Technical Efficiency of Sugarcane Monoculture and Sugarcane-Soybean Integration among Smallholder Farmers in Awendo Sub-County, Kenya

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Abstract

The demand for sugar in Kenya has been rising with low farm level productivity and high cost of production of USD 870 per MT. The ability of smallholder sugarcane farmers to improve sugarcane output levels and attain sustainable production depends on efficient farm practices, hence technical efficiency. The study analyzed technical efficiency of sugarcane-based cropping systems among smallholder farmers in Awendo Sub-County, Kenya. Primary cross-sectional data were collected from 246 randomly selected sugarcane farmers using multi-stage sampling method. The study identified two sugarcane-based cropping systems, namely; sugarcane monoculture which accounted for 62.6% of the cropping systems and sugarcane-soybean integration which accounted for 37.4 % of the cropping system, indicating that sugarcane monoculture dominated sugarcane based enterprise in the study area. The analysis employed Cobb Douglas stochastic production frontier model to estimate technical efficiency levels. A two-limit Tobit model was used to examine the factors influencing technical efficiency. Results indicated the highest output elasticity for land size (0.532) followed by herbicides (0.051). Fertilizer quantity and sugarcane cuttings had output elasticities of 0.029 and 0.015 respectively. The sum of the partial elasticities in the estimated model was 0.583. Results also showed that sugarcane-soybean integrators were more efficient than sugarcane monoculture farmers and land was found out to be the single most important variable in influencing the farmer's efficiency. The mean technical efficiency of 62% and 64 % showed that the potential exist to increase output by 38% and 36% for non-integrators and integrators respectively with the present technology. This study recommends that sugarcane farmers be encouraged to allocate part of their land to production of soybean to enhance food security and improve household income. It further recommends that there is need for training sugarcane and soybean farmers on optimum utilization of farm inputs the study area.

Keywords: Technical efficiency, Sugarcane monoculture, Sugarcane-Soybean Integration, Smallholder farmer

1. Introduction

Agriculture is the backbone of Kenya's economy. The contribution of the sector to the country's Gross Domestic Product (GDP) has been declining over the years from 40 percent in 1963, 33 percent in 1980s to 27 percent in 2014, (KNBS, 2015).The sector however remains dominant sector in the overall economy. The sector accounts for about 60 percent of the foreign exchange in Kenya and about 16 percent of the formal sector employment (KNBS, 2015) and also provides for self-employment. The Kenya's development policy for the medium term (2000 - 2030) continues to recognize agriculture as an important sector for the economy, with priority centred on food security initiatives and provision of employment opportunities (Okuro *et al.*, 2000). For the agricultural sector to play this central role in the economy rapid growth in output and productivity are critical and the role of sugarcane (*Saccharum officinarum*) and soybean (*Glycine max*) in the subsector is important as well.

In Kenya, sugarcane is mostly grown in rural areas of western parts of the country, which also predominantly comprises of low income earners (KNBS, 2007). Historically, sugarcane has been one of the most important crops in the Kenyan economy alongside tea, coffee, horticulture and maize. According to KSB (2010), the sugar sub-sector contributes about 15% of the agricultural GDP. By far, the largest contribution of the sugarcane industry is its silent contribution to the rural economies in the sugar belts. Farm households and rural businesses depend on the injection of cash derived from the sugar sub-sector. The survival of small towns and market places is also dependent on the incomes from the same. Besides the socio-economic contributions, the industry also provides raw materials for other industries such as bagasse for power co-generation and molasses for a wide range of industrial products including ethanol (KSB, 2010).

Over the years, the total land brought under cane production has been increasing in the sugar belts. Commercial sugarcane farming has transformed more arable land, particularly in the former Western and Nyanza provinces into expansive monoculture landscapes than any other single plantation crop (GoK, 2006). The total area under cane production in Kenya as at March 2013 was 206,809 hectares and the estimated area and yields by 2014 was 224,925 hectares and 100 tonnes cane per hectare (tch), respectively (KSB, 2010).The increase in area under cane is due to high cane demand because of new mills and expanded capacity of most sugar factories. The sugarcane growing is comprised of both the smallholder farmers as well as the nucleus estates commissioned by the sugar factories. The smallholder farmers supply 92% of the sugar milled in the country and the rest is provided by the nucleus estates (KSB, 2010). The smallholder farmers comprise about 85% of the cane growers in the country (GoK, 2007).

Sugar production in Kenya has grown from 548,206 MT of sugar in 2009 to 639,741 MT in 2016. During the same period, the quantity of sugar consumed increased from 762,023 MT in 2009 to 972,599 MT in 2016 (KSB, 2017). The deficit in meeting domestic sugar consumption needs from imports has grown from 169, 761 MT in 2009 to 334,109 MT in 2016 (KSB, 2017).The sugar deficit is usually covered by stringently controlled imports from the Common Market for Eastern and Southern Africa (COMESA) trade bloc where Kenya has a quota of 300,000 tonnes annually. On the other hand, the country's average yields have continued to decline to a low of 58.9 tch in 2011 from the historical high of 137 tch in 1973 (KESREF, 2011), this is in spite of improved sugarcane production technologies such as introduction of new cane varieties developed by KESREF. This average yield is very low compared to other COMESA countries like Egypt 126.4 tch, Zimbabwe 93 tch, Tanzania 85 tch and Malawi 113 tch (MAFAP, 2013).

Despite the immense potential of sugarcane production in Kenya, the farmers have always reported low yields. The poor performance puts at risk the livelihoods of over 250,000 small scale farmers who depend on the sector. Currently, Kenya is witnessing a massive challenge in meeting the ever growing demand for sugarcane products by achieving self-sufficiency in sugarcane production. This could be due to increase in small scale growers who have autonomy in their operations. This leads to adoption of diverse farm practices which contribute to low sugar cane yields. The unsustained supply of sugarcane to the processing industries has led to a steep increase in the sugar price in the country. The cost of sugar production in Kenya is currently estimated at USD 870 per MT which is twice the cost of production in other COMESA competing countries. This is very high compared to Zimbabwe (USD 300), Malawi (USD 350), Swaziland (USD340), Sudan (USD 340), and Zambia (USD 400), (Kenya National Assembly, 2015).

In Awendo Sub-County, Kenya, approximately 60 percent of arable land is under cash crop, 30 percent under food crop and 10 percent is left fallow (CIDP, 2013). Sugarcane occupies 2,400 ha within the nucleus of SONY factory with over 18,000 ha under the out growers (CIDP, 2013). Sugarcane is mainly grown under contract between farmers and South Nyanza (SONY) Sugar Company. SONY Sugar Company was incorporated by the Kenyan Government in 1976 and commissioned in 1979 with the objective of generating economic, social and financial gains for the local community and the country through the manufacture of mill white sugar for local consumption. (SONY Sugar Company, 2009). The SONY Sugar Company contributes 15% of the sugar produced in Kenya and is only second to Mumias Sugar Company that contributes 53% .The performance of the company therefore has a significant impact on the sugar industry in Kenya. Over the years, the company has experienced production shortfalls, with sugarcane delivery to the factory by contracted farmers declining from 603,646 tonnes of sugarcane (tc) in 1998/99 to 464,754tc in 2011/12 against a target of 651,600tc; while the non-contract farming has been on the rise from 45,133tc to 81,338tc over the same period (FAO, 2013).The continuous production shortfalls is likely to hurt the sugar industry in Kenya; since the country is already a net importer of sugar to meet the domestic consumption.

Table 13 Kenya Sugar Demand, Supply and Consumption Schedule

Figures in tonnes	**Production**	**Consumption**	**Imports**
2009	548,206	762,023	169,761
2010	523,652	772,731	258,578
2011	490,210	783,660	139,076
2012	493,937	794,844	238,589
2013	600,179	841,957	238,046
2014	592,668	860,084	192,121
2015	635,674	889,233	247,392
2016	639,741	972,599	334,109
Average annual growth rate	3%	3%	-7%

(Kenya Year Book of Sugar Statistics, 2017).

Kenya has been experiencing a steady rise in the domestic demand for sugar. The gap between sugar production and consumption has continued to increase making Kenya a net importer of sugar as shown on Table 1.

According to Maurice *et al* (2013), efficient use of input is an important part of sustainability while inefficient use can jeopardize food availability and security. With huge potentials of sugarcane in terms cash crop, there seems to be inadequate supply to meet both domestic and international market demand despite numerous efforts by the government such as crop improvement practices and researches; hence, the need to investigate the level of productivity and efficiency. This is based on the assumption that if farmers are not making efficient use of existing technology, then efforts designed to improve efficiency would be more cost-effective than introducing new technologies as a means of increasing agricultural output. To this end, the technical efficiency of sugarcane - based cropping system is examined because productivity growth and efficiency of inputs in agricultural production are the core-elements of sustainable crop production of small-scale farming activities

1.1 Statement of the Problem

Sugarcane is a major cash crop produced in the agro-ecological zones of Awendo Sub-County of Kenya either as a monoculture or intercrop system. Despite the increase in total land allocation brought under cane production by the smallholder farmers and improved production technologies developed by various research institutes such as Kenya Sugar Research Foundation (KESREF), there has been a steady decline in sugarcane yields over the past few years in Awendo Sub-County. This implies that increase in land size under cultivation and technological advances generated through research have not widely translated to increased sugarcane production. The huge differentials between actual and potential yields suggests underlying production inefficiencies. On the other hand, other alternative crops with potential benefits such as soybeans have emerged and are being promoted by agricultural extension officers as one of the value chains in Awendo Sub-County. Soybean is regarded as both a subsistence and cash crop and can be intercropped with sugarcane. However, the uptake and performance of this cropping system and technical efficiency measures in Awendo Sub-County has not been evaluated. This research intended to address this knowledge gap by comparing the technical efficiency of sugarcane monoculture and sugarcane soybean integration among smallholder farmers in Awendo Sub-County.

1.2 Objectives of the Study

The general objective of this study was to increase household income by evaluating the technical efficiency of sugarcane monoculture and sugarcane-soybean integration among smallholder farmers in Awendo Sub-county, Kenya.

This study sought to address the following specific objectives:

1. To determine the level of technical efficiency of sugarcane monoculture and sugarcane- soybean integration among smallholder farmers.
2. To examine the farm and farmer characteristics affecting technical efficiency of sugarcane monoculture and sugarcane-soybean integration among smallholder farmers

3. Research methodology

3.1 Study area

This study was undertaken in Awendo Sub-County which is located in Migori County in South Western part of Kenya. The Sub-County consists of four wards namely, North Sakwa, South Sakwa, West Sakwa and Central Sakwa. The sub-county covers an area of 261.90 km^2 (KNBS, 2010).The Sub-County enjoys a bimodal rainfall pattern ranging from 700mm to 2,200mm (PRSP, 2004).The long rain commences in February/March and continues up to June while the short rain starts in July/August and ends in November. Temperatures ranges between 21^0C and 35^0C.The soil ranges from deep red clay loam soils to black cotton soil. Therefore, the climate and soils are suitable for the cultivation of sugarcane which is the main industrial crop. Other major crops include soybean, tobacco, and beans. The land tenure is mainly freehold and each landowner can be granted a freehold title deed in respect of their land parcels (CIDP, 2013). According to the national census 2009, the populations of the sub-county stands at 108,913 persons (KNBS, 2010).The main economic activities in the sub-county include agriculture, manufacturing and mining. Specifically, this study focused on Awendo Sub-County in the South Nyanza Sugarcane belt where the SONY Sugar Company operates because of its significant contribution to the sugar industry in Kenya (CIDP, 2013).

3.2 Sampling procedure and sources of data

The population of interest constituted all farmers who practice sugarcane monoculture and sugarcane-soybean integration in Awendo Sub-County. A multistage sampling technique was used to get the study sample where the household was the sampling unit in this study. The first stage was the purposive selection of Awendo Sub-County, the region that harbors' higher potential for sugarcane and soybean production in the County (CIDP, 2013). All the four wards in the sub-county were included in study that is North Sakwa, South Sakwa, West Sakwa and Central Sakwa. Afterwards simple random sampling technique was used to select the respondents from all the wards proportionally according to size based on the list of sugarcane and soybean farmers given by the sub-county extension officers at the ward headquarters in Awendo Sub-County. Using the 2009 Kenya Bureau of Statistics (KBS) data on the population of the 4 wards of interest (clusters) as reported by the Kenya Population and Housing Census, a proportionate to population size (PPS) of respondents for each ward was computed to arrive at 246 respondents.

The study utilised primary data collected using semi-structured questionnaires administered by trained enumerators. Cross-sectional data was collected for the period 2014/2015 production season

3.2 Analytical Framework

3.2.1 Stochastic Frontier Analysis

Efficiency of a farm refers to its performance in the utilization of resources at its disposal (Kalirajan,2007). This performance is either compared with the normative desired level or with that of any other farm. The analysis of efficiency is generally associated with the possibility of farms producing a certain optimal level of output from a given bundle of resources or certain level of output at least cost.

The Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are the two main methods used to measure farm efficiency. According to Coelli *et al.* (1998), the SFA is considered more appropriate than DEA in agricultural applications, especially in developing countries, where the data are likely to be heavily influenced by the measurement errors and the effects of weather conditions, and diseases. Thus, following Aigner *et al. (*1977) and Meeusen and van den Broeck (1977), the stochastic frontier production with two error terms can be modelled as:

$$Y_i = f(X_i, \beta)\exp(V_i - U_j) \qquad (1)$$

Where Y_i is the production of the i^{th} farm (i=l, 2, 3 ......n); X_i is a (l×k) vector of functions of input quantities applied by the i^{th} farm.; β is a (k×l) vector of unknown parameters to be estimated; V_{is} are random variables assumed to be independently and identically distributed *(N (0, δ^2))* and independent of U_{is} and the U_{is} are non-negative random variables, associated with technical inefficiency in production also assumed to be independently and identically distributed.

The first error component *V* is intended to capture the effects of random shocks outside the farmer's control, measurement error and other statistical noise and the second error component *U* is intended to capture the effects of technical inefficiency. Following Battese and Coelli (1995), the technical inefficiency effects, U_i can be expressed as:

$$U_i = Z_i\delta + W_i \qquad (2)$$

Where W_i, are random variables, defined by the normal distribution with zero mean and variance $\sigma^2 u$. Z_i is a vector of farm specific variables associated with technical inefficiency and δ is a (mxl) vector of unknown parameters to be estimated. The technical efficiency of the i^{th} sample farm denoted by *TE;* is given by:

$$TE_i = \exp(-U_i) = Y_i \big/ f(X_i\beta)\exp(V_i) = Y_i \big/ Y_i^* \qquad (3)$$

Where $Y_i^* = f(X_1\ \beta,)\ exp\ (V_i)$ is the farm specific stochastic frontier. If Y_i is equal to Y_i^* then $TE_i = 1$, reflects 100% efficiency. The difference between Y_i, and Y_i^* *is* embedded in U_i. If U_i=0, implying that production lies on the stochastic frontier, the farm obtains its maximum attainable output given its level of input. If $U_i<0$, production lies below the frontier which indicates inefficiency.

The efficiencies are estimated using a predictor that is based on the conditional expectation of *exp (-U)* (Battese and Coelli, 1993; Coelli, 1994). In the process, the variance parameters $\sigma^2 u$, and $\sigma^2 v$, are expressed in terms of the parameterization:

$$\delta^2 = (\delta^2 u + \delta^2) \qquad (4)$$

And

$$\gamma = \delta^2 u \big/ \delta^2 \qquad (5)$$

The value of γ ranges from 0 to 1 with values close to 1 indicating that random component of the inefficiency effects makes a significant contribution to the analysis of the production system (Coelli and Battese, 1996). The Cobb-Douglas stochastic frontier production function was used to estimate the level of technical efficiency in a way consistent with the production theory in order to achieve objective one of the study. The Cobb-Douglas specification provides an adequate representation of the production technology, if emphasis is placed on efficiency measurement and not on an analysis of the general structure of the underlying production technology (Taylor *et al.*, 1986). The Cobb-Douglas model is flexible and widely used in agricultural economics (Marinda, 2006). The empirical model of the stochastic production function for the sampled sugarcane and soybean farmers is specified as;

$$\ln Y = \beta_0 + \beta_1 \ln Area + \beta_2 \ln Cuttings + \beta_3 \ln Fertilizer + \beta_4 \ln Herbicides + \beta_5 \ln Labour + V_i - U_i \qquad (6)$$

Where,
ln = Logarithm to base e (natural log)
β_0 = Constant or intercept
β_k ($\beta_1 - \beta_5$) = Unknown scalar parameters to be estimated
Y = Quantity of sugarcane in tonnes
V_j = Stochastic error term
U_j = Technical inefficiency effect predicted by the model
In the Cobb-Douglas functional form the parameters to be estimated, β_k, represent the elasticity of output with respect to each i^{th} input, which is the percentage change in output from a 1% change in the i^{th} input.
$\sigma^2 u / \sigma^2$ was computed to assess goodness of fit and correctness of the specified normal/half-normal distribution assumption. It is also used to explain the disparities of sugarcane and soybean output among farmers. Marginal effects were also computed as {δ (lny/lnx)} at the mean of the independent variables values.
Cost savings were also computed to explain the implication of technical efficiency improvement as shown in equation below

$$Cost\ savings\ \% = 1 - \frac{Mean\ Technical\ Efficiency}{TE\ of\ the\ most\ efficient\ farmer} \times 100 \qquad (7)$$

3.2.2 Tobit Model
Since technical efficiency scores lies between 0 and 1, the Tobit model was used to analyse the factors influencing technical efficiency among integrators and non-integrators. This approach has been used widely in efficiency literature (Obare *et al.,* 2010). The estimation with OLS leads to biased parameters of the estimates hence it is not appropriate. The technical efficiency scores are continuous hence probit and logit models cannot be used in this case because they are only used when the dependent variable takes two values (Gujarati, 2006). Therefore, Tobit regression model offers the most preferred options.
The two-step procedure was used in this study. In the first case, technical efficiency scores were estimated using the stochastic frontier model and secondly the technical efficiency scores obtained were then be regressed on farm and farmer characteristics variables to identify their influence on technical efficiency. Technical efficiency scores ranges between 0 and 1, hence the two-limit Tobit regression model (as shown below) was used. Thus as Coelli *et al*., (2002),

$$U_i^* = \beta_0 + \sum_{j=1}^{k} \beta_j Z_{ij} + \mu_i \qquad (8)$$

$$U_i^* = \begin{cases} 1 & \text{if } U_i^* \geq 1 \\ 0 & \text{if } U_i^* \leq 1 \end{cases} \qquad (9)$$

Where i refers to the ith farmer, U_i is the efficiency scores of the ith farmer, U_i^* is the latent efficiency, β_j are parameters that were estimated and u_i is the error that is independently and normally distributed with a mean zero and common variance. Z_{ij} are the farm and farmer characteristics variables.
The farm and farmer characteristic regressed here included gender, age, education, farming experience, occupation, value of assets, household size, extension services, group membership, and access to credit. The choice of these variables was intuitive although they have been found to have an effect on farm efficiency among smallholder farmers.Thus, the tobit model to be used for this study is specified as:

$$\begin{aligned} U_i = {} & \beta_0 + \beta_1 gender + \beta_2 age + \beta_3 education + \beta_4 far\min g\exp erience \\ & + \beta_5 occupation + \beta_6 credit + \beta_7 groupmembe\ rship + \beta_8 extension \\ & + \beta_9 Farmassets\ V + \beta_{10} hhsize + \mu_i \end{aligned} \qquad (10)$$

4 .Results and Discussions
4.1 Sugarcane-based cropping systems
According to Panda (2007) cropping systems are the yearly sequence and spatial arrangement of crops on a farm during a given period of time with the objective of obtaining maximum return from each crop without

compromising the soil fertility. The aim of any cropping system is to efficiently allocate all production resources while maintaining stability in production and obtaining higher net returns. The distribution of the cropping systems is presented in Table 2. The distribution shows that two sugarcane based cropping systems abound in Awendo Sub-County, namely: sugarcane monoculture (non-integrators) and sugarcane-soybean integration (integrators). Majority of the farmers (62.6%) cultivated sugarcane as a sole crop while only about 37.4% intercropped sugarcane with soybeans. The reason why majority of the farmers in the area practiced sugarcane monoculture could be attributed to the strategic location of SONY Sugar Company which is a major market for the sugarcane crop among the farmers.

Table 14: Distribution of respondents by cropping systems

Cropping system	Frequency	Percentages
Sugarcane monoculture(Non-Integrators)	154	62.6
Sugarcane-Soybean Integration (Integrators)	92	37.4

Source: Field Survey, 2016

4.2 Descriptive statistics of Variables

A summary statistics of the variables which are defined in the production function empirical model are presented in Table 3. The mean land size under sugarcane production of the sampled farms was 2.688 hectares with a range of about 0.12 to 40.1 hectares. This implies that most of the farmers grew sugarcane in small-scale. On average the national sugarcane acreage ranges between 0.5 to 5 hectares (Lung'aho *et al.*, 2006).

The mean sugarcane yield obtained by farmers was approximately 168.782 tonnes per hectares with a standard deviation of 200.228. Sugarcane yields were highly variable, ranging from 9.88 tonnes per hectares to 1240 tonnes per hectares. These results suggest that there is considerable room for improving average sugarcane yields in Awendo Sub-County. In terms of soybean productivity, the results show that the maximum yield obtained by soybean farmers in Awendo Sub-County was 17,297 kg per hectares with the minimum of 247.1 kg per hectares. On average, the results show that soybean farmers obtained the yield 2,788.128 of kg per hectares, which is low compared to the potential level of between 3000 –3600 kg per ha (Mahasi *et al.*, 2010).

Fertiliser is another important variable and is one of the critical inputs in sugarcane production because of high nutrient requirements of the crop. Average fertiliser use in sugarcane was 273.599 kilograms per hectare. The average quantity falls below the recommended fertilizer quantity of 500 kilograms per hectare of Diammonium Phosphate (MoA, 2002).

The quantity of soybean seed is also an important variable, which might cause considerable variation in yield. The average quantity of soybean seeds planted in the study area by the farmers was 5.404 kilograms per hectare and this was found to vary from 2.47 to 14.83 kilograms per hectare.

Average labour use was for sugarcane farming was 10.057 man-days per hectare which varied widely from a minimum of 2 to a maximum of 35 man-days while the average labour use for soybean farming was 1.262 man-days per hectare which varied widely from a minimum of 1 to a maximum of 7 man-days per hectare.

Table 3: Overall summary of descriptive statistics for the input and output variables assessed (n=246)

Variables	Obs	Mean	Std. Dev.	Min	Max
Land under Sugarcane(Ha)	246	2.688	3.424	0.12	40.4
Sugarcane Cuttings (Kgs/Ha)	246	16.212	14.318	1.24	135.91
Sugarcane Yield (Tonnes/Ha)	246	168.782	200.228	9.88	1240
Sugarcane Price (Ksh/Tonne)	246	2862.195	612.301	1200	4500
Soybeans Area planted (Ha)	92	0.368	0.183	0.2	1
Soybean seeds(Kgs/Ha)	92	5.404	2.609	2.47	14.83
Soybeans yield (Kgs/Ha)	92	2788.128	3144.659	247.10	17297
Price per unit soybean(Ksh/Kg)	92	91.264	12.050	70	125
Sugarcane Fertilizer (Kgs/Ha)	246	273.599	1925.621	2471	2965.2
Sugarcane Herbicides(Litres/Ha)	246	6.679	5.453	2.47	32.12
Sugarcane Labour (Man days/Ha)	246	10.057	7.102	2	35
Soybean Labour (Man days/Ha)	91	1.262	1.043	1	7

Note: Conversion rate, 1 acre=0.40 hectares; 1 tonne per acre= 2.471 tonnes per hectares

4.3 Maximum Likelihood Estimates of the Stochastic Frontier Production Function Results

A generalized stochastic production frontier was estimated using the STATA software. The dependent variable of the estimated model was sugarcane output in the 2014/2015 production season and the independent variables

include; land size under production, amount of fertilizer in kilogrammes, labour in man days and amount of sugarcane cuttings planted in kilograms. Technical efficiency scores were thus generated from this estimation.
Table 4 presents the results of the maximum likelihood (ML) estimates of Cobb-Douglas stochastic frontier production function. All the coefficients of the inputs in the production function were positive, with the exception of the coefficient of labour which was negative. The positive effects of inputs on the output were expected because more inputs used in rightful proportions increases production. The coefficients of land area under production, fertilizer, herbicides and sugarcane cuttings were positive implying that increase in the use of any of these factors, all things held constant, will increase the total production of sugarcane.
Results indicated the highest output elasticity for land size (0.532) followed by herbicides (0.051). Both variables were positively related to sugarcane productivity. The higher elasticity of herbicides and land size implied that their contribution to total factor productivity was dominant. A one percent increase in the use of land size and herbicides, *ceteris paribus*, leads to a 0.532 and 0.051 percent increase in sugarcane output, respectively. Land area had a strongly significant influence in sugarcane production at 1% level. This suggests that land is a significant factor associated with changes in sugarcane output. The results suggests that the more farm land a farmer allocated to sugarcane farming, the higher the yields obtained, which presents similar findings as those reported by Goni *et al.* (2007). The authors argued that most smallholder farmers usually fail to maximize yields due to underutilization of farm land. This might be due to limited availability of other production factors or due to farmers' risk averseness coupled with rainfall fluctuations brought about by climate change. However, Ugwumba (2010) in Nigeria observed that land was underutilized mainly due to land tenure problems associated with land fragmentation.
Another important input in terms of its effect on the sugarcane production is the amount fertilizer followed by sugarcane cuttings. An addition of one percent of amount of fertilizer area and sugarcane cuttings increases output by 0.029 and 0.015 percent, respectively. This implies that increase in the amount of fertilizer use holding other inputs constant, will increase output. This agrees with the findings of Oladiebo and Fajuyigbe (2007), who asserted that fertilizer significantly increase output in upland rice cultivation in Osun State.
The sum of the partial elasticities (function coefficient) indicates the scale of production. A function coefficient of one indicates constant returns to scale. Similarly, a function coefficient less than one and greater than one indicates decreasing and increasing returns to scale respectively. The sum of the estimates for the coefficients in the estimated model was 0.583 which implies that on average, the production frontier exhibited decreasing returns to scale and that the farmers were operating on the rational part of the production process that is stage II of the production region. The implication of this result is that every proportionate increase to the production inputs would lead to less than proportionate addition to the sugarcane output for the farmers. In other words, if all the inputs are increased by 1%, output of sugarcane will increase on average by 0.583%.
The parameter sigma-squared lies between 0 and 1; with a value equal to 0 implying that technical inefficiency is not present and the ordinary least square estimation would be an adequate representation and a value close or equal to 1 implying that the frontier model is appropriate (Piesse and Thirtle, 2000). The value of the sigma square indicates the goodness of fit and correctness of the specified assumption of the composite error terms distribution. The value of the parameter lambda (λ) is 0.95 is statistically significant at the 1% level, which implies that 95% of variation in output is attributable to inefficiency. The log likelihood ratio was found to be 299.20 and was statistically significant at 1% level. This log likelihood ratio test indicates that inefficiency exists in the data set.

Table 4: Maximum likelihood estimates of the stochastic frontier production function results

Ln_yield	Coefficient	Std. Error	Z	P>z
Ln_ Land size	0.5317***	0.07134	7.45	0.000
Ln_ Amount of fertilizer	0.0286	0.02240	1.2s8	0.202
Ln_ Herbicides	0.0509	0.07932	0.64	0.521
Ln_ Labour	-0.040	0.0837	-0.48	0.631
Ln_ Sugarcane Cutting	0.0146	0.0533	0.28	0.783
_cons	3.399***	0.5375	6.32	0.000
/lnsig2v	-0.6913**	0.3098	-2.23	0.026
/lnsig2u	-0.7732	0.9279	-0.83	0.405
Sigma_v	0.7078	0.1096		
Sigma_u	0.6794	0.3152		
Sigma_Squared	0.9624	0.2913		
Lambda	0.9599	0.4185		
n = 246		Wald $chi^2(5)$	= 60.48	
Log likelihood = 299.20		Prob >chi^2	= 0.0000	

*, **, ***: significant at 10%, 5% and 1% level respectively

4.4 Technical Efficiency Levels of Integrators and Non-Integrator Farmers

The results of the Stochastic Frontier Models showed that the mean technical efficiency of integrators and non-integrators were 0.64 and 0.62, respectively (Table 5). This shows that farmers practicing sugarcane-soybean integration and sugarcane monoculture were 64% and 62% technically efficient, respectively. The results mean that the farmers in both categories produced sugarcane below their respective frontier levels with non-integrators producing at a lower level than the integrators, although the two categories produced at above half of the frontier. The aggregate maximum, minimum and mean technical efficiencies for farmers in the study area were found to be 0.83, 0.22 and 0.63 respectively. This implies that, the farmer with the best practice had a technical efficiency of 0.83; farmer with the worst practice had a technical efficiency of 0.22 while in general, farmers in the study area had an average technical efficiency of 0. 63 .The aggregate mean technical efficiency of 0.63 implies that on the average, the respondents were able to obtain a little over 63% of optimal output from a given mix of production inputs and production technology. This indicates that there is a scope for increasing technical efficiency by 37 % in the short-run under the existing technology. Even though for the two types of cropping systems, integrators and non-integrators none of the respondents achieved a technical efficiency of 100%, which implied that improved efficiency in sugarcane production was still possible in the study area without any improvement in the resource base. But the integrators revealed the possibility for a more technically efficient and well sustainable sugarcane production in the study area.

Table 5: Distribution of technical efficiency scores based on Cobb-Douglas specification

	Non-Integrators		**Integrators**		**Aggregate**	
TE score	**No of farmers**	**Percentage**	**No of farmers**	**Percentage**	**No of farmers**	**Percentage**
≤ 0.2	0	0	0	0	0	0
0.21-0.40	7	4.55	0	0	7	2.85
0.41-0.60	50	32.47	30	32.61	80	32.52
0.61-0.80	96	62.34	59	64.13	155	63.01
0.81-1.00	1	0.65	3	3.26	4	1.63
Total	**154**	**100**	**92**	**100**	**246**	**100**
Mean	0.62		0.64		0.63	
Minimum	0.22		0.44		0.22	
Maximum	0.80		0.83		0.83	
Std. Dev.	0.1152		0.0884		0.1066	

For non-integrators technical efficiency level of its most efficient counterpart, the average farmer could realize a cost saving of 22 % (1- [62/80]). A similar calculation for the most technically inefficient farmer reveals cost saving of 72.5% (1-[22/80].On the other hand for integrators the technical efficiency level of its most efficient farmer, the average farmer could realize cost saving of 22.89% (1-[64/83]. And a similar calculation for the most technically inefficient farmer reveals cost saving of 47% (1-[44/83]). Therefore it is evident from these results that technical efficiency among the smallholder sugarcane and soybean farmers in Kenya could be improved substantially.

It was observed from the study that 35.37 % of the farmers had the lowest efficiency levels below 0.60; whereas the largest percentage (64.63%) of them had efficiency levels above 61%.Generally integrators had a majority of farmers(67.39%) having efficiency levels of 0.61 and above as compared to non-integrators (62.99%) who were in similar range of efficiency scores.

4.5 Factors influencing Technical Efficiency among Integrators and Non-Integrators

In order to make appropriate recommendations for relevant policy review and implementation, it is necessary to identify sources of variations in technical efficiencies among integrators and non-integrators. As it follows from SFA, the efficiency scores fall between 0 and 1, hence making the dependent variables (technical efficiency scores from SFA model) a limited dependent variable. In this regard, censored regression model (the Tobit model) was applied as the most appropriate analytical model. Selected farm and farmer characteristics were regressed against the TE scores of each farmer using the Tobit model and censored. The results describing the influence of the selected variables and their direction of influence on TE overall among the two categories of farmers (integrators and non-integrators) as presented in Table 6. The results from Tobit were then subjected to post estimation test using marginal effect analysis in order to estimate the trivial change from each factor that influence TE. Over 15 variables expected to influence technical efficiency of sugarcane and soybean production were estimated by the Tobit model. Some of the variables that yielded positive and significant coefficients among integrators included age, secondary education level, university education level and household size. Sugarcane farming experience, farm asset value and occupation of the farmer (farming and others) yielded negative and significant coefficients among integrators. This implies that the variables which influenced technical efficiency positively meant that their increase respectively improved technical efficiency of sugarcane and soybean production while the variables that influenced technical efficiency negatively implied that their increase respectively decreased the technical efficiency of sugarcane and soybean production.

Table 6: Factors influencing technical efficiency among integrators and non-integrators

	Non-integrators		Integrators	
Technical Efficiency	**Coefficient**	**t-value**	**Coefficient**	**t-value**
Age	0.0019**	2.02	0.0019**	2.15
Gender	0.0063	0.33	0.0118	0.64
None_ Education dummy	-0.0006	-0.02	0.0402	0.73
Secondary_ Education dummy	0.0704*	3.03	0.0739*	4.14
Tertiary_ Education dummy	0.0041	0.09	0.0231	0.59
University_ Education dummy[1]	0.0400	0.76	0.0902**	1.67
Household size	0.0035	0.87	0.0108*	2.85
Sugarcane Farming Experience	-0.0003	-0.26	-0.0019**	-1.76
Credit Access	-0.0110	-0.45	-0.0027	-0.13
Extension	0.0849*	3.42	0.0040	0.22
Group	-0.201	-0.99	-0.0102	-0.54
Farm Asset Value	3.62e-07	0.66	1.34e-06**	2.63
Off farm_ Occupation dummy	0.3342	1.49	-0.0132	-0.71
Farming & salaried_ Occupation dummy	0.5748	1.30	-0.0274	-0.82
Farming & others_ Occupation dummy[2]	0.3224	0.84	-0.0701	-2.54
Constant	0.4707***	10.43	0.4956***	11.65

LR chi2(15) =	29.90	38.95
Prob > chi^2	0.0123	0.0007
Pseudo R^2 =	-0.2556	-0.2668
Log likelihood =	73.4551	92.4675

Note: *, **, ***: significant at 10%, 5% and 1% level respectively; [1] and [2] are dummies

On the other hand among the non-integrators only three variables were significant and positively influenced technical efficiency. According to the results, these variables included age, secondary education and extension service. The differences in the two types of cropping systems occurred in variables such as university education which was positive and significant to technical efficiency among integrators while positive and not significant among non-integrators . Household size was positive to technical efficiency and significant at 1% level among integrators while among non-integrators though positive to technical efficiency was not significant at 5% level. Other variables that displayed differences were sugarcane farming experience, farm assets value and occupation (farming and off farm income which were negative and significant to technical efficiency among integrators except farm assets value which was positive and significant.

The coefficient for age of a farmer was positive and significant at 5% level. The positive effect of this coefficient implies that as the sugarcane-soybean integrator farmers grow old by a year, holding other factors constant, the inefficiency in sugarcane and soybean production increases by 0.19%. This means that older farmers were less technically efficient in sugarcane-soybean integration than their younger counterparts. The finding is attributed to the fact that older sugarcane-soybean integrator farmers are relatively more reluctant to take up better technologies, instead they prefer to hold to the traditional farming methods thus become more technically inefficient compared to their younger counterparts. This is consistent with findings by Waluse (2012), Sarfraz and Bashir (2005) and Idiong (2007).

Farmers with secondary and university level of education were found to be more efficient and significant at 10% and 5 % respectively as compared to their primary level counterparts. Educated farmers are generally better placed to receive, interpret and respond to new information. These results are in agreement with the findings of Nyagaka *et al* (2011), Mussa *et al (*2011), Shehu et al (2010), Njeru (2010), Ajewole and Folayan (2008), Elibariki and Shuji (2008), Chirwa (2007), Idiong (2007) and Amaza *et al* (2006). All these studies have argued that high formal education level reduces inefficiency. More educated farmers tend to adopt and respond rapidly to the use of improved technologies which could positively influence the technical efficiency of sugarcane-soybean integration

Experience in sugarcane-soybean integration was negative and significant at 5% level. This implies that as years pass with continuous sugarcane-soybean integration farming, farming experience tends to decrease farmers' capacity to do better, hence; they become more technically inefficient. These findings are in line with those of Ajewole and Folayan (2008) but contrary to those of Gul *et al* (2009) and Padilla-Fernandez and Nuthall (2009). Farmers with more years of farming experience are better placed to acquire knowledge and skills necessary for choosing appropriate new farm technologies over time.

The size of the household was positive and significant at 10% level in explaining the technical efficiency, implying that as the household size expanded, the technical efficiency of sugarcane-soybean integration increased. Wakili (2012), Shehu *et al* (2010),Ajewole, and Folayan (2008) found that household size was positive and significant in explaining technical efficiency. Larger household size increased the labour available, hence increase in the technical efficiency.

Farm assets value possessed by sugarcane-soybean integrators had the expected positive and was significant at 5%. According to Chimai (2011), assets are taken to indicate the household wealth status. In regard to smallholder sugarcane and soybean farmers, assets are expected to influence technical efficiency positively. This is because assets act as shock absorbers, especially when sold off in times of need.

5. Conclusions and policy implications

This study set out to estimate the technical efficiency and also determine socio-economic and farm specific factors that influence technical efficiency of sugarcane monoculture and sugarcane soybean integration among smallholder farmers in Awendo Sub-County, Kenya. Land under sugarcane production was the most single most important variable in influencing the farmers' level of efficiency. This implies that land was the most motivating factor in sugarcane farming in Awendo Sub-County since its function coefficient was positive. This was against the expectation of the study that farmers were not properly utilizing the land resource in production suggesting that other factors outside the estimated model could be the major cause of sugarcane productivity decline. The results also indicated that non-integrator farmers were less technically efficient as compared to integrator farmers. The mean technical efficiency of 62% and 64 % showed that the potential exist to increase output by 38% and 36% for non-integrators and integrators respectively with the present technology Therefore, non-integrator farmers had the highest scope in the improvement of their efficiency. It was also encouraging that at least half of the farmers had technical efficiency scores exceeding the 50% limit and could easily improve to the level of the most efficient farmers. Since the technical efficiency was found to differ among integrator farmers and non-integrators, the production of sugarcane and soybeans crops by the farmers can only be guaranteed in the short-run. The average non-integrator farmer could make a cost saving of 22% to the current production costs incurred through improved technical efficiency to that of the most efficient farmer while the average integrator farmer could realize a cost savings of 22.89%. This study has therefore concluded that there exist technical inefficiencies among sugarcane and soybean farmers in Awendo Sub-County, Kenya.

Based on the findings of the study, the following recommendations are made for policy implementation. It is envisaged that these recommendations would provide a framework for increasing the overall efficiencies of smallholder sugarcane and soybean farmers within the study area and other related areas. The following recommendations are provided based on the results of the study:

1. There is the need for farmers' to increase their use of land, fertilizer, herbicides and sugarcane cuttings since they were found to have an impact of the output. The study recommends that farm inputs should be made readily accessible to farmers and at subsidized prices through adequate supply and efficient distribution. The resource inputs used were as well not efficiently being utilized. Thus, there is need for training sugarcane

and soybean farmers on farm inputs optimum utilization by the extension agents in order to increase the overall productivity. The farmers should also allocate part of their land to incorporate soybean production in order to increase the household food security and improve the household income.

2. Efforts should be made to improve farmers' education, since education was found to affect farmers' technical efficiency positively. This can be achieved through increased extension contact, non-formal education and farmer-based organizations (FBOs) that promote farmer education. Proper policies measure that strengthening the provision of education to farmers will lead to the increase of technical efficiency of farmers in long run. Importance of education comes on decision making and implementing informed and timely farming decisions.

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