

*Full Length Research Paper*

# **Analysis of economic efficiency among smallholder sorghum producers in Kenya**

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**This study used Cobb-Douglas Stochastic Profit Frontier to analyze economic efficiency of sorghum farmers in Tharaka Nithi County, Kenya. Using a multi-stage stratified sample of 259 farmers, results depicted a wide range of profit efficiency between the best (0.96) and the worst (0.12) farmer with a mean of 0.17. The actual and potential profit was USD 164.88 ha<sup>-1</sup> and USD 969.87 ha<sup>-1</sup> respectively. This indicates that, sampled farmers incurred profit-loss of approximately USD 804.99 ha<sup>-1</sup>. Family labour and fixed capital base were the major contributing factors to sorghum profitability. Drivers of profit efficiency pointed out that, farmers who had more experience in sorghum farming, accessed agricultural credit, attended trainings, lived closer to the market and agro-dealers were likely to be more efficient. To increase profit efficiency, this study therefore advocates for policy strategies targeting these factors. Further, policy move targeting increase in uptake and correct application of fertilizer and other inputs should be reinforced.**

**Key words:** Improved sorghum varieties, economic efficiency, Cobb-Douglas stochastic profit frontier, Kenya.

## **INTRODUCTION**

In the past decade, Kenya's population has increased by over 25% and stands at 47.56 million by year 2019 (GoK, 2019a). The population growth trend is expected to exert more pressure on food production and worsen the current situation where demand outstrips supply. This underpins the need to address agricultural production in the country which is a net importer of many agricultural products. From year 2006 to 2016, food imports in the country increased at a rate of 10% annually (GoK, 2019b). Population increase and existing land practices including massive fragmentation into uneconomic units adversely affect food production in the country (GoK, 2019b).

This means that, for Kenya to produce enough for her population, several strategies should be employed including increasing agricultural productivity by efficiently utilizing available limited resources.

Sorghum, which ranked fourth important cereal after maize, wheat and rice (CBS, 2016) is a good option for farmers especially in arid and semi-arid areas. This is because of its adaptability and resilience to low moisture stress and excessive heat (Orr et al., 2016). By the year 2018, about 43 improved sorghum varieties (ISVs) had been released (GoK, 2018). However, it is disappointing that nationally, average yields remain below 1 ton ha<sup>-1</sup>

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compared to potential of 2-5 tons ha<sup>-1</sup> (GoK, 2015).

In Kenya, eastern region is the country's sorghum basket that has continued to benefit from Government's heavy investment in the sector. Several big sorghum projects have been launched in the area in partnerships with donors latest being Kenya Cereal Enhancement Programme-Climate Resilient Agriculture Livelihood (KCEP-CRAL). However, despite these investments in the sorghum sector, yields are still low (GoK, 2015).

Although low yields can be attributed to several factors some of which are beyond farmers' control such as climate change, high level of inefficiencies is a major contributing factor (Wollie et al., 2018; Chepng'etich et al., 2014; Chimai, 2011). Sorghum farmers in eastern Kenya have been reported to be technically inefficient with a low mean level of 41% (Chepng'etich et al., 2014) despite huge investment in the value chain. This underscores the need for continued research efforts on efficiency which perhaps should expand the scope to other efficiency aspects beyond technical. This study is not aware of any research that has attempted to assess profit efficiency levels of sorghum farmers in eastern Kenya.

Therefore, this study aimed to bridge the identified knowledge gap by analyzing profit efficient levels among sorghum farmers in Tharaka Nithi County using Cobb-Douglas Stochastic Frontier. This method allows a researcher to investigate both the profit efficiency levels of individual farms and their underlying determinants (Battese and Coelli, 1995). Understanding the causal effect of these determinants on profit efficiency is crucial in generating valuable information to inform policy.

## METHODOLOGY

### Data

The data used in this study are based on a farm survey of 259 sampled households from Tharaka Nithi County collected in year 2018. Multi-stage stratified sampling technique was utilized with the first stage involving purposive sampling of Tharaka Nithi County, which is one of the leading sorghum producing regions in upper eastern Kenya (KBL, 2018). The second and third stages involved purposive selection of Tharaka Sub-County and Mukothima ward due to their high sorghum production levels respectively (Figure 1). The fourth and fifth stage entailed selection of 36 sample villages and construction of a sample frame comprising of all households in the sampled villages from where respondents were selected randomly. The sampling of households was random based on proportionate to size of the population in each village. The sampled households from these villages ranged from 6 to 25.

### Theoretical framework

In 1957, Farrell first defined frontier production functions including maximality aspect and provided a three-dimensional way of distinguishing efficiency, viz; technical, price or allocative and economic (which combines technical and allocative aspects). The study defined productive efficiency as the ability of a firm to produce a given level of output at lowest cost. The three efficiency

components have been measured by the use of frontier production function which can be deterministic or stochastic. Deterministic frontier production function explains that all deviations from the frontier are attributed to inefficiency whereas in stochastic frontier production function, it is possible to discriminate between random errors and differences in efficiency.

Theory evolved and afterwards, Aigner et al. (1977) and Meeusen and Van den Broeck (1977) proposed a stochastic frontier model. Several authors later argued that, it was important while dealing with farm level efficiency in developing countries to include several important aspects especially on selection of functional forms and relevant parametric estimation approaches as opposed to non-parametric (Battese, 1992; Bravo-Ureta and Pinheiro, 1993; Coelli, 1995). In profit function context, Ali and Flinn (1989) defined profit efficiency as the ability of a farm to achieve the highest possible profit, given the farm's prices and levels of fixed factors. Consolidating on this, Ali et al. (1994) stated that, profit function approach combines the concepts of technical and allocative efficiency and any error in the production decision is assumed to translate into lower profits or revenue for the farmer.

In literature, several function forms for estimating profit function exist that includes Cobb-Douglas, normalized Quadratic, normalized Translog and generalized Leontif. The results significantly differ across different function forms and thus the choice is critical. Battese and Coelli (1995) contributed to improvement of the stochastic profit frontier model by suggesting that the inefficiency effects can be expressed as a linear function of explanatory variables, reflecting farm-specific characteristics.

### Sorghum profitability analysis

This study used profitability analysis on data collected during 2017/2018 cropping year to evaluate performances of sorghum farmers in Tharaka Nithi County. The basis of this analysis for profitability was on per unit of land measured in hectares (ha). Dependent variable net profit was derived by subtracting the total cost from total revenue.

The total variable cost include costs of inputs (seed, fertilizer, labour and insecticides) which was used as opposed to their respective prices due to their similarity, thus no difference would be evident. Since farmers would buy different quantities of inputs, then cost would vary. Labour costs were captured and quantified as per activities executed during sorghum production such as land preparation, planting, fertilizer application, weeding, spraying, birds scaring, harvesting, transport to homestead, threshing, transport to collection centre and loading to buyer's vehicle. Labour was categorized as hired or from family members. Family labour segment captured the ages and gender of the member and subsequently male equivalent opportunity cost was calculated using wage rate for the study area as the base using <sup>1</sup> formula suggested by FAO (2005).

The total cost included value of fixed capital assets such as farming implements, buildings, machinery and land. Farmers in the study area were customary owners of land and hence not paying taxes. Sometimes, the farmers would leave land fallow for a certain period and as such during fallow period, land had no economically valuable output. Several studies have argued that, fixed cost has a negligible contribution to the farming enterprise especially in smallholder subsistence farming (Ohen and Ajah, 2015; Abdullahi, 2012). With this in mind, and due to the unreliability of data, cost of land was not included in the analysis. However, this study included depreciation cost for fixed capital. Given that the implements were used until completely worn out, their residual value was equated to zero.

<sup>1</sup>1 man-equivalent day (8 hours) = 1.25 woman days = 2 child days

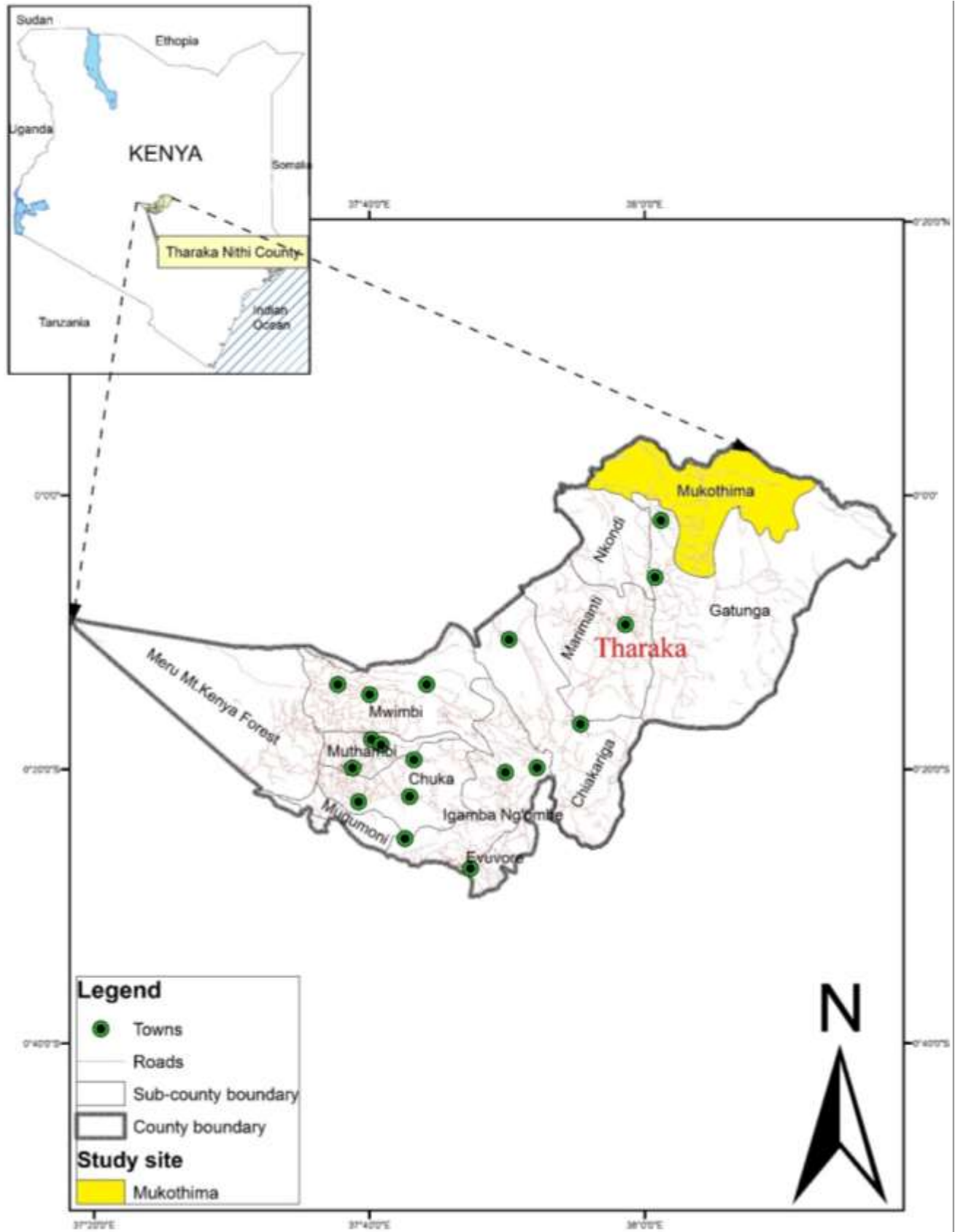


Figure 1. Map of the study area.  
Source: Generated from ArcGIS using georeferenced survey data (2019).

**Table 1.** Likelihood ratio tests for underlying hypotheses.

Null hypothesis	$\chi^2$ /LR	df	Prob> $\chi^2$	Decision
$H_0: \beta_{ij} = 0$	23	21	0.34	Fail to reject $H_0$ Cobb-Douglas function is appropriate
$H_0: U_i = iidN^+(0, \delta_u^2)$	0.06	1	0.26	Fail to reject $H_0$ Profit efficiency levels are assumed to be half normal distributed
$H_0: \gamma = 0$	7.81	1	0.002	Reject $H_0$ Inefficiency effects are present in the model

Depreciation for farm implements used for production of ISVs was carried out using straight line method as follows.

$$d = \frac{Iv - Rv}{n} \left( \frac{LdISV}{TotLD} \right) \quad (1)$$

where:

$d$  = annual depreciation

$Iv$  = initial value of the tool

$Rv$  = residual implement value

$n$  = economic life span of the implement in years

$LdISV$  = area of land under ISV

$TotLD$  = total area of land under crops.

### Empirical model specification

Several profit efficiency models exist in literature including Data Envelopment Analysis (DEA). However, this study used Stochastic Profit Frontier due to its ability to give way for the sensitivity of data to random shocks and includes a conventional random disturbance term in the estimation of the profit frontier. This enables the research to attribute only deviations influenced by controllable decisions to inefficiency (Joforullah and Premachandra, 2003).

### Hypotheses tests for model specification

The choice of functional form is important due to the fact that, results significantly differ according to the function form applied. In profit function literature, many functional forms are available and have been used extensively. However, the two most popular functional forms are Translog and Cobb-Douglas (Battese and Coelli, 1995). Therefore, the first test was to choose the functional form which best fitted the data using likelihood ratio test conducted following the formula by Greene (2012).

$$LR_\lambda = -2 \left\{ \ln \frac{L(H_0)}{L(H_1)} \right\} = -2 \{ \ln[L(H_0)] - \ln[L(H_1)] \} \quad (2)$$

where:  $L(H_0)$  and  $L(H_1)$  represent the values of the log likelihood under null and alternative hypothesis, respectively.  $LR_\lambda$  has approximately a Chi-square distribution with the number of degrees of freedom equal to the number of restrictions, assumed to be zero in the null hypothesis. Null hypothesis fails to be rejected when  $LR_\lambda$  is lower than the correspondent critical value for a given significance level (Abu and Kirsten, 2009).

The null hypothesis stated that, coefficients of the second-order variables in the Translog model are zero; implying that the Cobb-Douglas function is best fit for the model (Table 1). Mathematically, this can be presented as follows:

$$H_0: \beta_{ij} = 0$$

The results failed to reject the first null hypothesis, meaning that, Translog model actually reduced to the Cobb-Douglas profit function. Therefore, results from Cobb-Douglas model were considered more accurate and was the functional form which best fits the data. Further, AIC and BIC values support the results in that, Cobb-Douglas model reported smaller values (943.48 and 968.38) compared to those of Translog function form (962.48 and 1,062.07) respectively.

The second test was on distribution assumption for the error term. Null hypothesis was half normal distribution while the alternate was the general truncated normal distribution. The results failed to reject the null hypothesis implying that, half normal distribution assumption was the most appropriate.

The third test was to find out whether inefficiency effects were present in the model. The null hypothesis specified that, inefficiency effects were absent in the model. Results in Table 2 rejected the null hypothesis. The findings were supported by the estimated Gamma value (0.95) highly significant at 1% significance level.

The Cobb-Douglas functional form was specified as follows:

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

where:

subscript " $i$ " represents the  $i_{th}$  farmer in the sample

$\pi_i$  = Normalized profit per ha in USD computed as profit divided by output price.

$P_{1i}$  = Normalized cost of seed per ha (standard prices for different seed varieties per 2 kg packet were as follows; *Gadam* = USD 4; *SC Sila* = USD 4.5; *Kari Mtama 1* = USD 3.2 and *Advanta 23012* = USD 12)

$P_{2i}$  = Normalized cost of insecticides per ha

$P_{3i}$  = Normalized cost of family labour per ha

$P_{4i}$  = Normalized cost of hired labour per ha

$P_{5i}$  = Normalized cost of fixed capital base per household

$P_{6i}$  = Area of under under ISVs in ha.

$\beta_k$  = Parameters to be estimated

$V_i$  = Random error assumed to be independently and identically distributed.

$U_i$  = Non-negative profit inefficiency effects which are assumed to be half normal and independently distributed.

It is worth noting that, all variables labeled as normalized means that, each of their totals was divided by the output price respectively.

Equation 3 was estimated using Frontier version 4.1 where several parameters were estimated and reported such as profit efficiency levels, value of gamma and determinants of inefficiency in the sorghum production.

To estimate inefficiency model, the following empirical expression was used:

**Table 2.** Description of variables used in the inefficiency model.

Variable	Description	Unit of measure	Hypothesized sign
Age	Age of household head	Years	- or +
School	Years spent in school by a household head	Years	-
Experience	Experience in sorghum farming	Years	-
Adult	Household's adult equivalent	Number	
Extension frequency	Average times a household sought extension advice	Number	-
Group membership	Whether a household head was a member of any farming group	1=yes; 0=no	-
Agricultural credit	Agricultural credit access	1=yes; 0=no	-
Agrodealer distance	Distance to the nearest agro-dealer	Kilometre (km)	+
Training	Whether household head attended any training on sorghum farming	1=yes; 0=no	-

$$U_i = \delta_0 + \delta_1 W_1 + \delta_2 W_2 + \delta_3 W_3 + \delta_4 W_4 + \delta_5 W_5 + \delta_6 W_6 + \delta_7 W_7 + \delta_8 W_8 + \delta_9 W_9 \quad (4)$$

where:

$W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8$  and  $W_9$  represents *extension frequency, experience in sorghum farming, group membership, school, adult, agricultural credit, age, training and distance to the nearest agro-dealer* respectively.

$\delta_0, \dots, \dots, \dots, \delta_9$ , represented parameters to be estimated.

Data diagnostic tests were carried out before running models. Variance Inflation Factor (VIF) and Breusch Pagan test were used to test for multicollinearity and heteroscedasticity respectively VIF mean value was less than 10 (1.06) indicating that there was no multicollinearity in the data, while the Chi-square value for Breusch Pagan test was insignificant.

## RESULTS AND DISCUSSION

### Summary descriptive statistics

On average, the household heads' were aged 45.4 years and had completed 7.7 years in school (Table 3). The mean adult was reported at 2.3. On average, distance from the location of sampled households to the nearest administration Centre where extension agents and agro-dealers are domiciled was 3.1 km with farmers traveling up to a maximum of 15 km to seek advice. Terrain is very rough and main mode of transport available is use of a motor cycle commonly referred to as '*bodaboda*'. The transport cost goes as high as USD 7.86 back and forth for a distance of 15 km.

Approximately, 4% of the sampled households used fertilizer for planting majorly Diammonium Phosphate (DAP). On average, farmers used 10% of the required planting fertilizer application rate per ha. About 33% of the sampled households used several insecticides namely; *Tihan, Thunder, Profile, Duduthrin, Oshothion, Voltage* and *Alphakil*. On average, majority of farmers used 20 to 50% of the recommended application rate per ha for the various insecticides especially *Oshothion, Duduthrin* and *Voltage*.

### Maximum likelihood parameter estimates of the profit efficiency model

Table 4 presents maximum likelihood estimates of the parameters of the Cobb-Douglas stochastic profit frontier model. The results show statistically significant coefficients for sigma squared ( $\sigma^2$ ) and gamma ( $\gamma$ ) parameters.

The estimated gamma or variance ration parameter coefficient (0.95) means that, approximately 95% of profit variation could be attributed to inefficiencies with one sided error. This confirms that, there exists a high level of inefficiency between sorghum farmers and is stochastic. The estimated sigma squared (5.91) is significant at 1% level of significance meaning the model was a good fit (Rahman, 2003). The elasticity findings show that, when the cost of family labour and fixed capital increases by 1%, profit increases by 0.14 and 0.20% respectively.

### Distribution of profit efficiency scores

Table 5 shows the distribution of profit efficiency levels among sampled sorghum farmers. The scores indicate a wide range of profit efficiency from 0.12 to 0.96 for the worst and best sorghum farmer respectively with a mean of 0.17. This implies that, on average, a farmer in the study area could increase profits by 83%.

Further, results reveal huge profit efficiency variation with over 70% of sampled farmers recording an efficiency score of less than 0.25. The least profit efficient and average farmers need a cost saving (efficiency gain) of 87.50%<sup>2</sup> and 82.3%<sup>3</sup> respectively, to attain the profit efficiency level of the best farmer in the study area. On the other hand, the best farmer needs a cost saving of 4%<sup>4</sup> to be on the frontier.

Further, with mean profit efficiency estimated at 0.17 and actual profit at USD 164.88 ha<sup>-1</sup>, sampled sorghum

<sup>2</sup> [1-(0.12/0.96)]\*100

<sup>3</sup> [1-(0.17/0.96)]\*100

<sup>4</sup> [1(0.96/1)]\*100

**Table 3.** Summary statistics of the characteristics of sorghum farmers (N=259).

Variable	Unit of measurement	Mean/Percent	Standard deviation
Age	Years	45.4	13.6
School	Years	7.7	4.2
Adult	Number	2.3	0.6
Experience	Years	20.3	12.8
Agrodealer distance	km	3.1	1.6
Group membership	1=Yes	65	
Agricultural credit	1=Yes	6	
Training	1=Yes	61	
Profit	USD ha <sup>-1</sup>	164.88 <sup>#</sup>	155.64
Sorghum yield	tons ha <sup>-1</sup>	1.39	0.75
Land area under sorghum	ha	1.05	0.86
Fixed capital base cost	USD/HH	6.07	2.06
Seed cost	USD ha <sup>-1</sup>	18.26	7.68
Hired labour cost	USD ha <sup>-1</sup>	49.11	11.37
Family labour cost	USD ha <sup>-1</sup>	150.85	93.04
Fertilizer cost	USD ha <sup>-1</sup>	0.28	1.48
Insecticide cost	USD ha <sup>-1</sup>	4.15	6.26

<sup>#</sup>1 USD was equivalent to 101.81 Kenya Shillings at the time of study, that is, end year 2018.

**Table 4.** Maximum likelihood estimates for parameters of the Cobb-Douglas stochastic profit frontier model.

Variable Name	Parameter	Coefficient	t-ratio
Constant	$\beta_0$	1.49 (0.66)**	2.26
$\ln P_{\text{seed cost}}$	$\beta_1$	-0.02 (0.27)	-0.08
$\ln P_{\text{insecticide cost}}$	$\beta_2$	0.08 (0.10)	0.80
$\ln P_{\text{familylabourcost}}$	$\beta_3$	0.14 (0.07)**	2.11
$\ln P_{\text{hiredlabour cost}}$	$\beta_4$	-0.12 (0.13)	-0.92
$\ln P_{\text{fixed capital cost}}$	$\beta_5$	0.20 (0.09)**	2.12
$\ln P_{\text{land under ISV}}$	$\beta_6$	0.21 (0.25)	0.85
<b>Diagnostic statistics</b>			
Sigma-squared	$\sigma^2$	5.91 (0.73)***	8.05
Gamma	$\gamma$	0.95 (0.02)***	39.62
Log likelihood function value	LLF	-461.81	
Sample size	259		

Figures in parentheses represent standard errors associated with the coefficients. \*\*\*P<0.01, \*\*P<0.05 and \*P<0.10 mean significant at 1, 5 and 10% probability levels, respectively.

Source: Survey data.

farmers incurred profit-loss<sup>5</sup> of approximately USD 804.99 ha<sup>-1</sup>. Therefore, this implies that, sorghum farmers could, on average, attain potential profit<sup>6</sup> of about USD 969.87 ha<sup>-1</sup> through improvement of technical, allocative, and scale efficiencies. This is quite a significant amount of income for sorghum farmers in Tharaka Nithi County

and calls for appropriate policies formulated and implemented with intent of enhancing profit efficiency of sorghum farming.

#### Sources of profit inefficiencies among sorghum farmers

Table 6 presents results of the inefficiency model. Since

<sup>5</sup> Profit-loss = Actual profit \* (1-Profit efficiency)/Profit efficiency

<sup>6</sup>Potential average profit = actual profit + profit-loss.

**Table 5.** Deciles frequency distribution of profit efficiencies of sorghum farmers.

Efficiency level	Frequency	Relative percentage
< 0.25	185	71.43
0.26 - 0.50	52	20.08
0.51 - 0.60	7	2.70
0.61 - 0.70	9	3.47
0.71 - 0.80	2	0.77
0.81 - 0.90	0	0.00
0.91 - 1.00	4	1.54
Total	259	100
Minimum		0.12
Maximum		0.96
Mean		0.17
Std. Dev.		0.21

**Table 6.** Determinants of profit inefficiency.

Variable name	Parameter	Coefficient	t-ratio
<i>Constant</i>	$\delta_0$	0.894 (0.054) ***	16.52
<i>W<sub>1</sub>=Extension frequency</i>	$\delta_1$	-0.001 (0.001)	-0.34
<i>W<sub>2</sub> = Experience</i>	$\delta_2$	-0.006 (0.002)***	-2.77
<i>W<sub>3</sub> = Group membership</i>	$\delta_3$	-0.001 (0.018)	-0.06
<i>W<sub>4</sub> = School</i>	$\delta_4$	0.003 (0.002)	1.22
<i>W<sub>5</sub> = Adult</i>	$\delta_5$	-0.013 (0.013)	-1.04
<i>W<sub>6</sub> = Agricultural credit</i>	$\delta_6$	-0.116 (0.026) ***	-4.38
<i>W<sub>7</sub> = Age</i>	$\delta_7$	0.001 (0.001)	1.33
<i>W<sub>8</sub> = Training</i>	$\delta_8$	-0.046 (0.021)**	2.21
<i>W<sub>9</sub> = Agro-dealer distance</i>	$\delta_9$	0.010 (0.003) ***	2.76

Figures in parentheses represent standard errors associated with the coefficients. \*\*\*P<0.01, \*\*P<0.05 and \*P<0.10 mean significant at 1, 5 and 10% probability levels, respectively.

Source: Survey data.

the dependent variable is the inefficiency component of the total error term estimated in combination with the profit frontier, the coefficients are interpreted in reference to inefficiency instead of efficiency. It is worth noting that, the coefficient sign is very important in result interpretation. A negative sign implies that, the variable has a reducing effect on profit inefficiency and vice versa (Abu and Kirsten, 2009; Galawat and Yabe, 2012). Assa et al. (2012) suggests that, one can interpret the coefficients in reference to profit efficiency instead of inefficiency by taking the opposite sign of the reported results.

The coefficient associated with experience in sorghum farming is negative (-0.006) and significant at 1% level. This implies that, experienced farmers are more likely to be profit efficient. They are expected to operate at a higher level of profit efficiency compared to their less experienced counterparts. The results corroborate those

of Konja et al. (2019), Saysay et al. (2016), Trong and Napasintuwong (2015), Munir et al. (2015), and Sadiq and Singh (2015) but contradict Tanko and Alidu (2017).

Access to agricultural credit and profit efficiency depicted a significant positive relationship denoted by negative coefficient (-0.116). Sampled farmers were reported to be cash constrained and access to credit could push the financial constraint outward enabling farmers to acquire required inputs in sorghum farming particularly fixed capital base with labour reported as the major contributing cost elements depressing profits. Further, access to credit hands farmers more purchasing power and catalyzes adoption and usage of improved seed and fertilizer. These determinants are reported to be crucial in improved productivity and profitability yet used by few sampled farmers. This result is in agreement with Wongnaa et al. (2018), Saysay et al. (2016) and Biam et al. (2015).

As expected, trained farmers were operating on a higher profit efficient level compared to their untrained counterparts. This is evident from the negative significant coefficient (-0.046). Trainings are crucial in disseminating extension information to farmers particularly on good agronomic practices, post-harvest handling and market information among other topical subjects. This finding is in agreement with Bocher and Simtowe (2017), Dang (2017), and Trong and Napasintuwong (2015).

Distance to the nearest agro-dealer depicted a negative relationship with profit efficiency (0.10). This relates to the high transaction and transformation cost associated with an increase in distance which discourages farmers from accessing inputs and information. Terrain in the study area is rough and motorcycles are the most predominant means of transport from households to the nearest market where agro-dealers are domiciled. Due to shortage of means of transport options, motorcycles charge exorbitant prices, therefore discouraging farmers from visiting the market to purchase input and acquire necessary information. This result concurs with those of Bocher and Simtowe (2017).

### Recommendations

Low average yield among the sampled farmers could be attributed to several factors among them like low usage of fertilizer and technical knowhow on sorghum production. The fact that, few farmers used fertilizer with an underdose application rate, which is a key ingredient to increased productivity, leads this study to recommend that, stakeholders formulate and adopt sustainable awareness and demand creation activities' models e.g. demonstration plots. The demonstration plots managed jointly by lead farmers, agro-dealers and fertilizer companies give farmers an opportunity to witness and associate themselves with the results. The demonstration plots could be used as training sites for more practical oriented approach.

Demand creation activities aim to increase the number of farmers who purchase and use correct dosage of the right fertilizer. However, availability and affordability might be limiting factors. Affordability is usually influenced by multiplicity of factors with product pricing and associated transformation and transactions costs being central. Therefore, deliberate concerted efforts should be channeled towards making sure that, fertilizer and other inputs in general are available closer to the farming households. This could be through incentivizing agro-dealer start-ups via waiving certification requirements e.g. licences, permits etc. Further, existing agro-dealers should be encouraged to expand their network through availability of favorable credit.

Credit providers should offer affordable facilities and consider relaxing loan application and processing requirements. They should also consider embracing

digital lending and adopt sustainable and cost effective delivery models such as use of business champions in the interior parts of the study area, opening up of agency banking among others.

To incentivize and increase lending appetite of credit institutions to smallholder farmers and agro-dealers often considered as credit risky, Government should put in place de-risking mechanisms e.g. guarantee schemes, insurance subsidies etc. This policy move would increase the number of farmers and agro-dealers accessing credit for sorghum production. Government should also consider improving rural access roads which would significantly reduce the costs of inputs and credit. This policy move would contribute significantly towards increasing profitability of sorghum farming in the study area.

### Conclusions

The purpose of this study was to evaluate the profit efficiency levels of smallholder sorghum farmers. From the Cobb-Douglas stochastic frontier model that was employed, the wide disparity of profit efficiency levels show that, sorghum farmers have opportunities to increase profit by 83%. This implies that the formulated hypothesis which states that smallholder sorghum farmers in Tharaka Nithi County are not profit efficient is not rejected.

Further, this study concludes that, family labour and fixed capital base are the major contributing factors to sorghum profitability. In the study area, sorghum productivity was less than half of the expected level of up to 5 tons ha<sup>-1</sup>. Also, few farmers (4%) used planting fertilizer and on average, their rate of application was about 10% to the recommended rate.

Several factors positively influenced profit efficiency namely experience level, access to agricultural credit and trainings. However, a negative significant influence between distance to the nearest agro-dealer shop and profit efficiency was reported. This means that, farmers who lived in close proximity to agro-dealer shops were reported to be more profit efficient.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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