can be considered sustainable technical efficiency. This range is equal to or greater than the average technical efficiency but less than the frontier efficiency. Given a group of single output enterprises, it will require efficient management of scarce firm resources for a member to operate on the average efficiency domain of the group. Also, given the small nature of farm firms considered in the study and the assumption of constant returns to scale on the model specification, it is assumed that the majority of waterleaf farms will want to work hard to attain the average efficiency level and above in farm resource management to sustain the business. Another reason is that frontier efficiency is not a sustainable efficiency because resources could be overstressed and this could result in the collapse of the entire production process. Hence, the decision for a farm to sustain efficient management of farm resources is assumed to be a summation of equal pressures from economic circumstances, environmental, cultural and political pressures, as well as social and climatic environments, among others. Based on this concept of the sustainability of small-scale farming, we considered sustainable farm resource efficiency indices as ranging from the average efficiency to the maximum efficiency possible (but not up to the frontier efficiency) obtained by a firm in the same category of the production group. In a more explicit form, we defined sustainable efficiency () of a small-scale farm or firm as:

$$Y_i = \textit{Technical efficiency} \geq \textit{Threshold} \vee \textit{averag eefficiency but} < \textit{frontier efficiency}$$

Hence, given:

$$\textit{Efficiency Index equation } Y_i^* = X_{Ii}'\beta_1 + (V_1 - U_1) \qquad (4)$$

$$\textit{Threshold equation } Y_i = \{1 \textit{ if } Y_i^* \geq ME < FE, \wedge \textit{ is } 0 \textit{ if } Y_i^* < ME < FE\} \qquad (5)$$

In a more explicit mathematical form it is given thus:

$$1 = Y_i^* = X_{1i}'\beta_{1i} + (V_1 - U_1) \textit{ if } X_{1i}'\beta_1 + + (V_1 - U_1) \geq ME < FE \qquad (6)$$

$$0 = Y_i^* = X_{1i}'\beta_{1i} + (V_1 - U_1) \textit{ if } X_{1i}'\beta_1 + + (V_1 - U_1) < ME < FE \qquad (7)$$

where:

Y_i^* – is the farm level efficiency index derived from the stochastic production function
X_{Ii}' – is a vector of farm resource used in the production function
β_i – is a vector of production elasticity,
ME – is the threshold or average efficiency index in a group of farms while
FE – denotes frontier efficiency.

A binary Logit model was fitted to indices of technical efficiencies generated from the stochastic production function following the definition of sustainable technical efficiency. The Logit model is given below:

$$SUE = \left(\frac{P_i}{1 - P_i}\right) = Z_i$$

$$= \beta_0 + \beta_1 AGE + \beta_2 EDU + \beta_3 GEN + \beta_4 EXP + + \beta_5 HHS + \beta_6 FAS + \beta_7 EXT + \beta_8 SOC + \beta_9 TIC + \beta_{10} LOW + \beta_{11} LAC + \beta_{12} SPT + \beta_{13} INC + u_i \qquad (8)$$

where:

SUE – is sustainable efficiency level and is a dummy representing 1 for farm index that occurs within the range defined as sustainable and 0 otherwise.

The marginal effect of the Logit model measures the instantaneous effect that a change in a particular explanatory variable has on the predicted probability when the other covariates are kept fixed. They are obtained by computing the derivatives of the conditional mean function for explanatory variables.

$$\frac{\delta P_i}{\delta X_i} = \frac{E(Y|X\}}{\delta X_i} = f(Z_i)\beta_i = f(X\beta_i)\beta_i \qquad (9)$$

Note, the dummies in equation 5 were converted to latent variables and the Tobit model fitted to the data. This was done to check the consistency of results from the two models. Hence, for the Tobit model, equation 5 became:

$$Y_i = \{Y_i \textit{ if } Y_i^* \geq ME < FE, \text{ and is } 0 \textit{ if } Y_i^* < ME < FE \qquad (10)$$

All variables for the determinants of sustainable efficiency are as defined previously.

Production parameters

The following production parameters were estimated and used to assess the farm factor productivity of waterleaf farmers in the study area.

$$APP = \frac{Output}{Input} = \frac{Q}{X} \qquad (11)$$

$$MPP = \frac{Change \in output}{Change \in input} = \frac{\Delta Q}{\Delta X} \qquad (12)$$

$$\text{Production Elasticity} = \frac{MPP}{APP} = \frac{\Delta Q}{\Delta X} \cdot \frac{X}{Q} \qquad (13)$$

note:

APP – is the average physical productivity,
MPP – is the marginal physical productivity,

while Q and X represent output and input, respectively.

RESULTS AND DISCUSSION

The maximum likelihood estimates of the Cobb Douglas production function for waterleaf farmers in the study area is presented in Table 1. The coefficient of the sigma square (0.2529) is statistically significant at a 1% probability level. This indicates the goodness of fit for the data used and the correctness of the specified distribution assumption of the composite error term for the model. The variance ratio coefficient of 0.7771 is significant at a 1% probability level suggesting that the systematic influence that is not explained by the production function is relatively dominant in the random error sources. This result means that the existence of inefficiency in

Table 1. Maximum likelihood estimates of Cobb-Douglas stochastic production function for waterleaf farms in Uyo Agricultural Zone Akwa Ibom State

Variable	Parameter	Coefficient	Standard error	t-value
Constant	$\varnothing_0$	0.6887	0.7087	0.9718
Farm Size	$\varnothing_1$	1.1106	0.5593	1.9856*
Family labour	$\varnothing_2$	0.0821	0.0264	3.1098***
Hired labour	$\varnothing_3$	0.0133	0.0333	0.3994
Qty. of Fertilizer used	$\varnothing_4$	–1.1752	0.3817	–3.0791***
Qty. of Manure used	$\varnothing_5$	0.0907	0.0294	3.0850***
Quantity of waterleaf planted	$\varnothing_6$	0.1269	0.0156	8.1346***
Capital depreciation	$\varnothing_7$	0.0362	0.0169	2.1420**
Determinants of technical inefficiency				
Age	β_1	–0.0023	0.0072	–0.3194
Education	β_2	0.2416	0.0377	6.4085***
Gender	β_3	–0.9176	0.4464	–2.0556**
Farm experience	β_4	0.0485	0.0225	2.1556**
Household size	β_5	–0.1956	0.0462	–4.2338***
Farm size	β_6	–0.9184	0.1996	–4.6012***
Extension access	β_7	–0.151	0.0404	–3.7376***
Social organization	β_8	–0.0633	0.0221	–2.8643***
Market ticket	β_9	0.0089	0.0017	5.2353***
Land ownership	β_{10}	–0.8659	0.2341	–3.6988***
Labour cost	β_{11}	0.0001	1E-05	10.0000***
Spoilt quantity in naira	β_{12}	0.0024	0.0012	2.0000**
Non- farm income	β_{13}	–1e-05	7e-06	–1.4286
Diagnostic statistics				
Sigma squared	∂^2	0.2529	0.0344	7.3517***
Gamma	Λ	0.7771	0.0649	11.9738***
Log-likelihood ratio		–0.123309		
LR test		0.476675		

*, ** and *** represent 10%, 5% and 1% significance levels respectively. Variables are as defined in equations 3 and 4.
Source: own elaboration.

resource use among waterleaf farmers' accounted for about 77.71% of the variations in the output level of waterleaf while the remaining 22.29% is due to the normal stochastic error sources. The presence of a dominant one-sided error component in the specified model is thus confirmed, implying that the Ordinary Least Squares estimation method would be an inadequate representation of the data used.

Farm factor productivity

Production parameters derived from the estimated Cobb Douglas production function are presented in Table 2. The result revealed that increased use of fertilizer in waterleaf production would result in a decline in the total output of waterleaf produced. The marginal physical product and production elasticity for this variable are negative, suggesting that its utilization level is in stage three in a classical production surface; hence, it is advisable to reduce usage. The reason for the result is likely connected to the fact that waterleaf is soft and succulent and can easily be scorched by inorganic fertilizer. Waterleaf farmers preferred organic manure, especially poultry droppings, to inorganic fertilizer.

The result also revealed that hired and family labour, manure usage and farm capital are rationally employed in the production of waterleaf by farmers in the study area. The increased use of these resources by farmers would lead to a corresponding and rational increase in the total output of waterleaf produced. Uko et al. (2019) have reported a positive relationship between organic manure application and waterleaf output.

Also, the farm size utilized by farmers is depicted in stage one (irrational stage) in the classical production surface. This implies that waterleaf farmland expansion would result in more addition to output. Hence, waterleaf production needs more farmlands to contribute rationally to overall farm yield. The return to scale coefficient revealed decreasing (diminishing) marginal returns (0.2846), implying that a change in the total farm inputs is less than a proportional change in output. This is a true characteristic of agricultural production depicting rational use of farm factors. This perhaps justifies the sustainability of waterleaf production in the study area.

Summary statistics for the technical efficiency and sustainable technical efficiency of waterleaf farms

Summary statistics presented in Table 3 show three categories of technical efficiency indices. The first is the technical efficiency range less than the average efficiency. The second category is those greater than the average efficiency and considered sustainable technical efficiency, while the third category is the combination of the first and second groups. The distribution for all farmers reveals an efficiency range from 0.2715 to 0.9644 units and a mean index of 0.7213 units which is similar to Udoh and Akpan (2007) report. For the entire distribution, it can be inferred that for a farm that operates at the average technical efficiency to attain the technical efficiency level of the most efficient farm (that is a farm with technical efficiency of 0.9644), such

Table 2. Farm resource productivity of waterleaf farmers

Variable	APP	MPP	Elasticity	Stage of production
Farm Size (ha)	94 403.5289	10 441.0303	1.1106	I
Family labour (manday)	13.8957	1.1408	0.0821	II
Hired labour (manday)	24.7268	0.3289	0.0133	II
Fertilizer (kg)	5.2166	–6.1305	–1.1752	III
Manure (kg)	19.9179	1.8066	0.0907	II
Quantity of waterleaf (kg)	21.3662	2.7114	0.1269	II
Farm Capital (Naira)	9.8341	0.3560	0.0362	II
Scale of return	0.2846			

Source: own elaboration.

Table 3. Summary Statistics for Technical and Sustainable efficiency indices

Statistic	TE < average TE	TE ≥ average	TE
Mean	0.5223	0.8777	0.7213
Minimum	0.2715	0.7383	0.2715
Maximum	0.7190	0.9644	0.9644
Standard deviation	0.1061	0.0606	0.1956
Coeff. of variability	0.2031	0.0691	0.2712
Skewness	–0.0040	–0.6767	–0.4549
Ext. kurtosis	–0.6644	–0.4932	–1.2166
% (frequency)	44 (88)	56 (112)	100 (200)

Note: TE and STE represent technical efficiency and sustainable technical efficiency respectively.
Source: own elaboration based on data obtained from a field survey conducted in 2022.

a farm would need [1 — (72.13÷96.44)]*100; that is, about 25.21 percent gain in resource use efficiency. On the other hand, the least technically efficient farm needs [1 — (27.14÷96.44)]*100; that is about 71.86 percent gain in resource use efficiency to achieve the level of the most efficient waterleaf farm in the zone.

For the sustainable technical category, it will require a farm with the least sustainable technical efficiency to obtain 23.44 percent [1 — (73.83÷96.44)]*100 gain in resource use efficiency to be at the best sustainable efficiency point in the farms' production surface. while a farm with an average sustainable technical efficiency would need only 8.99 percent gain in resource use efficiency [1 — (87.77÷96.44)]*100 to be at the level of the best sustainable technical efficient farm. This means that within the sustainable range, there are opportunities to increase the technical efficiency of farm resource use. Hence, the sustainable technical efficiency range lies from 0.7383 to 0.9644, which implies that there is still room for farms to increase their sustainable technical efficiency. In this category, it is much easier to attain the level of the best efficient farmer in the region. Only 56% of waterleaf farmers in the zone produced within the sustainable technical efficiency range, while 44% were outside the range. The distribution of the sustainable technical efficiency is left-tailed, implying that few farms that attained sustainable technical efficiency are closer to the frontier efficiency while majority clusters around the lower limit of the sustainable range.

Determinants of technical efficiency of waterleaf farmers

The estimated coefficients of the technical inefficiency model are presented in Table 1. The estimates represent the distribution of technical efficiency irrespective of whether it is sustainable or not. The results reveal that female waterleaf farmers' household size, farm size and access to extension services, as well as membership of a social group and the probability of owning farmland have significant negative relationships with the technical inefficiency. This means that these variables have a positive influence or stimulating effects on the technical efficiency of waterleaf production in the zone. An increase in these variables will lead to a decrease in technical inefficiency, but an increase in technical efficiency of resource use. For instance, an increase in socialization activities among waterleaf farmers would lead to increased access to farm resources that will possibly result in improved farm planning and efficient management of farm resources. In a similar vein, the farms owned by females tend to be efficient in farm resource use. The possible reason for this result could be that women are more likely to endure the rigorous activities involved in waterleaf production than the male counterpart.

In addition, an increase in household size is a good source of cheap labour for waterleaf farmers. Since waterleaf production is organized on a small-scale and is labour intensive, cheap family labour will lower the cost of production and increase the efficiency of resource use. Likewise, an increase in farm size and probability to own farmland would promote technical efficiency of farm resources. The reason for the result could be linked to the fact that an increase in farm size would likely increase farm investment including improved techniques of production. Similarly, increased access to extension services increases the chance of innovation adoption and the use of best agronomical practices in production. Similar results with respect to some variables have been reported by Udoh and Akpan (2007) and Udoh and Etim (2008).

Contrastingly, an increase in farmers' educational level, farming experience, the amount paid as market ticket/charge, labour cost and amount of waterleaf spoilt have a positive correlation with technical inefficiency. By implication, an increase in these variables would lead to a corresponding reduction in the technical efficiency of resource use in waterleaf production. The result of education could be explained by the fact that an increased level of formal education would stimulate job diversification. Waterleaf cultivation in the zone is mainly practiced by resource-poor farmers with low levels of formal education (Udoh and Akpan, 2007).

Similarly, an increase in farming experience may be connected to the conservative nature of farmers. Experienced farmers are often conservative in resource use and will not adopt innovations that enhance resource use efficiency. Also, an increase in years of farming experience without corresponding increase or improvement in farm objectives could lead to crop/enterprise diversification among others, thereby increasing resource use inefficiency. An increase in the amount paid as a market ticket and the cost of hiring labour would increase the cost of production, thereby stimulating inefficiency in resource use. The finding also showed that post-harvest losses (amount in naira of waterleaf spoilt/stolen on the farm and during transit) increase farm inefficiency or reduce resource use efficiency in waterleaf production. An increase in this variable reduces the farm output, thus, obstructing the overall efficiency of resource use.

Determinants of sustainable technical efficiency among waterleaf farmers

Using derived indices of sustainable technical efficiency of waterleaf farms, the Logit model estimates are presented in Table 4, while the Tobit model estimates are presented in Table 5. The reason for estimating the two forms of the model from the same set of data was to

Table 4. Estimates of the Logit model – determinants of the probability of waterleaf farms to attain sustainable technical efficiency

Variable	Coefficient	Z-Value	Marginal effect	p-value	VIF	Tolerance factor
Constant	–19.8512	–3.134***	–	0.0017	–	–
Age	0.4346	2.461**	0.0235	0.0138	1.599	0.6254
Education	–4.3378	2.287**	–0.2342	0.0222	2.157	0.4636
Gender	14.7002	1.724*	0.7492	0.0847	2.983	0.3352
Farming experience	–0.6763	1.598	–0.0365	0.1100	1.407	0.7107
Household size	3.5108	2.760***	0.1895	0.0058	1.997	0.5008
Farm size	225.935	3.492***	12.1962	0.0005	1.965	0.5089
Extension access	3.2979	2.836***	0.1780	0.0046	1.024	0.9766
Social organization	0.2865	1.670*	0.0155	0.0949	1.857	0.5385
Market ticket	–0.0064	–1.038	–0.0003	0.2993	2.346	0.4263
Land ownership	12.8451	4.760***	0.6934	<0.0001	1.988	0.5030
Labour cost	–0.0012	–3.207***	–6.289e-05	0.0013	3.072	0.3255
Spoilt quantity in naira	–0.0014	–2.911***	–7.301e-05	0.0036	1.684	0.5938
Non- farm income	0.0002	4.727***	9.601e-06	<0.0001	1.594	0.6274
Log-Likelihood	–14.8779	Likelihood ratio test: Chi-square (13)			244.616 (0.0000)	
McFadden R^2	0.8916	Correct prediction			195 (97.5%)	

*, ** and *** represent significant levels at 10%, 5% and 1% respectively. Variables are as defined in equation 1.
Source: computed by authors using gretl software, data from field survey 2022.

Table 5. Tobit model – determinants of sustainable technical efficiency of waterleaf farm

Variable	Coefficient	Z-Value	Marginal Effect (uncensored observation)	p-value
Constant	–0.4705	–1.512		0.1307
Age	0.0067	1.809*	0.0067	0.0704
Education	–0.1153	–6.447***	–0.1153	<0.0001
Gender	0.8265	6.163***	0.8265	<0.0001
Farming experience	–0.0461	–3.647***	–0.0461	0.0003
Household size	0.1162	6.299***	0.1162	<0.0001
Farm size	5.2630	3.984***	5.2630	<0.0001
Extension access	0.1203	6.185***	0.1204	<0.0001
Social organization	0.0383	8.351***	0.0383	<0.0001
Market ticket	–0.0004	–1.116	–0.0004	0.2645
Land ownership	0.4688	3.860***	0.4688	0.0001
Labour cost	–3.82e-05	–4.105***	–0.00004	<0.0001
Spoilt quantity in naira	–7.17e-05	–6.707***	–0.00007	<0.0001
Non-farm income	6.49e-06	4.554***	6.49e-06	<0.0001
Log-Likelihood	81.812398	Likelihood ratio test: Chi-square (13)		232.00(0.000)
Pseudo R^2	0.8864	Normality test: Chi-square(2)		2.876 (0.6001)
Sigma	0.3415(0.0251)			

*, ** and *** represent significant levels at 10%, 5% and 1% respectively. Variables are as defined in equation 3. Data: 88 left-censored observations and 112 uncensored observations.

Source: computed by authors using gretl software, data from field survey 2022.

test the consistency of the results. The major econometric issue associated with cross-sectional data is multicollinearity. The variance inflating factor and tolerance factors were used to ascertain its presence. The results of the multi-collinearity test are presented in Table 4. The estimates of the VIF are below the threshold of 10 units. The result indicates that the independent variables are independently distributed and hence, showed an insignificance level of multicollinearity. The tolerance factor of each explanatory variable is below unity. This indicates that the incidence of multi-collinearity in the explanatory variables is negligible and the estimates are stable. The diagnostic tests for the Logit model showed a McFadden R-squared of 0.8916. This means that about 89.16% variations in the probability of waterleaf farmers having sustainable technical is explained by the specified explanatory variables. The Likelihood ratio test is statistically significant at a 1% probability level implying well-fitted data. The model was also able to predict correctly about 97.5% of the probability of farmers being in the sustainable technical efficiency range.

The estimated Logit model revealed that farmers' age, female waterleaf farmers, household size, farm size, farming experience, access to extension services, membership in a social organization, land ownership status and non-farm income earned by farmers have positive relationships with the probability of waterleaf farmers having sustainable technical efficiency. For instance, an increase in household size increases the quantity of family labour and at the same time lowers the cost of hiring labour and correspondingly increases the efficiency of farm resource use. This helps to reduce the production cost while expanding the farm profit margin. Also, an increase in non-farm income would increase the farm investment capacity of waterleaf farmers, thereby increasing the level of resource utilization in a sustainable manner. Based on the magnitude of the marginal effect of the explanatory variables, the result showed that farm size, female waterleaf farmers and probability of owning farmland, as well as education and household size are the major determinants of attainment of sustainable technical efficiency by waterleaf farmers in the zone.

On the other hand, farmers' education, farming experience, labour wage and value of post-harvest losses negatively affected the probability of attaining sustainable technical efficiency. This implies that as these variables increase in the population of waterleaf farmers in the zone, the probability of attaining a sustainable technical efficiency declines. However, this finding is similar to the previous result generated from the technical inefficiency function in Table 1.

The diagnostic tests for the Tobit model revealed the pseudo-R-squared of 0.8864, which implies that about 88.64% of the variability in indices of sustainable technical efficiency among waterleaf farmers is attributed to the specified explanatory variables. The normality test result reveals that the error terms generated from the model have a symmetric distribution. This justifies the efficacy of the maximum likelihood estimation method used in the Tobit model.

The likelihood ratio test is statistically significant at a 1% probability level, showing that the model has the goodness of fit. The result of the Tobit model shows that age, gender, household size, farm size, contact with an extension agent, being a member of a social organization, owning farmland and non-farm income are positive significant factors that affect the attainment of sustainable technical efficiency of waterleaf farmers in the region. Contrastingly, education, farming experience, cost of labour and post-harvest losses have a negative impact on the attainment of sustainable technical efficiency by waterleaf farmers in the zone. It is observed that the result of the Logit and Tobit models showed a high level of consistency in the direction and magnitude of the coefficients and the marginal effects.

CONCLUSION AND RECOMMENDATIONS

Small-scale farming is the heart of the agricultural system in Nigeria, and its sustainability is hinged on the sustainable use of farm resources now and in the future. The need for sustainable use of farm resources is even more pertinent due to the rampaging poverty and high rate of unemployment among Nigerians. The study has demonstrated the use of technical efficiency estimates of small-scale waterleaf farms to derive indices of sustainable technical efficiency. Furthermore, the factors that affect sustainable technical efficiency were identified. The methodology used is adequate and can be applied to the agricultural sector. However, the empirical results revealed that about 56% of waterleaf farms in the region operated in the range of sustainable technical efficiency. The determinants of sustainable technical efficiency were consistent in the Logit and Tobit models estimated. The finding revealed that farm size, land ownership, membership in social organizations and gender composition of waterleaf farmers were critical factors influencing the sustainable technical efficiency of small-scale waterleaf farms. To achieve this sustainable technical efficiency among waterleaf farms in the zone, the following recommendations are strongly advocated:

1. Land ownership is critical for attaining sustainable technical efficiency of waterleaf production in the zone. The Akwa Ibom State government should help farmers develop green fields and marginal lands as these would ensure economies of scale and efficient use of farm resources in a sustainable manner.
2. The women are the dominant players in waterleaf production in the region. Therefore, they should be involved in the planning and implementation of interventions on waterleaf production in the region.
3. On-farm training and demonstration, advocacy and talks are strongly recommended instead of the imposed formal education for waterleaf farmers in the State. An increased level of formal education induces job diversification and this is detrimental to the sustainability of the enterprise.
4. Formation of farmers' organizations should be encouraged among waterleaf farmers in the zone.
5. The government of Akwa Ibom State should reduce excessive market tickets to eliminate exploitative situations on marketers of waterleaf.
6. Research should be carried out to proffer solutions or reduce the post-harvest losses in waterleaf production.
7. Agricultural extension services should be intensified and improved strategies adopted for effective service delivery in the State.

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