



# **Production Efficiency of Sorghum: The Case of Smallholder Farmers in Kafta-Humera District Tigray Ethiopia**

**Tewoderos Meleaku<sup>1\*</sup>, Degye Goshu<sup>2</sup> and Bosena Tegegne<sup>2</sup>**

<sup>1</sup>*Tigray Agricultural Research Institute, Humera Agricultural Research Center, P.O.Box 62, Tigray, Ethiopia.*

<sup>2</sup>*Agricultural Economics and Agribusiness, Haramaya university, P.O. Box138, Dire Dawa, Haramaya, Ethiopia.*

## **Authors' contributions**

*This work was carried out in collaboration among all authors. Author TM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DG and BT managed the analyses of the study. Author BT managed the literature searches. All authors read and approved the final manuscript.*

## **Article Information**

DOI: 10.9734/SAJSSE/2021/v11i230282

### Editor(s):

(1) Dr. John M. Polimeni, Albany College of Pharmacy and Health Sciences, New York.

### Reviewers:

(1) Sinimole K. R., N. L. Dalmia Institute of Management Studies and Research, India.

(2) Dra. Michelle Garcia Gomes, Federal University of Uberlândia, Brazil.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/62253>

**Original Research Article**

**Received 22 August 2020**  
**Accepted 28 October 2020**  
**Published 24 June 2021**

## **ABSTRACT**

Efficiency is an important factor for increasing productivity which leads to increase market output to achieve the goal of food security. In economics where resources are scarce and opportunities to use new technologies are limited, increasing efficiency remains the most reasonable means to raise productivity without necessarily developing new technologies or increasing the resource base. So, this study aimed to investigate level of production efficiency, factors affecting production inefficiency of sorghum small holder farmers in Kafta-humera district of Tigray Ethiopia. A two stage sampling technique was used to select 289 sample farmers who were interviewed using a semi- structured questionnaire to obtain data pertaining to sorghum production during the year 2016/2017. Stochastic production frontier model was used to identify production efficiency levels, where as Tobit models was used to estimate factors affecting production efficiency levels. Accordingly, the mean technical, allocative and economic efficiencies were 78.01%, 65.21% and

\*Corresponding author: Email: [tediyo.143@gmail.com](mailto:tediyo.143@gmail.com);

39.91% respectively. This implies that output can be increased by 21.99% or cost can be reduced by 34.79% with the existing level of technology and resources. Input variables such as land, labor, tractor plow power, chemicals, DAP and Urea fertilizers positively affects production of sorghum. The discrepancy ratio ( $\gamma$ ) implied that about 91.91% of the variation in sorghum production was attributed to technical inefficiency effects. Tobit model revealed that age, education, non-farm income, credit, extension service and training positively and significantly affected technical efficiency while age square and total livestock holding had negatively and significantly affected. Additionally, age square, education and frequency of farm visit positively and significantly affected allocative efficiency, while age, non-farm income, credit and extension contact have a negative and significant affect. Economic efficiency was positively and significantly affected by age, education, non-farm income, credit, extension contact and frequencies of farm visit but negatively affected by age square. These indicate that there is a room to increase in production efficiency of sorghum in the study area. Therefore, government authorities and other concerned bodies should take into consideration the above mentioned demographic, socioeconomic and institutional factors to increase efficiency of sorghum.

*Keywords: Sorghum; production efficiency; tobit; stochastic production frontier.*

## 1. INTRODUCTION

The majority of poor households living in the developing areas rely on agriculture for their food, income, and livelihood [1]. Agriculture has been the leading sector of the Ethiopian economy for several centuries. Where around 95% of the country agricultural output is produced by smallholder farmers [2]. Hence, agriculture takes the lion's share of Ethiopian economy; it contributes 70% of export earnings and 80% of employment [3]. It is still the dominant sector being contributing (38.5%) of the total GDP and the livelihood of the 75.26 million (79.77%) of the population [4],[5]. Therefore, improving agricultural practices is as a means of increasing productivity, efficiency and ultimately income [6].

Even though agriculture is the corner-stone of Ethiopian economy, its performance has been unsatisfactory and unable to meet the ever increasing demand of the increasing population [7]. The performance of the agricultural sector is remains backward and undeveloped. Agriculture in Ethiopia in general especially Tigeray explained by low productivity caused by a combination of agro climatic, demographic, technical, socio-economic and institutional constraints and shocks (WFP, 2010). As a result, the growth in agricultural output has failed to provide food for the fast growing population and thus aggravated the food insecurity situation in the region [8],[9].

Globally, sorghum is the fifth most important staple food crop after wheat, rice, maize and barley (FAO, 2016). Ethiopia is the third-largest

sorghum producer in Africa after Nigeria and Sudan [10]. It accounts for 19% of the domestic cereal production and 20% of the total area under cereals [11] and [12]. The crop also ranks third next to maize and teff for which the total annual production is estimated to be 4.75 million tonnes [13]. Sorghum in Ethiopia it is important indigenous food crop consumed at household level and the second most important crop for *injera* quality next to *teff*. The grain is also used for preparation of other traditional foods and beverages (FAO, 2005; USDA, 2012 and ATA, 2015).

In the western lowland part of Tigeray, particular in *kafta-Humera* district where the study was carried out, mixed farming system is the means of livelihoods of the people. Peoples in the area are not attaining food self-sufficiency due to; recurrent drought, coupled with erratic rainfall, low productivity, low input utilization and poor soil fertility. Most of the increase in crop production in the past decade has been due to increase in area cultivated. Increasing productivity in smallholder agriculture is government top priority, recognizing the importance of the smallholder sub-sector, the high prevalence of rural poverty and the large productivity gap. According to research conducted by HuARC, 2015 yield potential for improved varieties for prescribed agronomic conditions ranges between 3.5-4.5 tons per hectare, however farmers are only able to achieve, on average, 1.7 tons per hectare (HuARC, 2015).

The national and regional agricultural research system has generated a number of improved agricultural technologies and recommendations

such as crop variety, agronomic practices, crop protection measures as well as other technical advices and practices to increase production and productivity. Improvement of agricultural productivity provides an important solution in addressing the problems of food insecurity and poverty, and enhancing the development of agriculture in Tigray. Consequently, attempts are being guided in ways by which increased agricultural productivity can be achieved through promoting the use of improved agricultural technologies and improving the efficiency of production of cereal crops [14],[15] and [16].

Despite its highest effort still productivity is low attributed mainly lack of knowledge on the efficient utilization of resources (especially labour, land and capital), poor and backward technologies (farm mechanization), inaccessibility and limited use of modern agricultural inputs (fertilizer, improved/hybrid seed, pesticide etc.), outdated farming techniques, poor complementary services (such as extension, credit, marketing, and infrastructure), lack of transportation and storage facilities, natural calamities and poor and biased agricultural policies (Arega and Rashid, 2005 [17],[8],[16],[18],FAO and WFP 2012 [19]).

There for theoretically, either of the following options can increase agricultural production. One is allocating more land area for cultivation. Second, adopting and developing modern production technologies. The second option is a long-term option and requires a lot of capital investment for research and extension works to develop other complementary activities and thus enhance the effectiveness of the strategy. The third option is improving the efficiency of inputs such as labour and management at the existing technology. The third option is the best way of increasing production, which is also compatible with a short-run production orientation [20],[21],[22].

The fundamental role of efficiency in increasing agricultural output has been widely recognized by the researchers and policy makers. The importance of studying efficiency is that the farmers are not making efficient use of the present technology, then efforts designed to improve efficiency would be less expensive than introducing new technology as a mean of increasing agricultural production output (Grabowski, 1985). Therefore, this study is intended to fill research gap in sorghum

production efficiency and factors affecting market supply in the study district.

The study was designed in achieving the following objectives

### 1.1 General Objective

To assess level and determinates of sorghum production efficiency: the case of smallholder farmers in Kafta-Humera district Tigray Ethiopia.

### 1.2 Specific Objective

1. To measure technical, allocative and economic efficiency levels of smallholder sorghum farmers.
2. To identify determinates of technical, allocative and economic efficiency of smallholder farmers.

## 2. METHODOLOGY

### 2.1 Data and Sample Selection

The study was carried out using cross sectional data taking the unit of analysis as smallholder sorghum producers. Both quantitative and qualitative data were collected using primary and secondary data sources. Focus group discussions (FGDs) that involved key informants drawn from small-scale sorghum producers were also used for data collection. The data collected from sample households focused on general socio-economic characteristics of the individual respondents, production system of respondents, quantity of sorghum produced, quantity of sorghum consumed and supplied to market, frequency of extension visit, market information, credit accessibility and other necessary information were collected. A multi stage random sampling technique was used to select sample households for this study. In the first stage, Due to the importance of sorghum and its extent of production from western zone of Tigray, Kafta-Humera district was selected purposively. In the second five kebeles (Maykadra, Baeker, Adebay, Rawyian and Berket) that produce sorghum were selected randomly. In the last stage, the sample farmers were selected using simple random sampling technique from each kebele proportional to the total number of households of each kebele. The intended total sample size was also determined based on the following formula developed by Yamane (1967).

$$n = \frac{N}{1 + N(e)^2} = \frac{29324}{1 + 29324(0.0586)^2} = 289 \text{ Households} \quad (2.1)$$

## 2.2 Methods of Data Analysis

### 2.2.1 Specification of the econometric models

To address the objectives of this study, both descriptive statistics and econometric models were employed. In descriptive statistics, the simple measures of central tendency, frequency and percentages were used. Where as in the econometric analyses method the stochastic frontier approach (SFA) and a Tobit model were used to estimate the level of technical, allocative and economic efficiencies and the relation between farm level socio-economic, demographic and institutional variables and inefficiencies, respectively. This study employed stochastic efficiency decomposition method to assess technical, allocative and economic efficiencies of sorghum producers as assumed in DEA, is difficult to accept, given the inherent variability of agricultural production due to many factors like climatic hazards, plant pathology and insect Coelli (1995) and Kirkley et al., (1995). According Aigner et al., [23], Bravo-Ureta and Rieger (1991) and Meeusen and van Den Broeck [24], the SPF model is specified as follows:

$$Y_i = F(X_i; \beta) + \varepsilon_i \quad \text{and } i = 1, 2, 3 \dots n \tag{2.2}$$

Where  $Y_i$  represents the sorghum output level of  $i^{\text{th}}$  sample of farmers,  $X_i$  is vector of input variables for the  $i^{\text{th}}$  farmer and  $F(X_i; \beta_i)$  is the appropriate functional form and  $\beta$  is vector of unknown parameters to be estimated.

$$\varepsilon_i = V_i - \mu_i \tag{2.3}$$

Where:

$U_i$  = non-negative random variable, independently and identically distributed as  $N(u_i, \delta^2_u)$  which intended to captures the technical inefficiency effects in the production of sorghum measured as the ratio of observed output to maximum feasible output of the  $i^{\text{th}}$  farm and  $V_i$  = a disturbance term independently and identically distributed as  $N(0, \delta^2_v)$  which intended to capture events or factors outside the control of the farmers.

The variance parameters for Maximum Likelihood Estimates are expressed in terms of the parameterization proposed the log likelihood function for the model in equation (2.2) assuming half normal distribution for the technical inefficiency effects ( $u_i$ ). They expressed the

likelihood function using  $\lambda$  parameterization, where  $\lambda$  is the ratio of the standard errors of the non-symmetric to symmetric error term (i.e.  $\lambda = \sigma_u / \sigma_v$ ). However, Battese and Corra [25] proposed that the  $\gamma$  parameterization, where  $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$  to be used instead of  $\lambda$ . The reason is that  $\lambda$  could be any non-negative value while  $\gamma$  ranges from zero to one and better measures the distance between the frontier output and the observed level of output resulting from technical inefficiency. However, there is an association between  $\gamma$  and  $\lambda$ . According to Bravo and Pinheiro [26] gamma ( $\gamma$ ) can be formulated as:

$$\gamma = \lambda^2 / (1 + \lambda^2)$$

### 2.2.2 Stochastic efficiency decomposition method

As SFA requires a prior specification of the functional form, given the assumption of self-duality Xu and Jeffrey [27], Cobb-Douglas production function was selected. According to Coelli [28] Cobb Douglas functional form has most attractive feature nature of the Cobb-Douglas production and cost functions provides the computational advantage in obtaining the estimates of TA and EE. As indicated by Arega and Rashid [29], inadequate farm level price data together with little or no input price variation across firms.

$$\begin{aligned} \ln(Y_i) = & \beta_0 + \beta_1(\text{Seed}) + \beta_2(\text{Land}) + \beta_3(\text{Plowpower}) \\ & + \beta_4(\text{DAP}) + \beta_5(\text{Urea}) + \beta_6(\text{Chemical}) \\ & + \beta_7(\text{Labour}) + v_i + \mu_i \end{aligned} \tag{2.4}$$

The economically efficient input vector of the  $i^{\text{th}}$  household  $X_{ie}$  is derived by applying Shepard's lemma as applied in the studies conducted by (Arega and Rashid, [30]; [31], [32], Zalkuwi et al., (2010) and Ermiyas (2013) for the expenditure equation and substituting the firms input prices and adjusted output level.

$$\frac{\partial C_i}{\partial w_i} = X_{ie}(w_i, Y^*; \alpha) \tag{2.5}$$

Based on Shepard's Lemma, the optimization profit principle of the Cobb Douglas production function to minimize cost subject to the optimum amount of output to be produced, for optimizing the return the cost must be held at its minimum. Due to the availability of two functions of the cost function and the production function the optimization technique is obtained through the lagrangian method. The minimum cost is derived analytically from the production function, using the methodology used in [17] and [31]. Given

input-oriented function, the efficient cost function can be specified as follows:

$$\text{Min } \sum_x C = \sum_{j=1}^7 X_j w_j \quad 2.6$$

$$\text{Subject to } Y_i^* = \hat{A} \prod X_i^{\hat{\beta}_j} \quad 2.7$$

Where;  $\hat{A} = \text{Exp}(\hat{\beta}_0)$

Substitution of the cost minimizing input quantities into equation (2.6) yields the following dual cost function.

The solution for the problem in the above equation is the basis for driving dual cost frontier. Substituting the input demand equations derived using Shepherd's Lemma (eq. 3.9) and yield adjusted for stochastic noise (predicted value of yield) in the minimization problem above, the dual cost function can be written as follows:

$$C(Y_i^*, w; \alpha_i) = H Y_i^{*\mu} \prod_j W_j^{\alpha_j} \quad 2.8$$

Where;  $\alpha_j = \mu \hat{\beta}_j$ ,  $\mu = (\sum \hat{\beta}_j^{-1})^{-1}$  and  $H = \frac{1}{\mu} (\hat{A} \prod \hat{\beta}_j^{\beta_j})^{-\mu}$

From here all the parameters will be determined the minimum (efficient) cost of production. We can define the farm-specific technical efficiency in terms of observed output ( $Y_i$ ) to the corresponding frontier output ( $Y^*$ ) using the existing technology.

$$TE_i = \frac{Y_i}{Y_i^*} = \sum_i X_{it} \frac{P_i}{\sum_i X_i P_i}, P_{ip} \quad 2.9$$

The farm specific economic efficiency is defined as the ratio of minimum total production cost ( $C^*$ ) to actual observed total production cost ( $C$ ).

$$EE_i = \frac{C^*}{C} = \frac{\sum X_i P_i}{\sum X_i P_i} = \frac{(g(P, y^* \alpha) + \varepsilon)}{(g(P, y^* \alpha) + V_i)} \quad 2.10$$

Cost efficiency (CEE) takes the values of 1 or higher with 1 defining cost efficient farm. From these two equations the allocative efficiency (AE) can also be derived as the ratio of the EE to the TE

$$AE = \frac{EE}{TE} = \frac{\sum X_i P_i}{\sum X_{it} P_i} \quad 2.11$$

### 2.2.3 Determinates of production efficiency

The technical, allocative and economic inefficiency estimates were derived from stochastic production frontier regressed using a censored Tobit model on farm-specific

explanatory variables that were explaining variation in efficiency across farms. The rationale behind using a Tobit model was that there were bounded natures of efficiency between 0 and 1 (Hussein, 1989; Greene, 1991). That is, the distribution of efficiency is censored above from unity. Estimation with OLS regression of the efficiency score would lead to a biased parameter estimate since OLS regression assumes normal and homoscedastic distribution of the disturbance and the dependent variable (Greene, [33]).

Smallholder sorghum producers are assumed to operate under the same policy and institutional environments and face exogenous variables denoted as  $Z_i$  in addition, it is also assumed that these conditions determine farmers' decision to choose set of input vector  $X$  and produce output vector  $Y$ . Accordingly, in the production process a given farmer is considered to be relatively full efficient if it operates along the boundary of the frontier ( $Y^*$ ) which also defines the level of technology in the system. The boundary of the frontier represents a locus of output points constructed by best practice farms. In this case the output of efficient farms ( $Y_i$ ) to the potential output along the frontier is equal ( $Y^* = Y_i$ ). Relative efficiency measures, computed as the ratio of actual (realized) to the potential (frontier) output level ( $Y^*/Y_i$ ), of these farms will be unity ( $Y^*/Y_i = 1$ ).

**Table 1. Kebeles, number of households, and sample size selected from sample kebeles**

Kebele	Number of households	Sample size	Percent
Maykadra	3260	79	27.34
Baeker	2682	65	22.49
Adebay	2229	54	18.69
Rawiyan	1898	46	15.91
Berket	1857	45	15.57
Total	11926	289	100

Source: From KHARDo, (2018)

On the other hand, firms which are relatively inefficient compared to the best practice (frontier) operate at points in the interior of frontier and score less than unity ( $Y^*/Y_i < 1$ ). Furthermore, the efficiency scores of the most inefficient farms in the system are found closer to zero ( $Y^*/Y_i > 0$ ). Therefore, while the scores are bounded between zero and unity with the upper limit set at one, the distribution is censored at both tails ( $0 < Y^*/Y_i \leq 1$ ). Thus, following Amemiya, [34]; Coelli et al., [35]; Greene, W.H., [36]; Bravo-Ureta et al., [37]; Mussaa et al., [38] and Tukela et al., [39]

the study adopts the two-limit Tobit model. The model is estimated as follows:

$$Y_{i,EE,TE,AE}^* = \delta_0 + \sum_{j=1}^n \delta_j Z_{ij} + \mu_i \tag{3.16}$$

Where  $Y_i^*$  is the latent variable representing the efficiency scores,  $\delta_0, \delta_1, \dots, \delta_{12}$  are parameters to be estimated, and EE, TE and AE are economic, technical and allocative efficiency of the  $i^{th}$  farmer, respectively.  $Z_i$  is demographic, socio economic and institutional factors that affect efficiency level. And  $\mu_i$  = an error term that is independently and normally distributed with mean zero and variance  $\delta^2$  ( $\mu_i \sim IN(0, \delta^2)$ ). And, farm-specific efficiency scores for the smallholder sorghum producers range between zero and one. Therefore, two-limit Tobit model can be presented as follow:

$$Y_i = \begin{cases} 1, & \text{if } Y_i^* \geq 1 \\ Y_i^*, & \text{if } 0 < Y_i^* < 1 \\ 0, & \text{if } Y_i^* \leq 0 \end{cases} \tag{3.17}$$

Where:  $I$  refer to the  $i^{th}$  decision making units inefficiency scores of the  $i^{th}$  DMU (Decision-Making Units).  $Y_i$  is the latent inefficiency variable,  $\beta_j$  are parameters to be estimated and  $\mu_i$  is an error term that is independently and normally distributed with mean zero and common variance of  $\delta^2$  ( $\mu_i \sim NI(0, \delta^2)$ ).  $Z_{ij}$  are host of socio economic, institutional and demographic variables.

### 3. RESULTS

#### 3.1 Estimation of Stochastic Frontier Production Function (SFPF)

The maximum likelihood (ML) estimates of the parameter of the stochastic frontier Cobb-Douglas production function results are presented in Table 2. The standard OLS estimate is also presented for comparison. As described in the data analysis of the methodological part, the specified Cobb-Douglas functional form of the stochastic frontier model with half-normal distributional assumption of the error terms is

considered to estimate the model or parameters of the model. The maximum-likelihood estimates of parameters of the stochastic production frontier a model was described equations (3.2). After testing the dataset a stochastic production frontier model permits to consider production of sorghum in the study area with a Cobb-Douglas type of production function.

The result of the model showed that all the input variables in the production function except seed had a positive and significant effect on the level of sorghum output. The interpretation of the parameters that entered the production function directly is given in the form of partial production elasticities that examines the degree of responsiveness of relative change in sorghum output due to relative change in each input. These serve as a measure of resource productivity. Hence, the point estimates indicated in Table 2 shows that 1% increase of land, plow power, DAP, urea, chemical and labour will increase sorghum output by 0.316%, 0.123%, 0.263%, 0.104%, 0.048% and 0.319% respectively.

The Maximum Likelihood estimation of the frontier model gives the value for the parameter ( $\gamma$ ), which is the ratio of the variance of the inefficiency component to the total error term is equal to  $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$  or  $\lambda^2 / (1 + \lambda^2)$  [26]. The  $\gamma$  value indicates the relative variability of the one-sided error term to the total error-term. In other words, it measures the extent of variability between observed and frontier output that is affected by the technical inefficiency. The closer ratio to one indicates more variability of the output affected by technical inefficiency than the usual random variability.

Estimated value of gamma was 91.85% which indicated that variation in sorghum farm output was due to technical inefficiency. The value of  $\sigma^2$  for the frontier of sorghum output was 0.123 which was significantly different from zero at 1% level of significance. The significant value of the sigma square indicates that the goodness of fit and correctness of the specified assumption of the composite error terms distribution as indicated in (Jondrow et al. 1982, Idiong, 2005; Okoye et al., 2007).

**Table 2. Estimation of stochastic frontier production function**

Ln sorghum production	Unit	OLS estimated model		ML estimate half normal model	
		Coefficient	Standard error	Coefficient	Standard error
LnSeed	Kg	0.042	0.101	0.058	0.077
LnLand	Ha	0.316**	0.133	0.306***	0.106
LnPlow power	Hour	0.123***	0.123	0.103***	0.045
LnDAP	Quintal	0.263***	0.054	0.187***	0.056
LnUrea	Quintal	0.104*	0.058	0.116**	0.053
LnChemical	Litter	0.048	0.056	0.102*	0.058
Lnlabour	Man day	0.319***	0.078	0.322***	0.065
Constant		1.919***	0.386	2.086***	0.325
Lamda ( $\lambda$ )		-	-	3.358***	0.053
Sigma ( $\sigma^2$ )		-	-	0.123***	0.018
Gamma( $\gamma$ )		-	-	0.919	
LR		-	-	34.08	
F statistics		427.08***			
Adjusted R <sup>2</sup>		0.911			
Returns to scale				1.194	

NB: \*, \*\*, \*\*\*, Significant at 10%, 5% and 1% level of significance

### 3.2 Partial Elasticity and Returns to Scale

**Elasticity of production:** It measures the effect of change in the factor input on output. In Cobb-Douglas production function, the regression coefficients stand for the elasticity's of the individual resources (Land, Labor, Seed, Urea, DAP, Chemical and Tractor power). The elasticity of production which is the percentage change in output as a ratio of a percentage change in input was used to calculate the rate of return to scale. It measures a firm/farm's success in producing maximum output from a set of input as stated in Farrell (1957). Parameter estimates from the Cobb-Douglas production function represent output elasticity with respect to the individual inputs. The output elasticity was calculated as:

$$\varepsilon = \frac{\partial \ln Y}{\partial \ln X} = \beta_i \ln X$$

Where  $\varepsilon$  is the output elasticity with respect to the individual inputs and  $X_i = 1, 2, \dots, 7$  for the seven individual inputs.

The returns to scale, from neoclassical theory of economics is used to show the proportionate increase in output resulting from a given proportionate increase in all inputs. The returns to scale can be either of increasing, decreasing or constant, if the sum of the estimated partial elasticities is greater than, less than or equal to one respectively. The summation of the partial elasticities ( $\sum \varepsilon_i$ ) of all the inputs is 1.19. This implies that increase in all inputs at the sample

mean by one percent may lead to increased production by 1.19 percent, ceteris paribus, i.e. sorghum producers in the study area were operating at increasing returns to scale of production (Table 3). The result is in line with results found by Haileselesse (2006) and Gosa (2016).

**Table 3. Partial elasticity and returns to scale**

Variables	Elasticity of production
LnSeed	0.058
LnLand	0.306
LnPlow power	0.103
LnDAP	0.187
LnUrea	0.116
LnChemical	0.102
LnLabour	0.322
Return to scale	1.19

### 3.3 Efficiency of Sorghum Producers

Efficiency score indicates the existence of room for improving the existing level of production through enhancing the farmer's efficiency using the existing limited resources by improving the firm capacity to utilize available resources in efficiently in order to get maximum production.

The result presented in Table 4 shows that the mean allocative efficiency of farmers in the study area was 65.21 percent. This result indicated presence of room to improve the present level of allocative efficiency. Moreover, estimates indicated that farmers have abundant opportunities to increase their allocative

efficiency. For instance, farmer with average level of allocative efficiency would have a cost saving of about 32.91 percent derived from  $(1 - 0.6521073 / 0.971973) * 100$  to attain the level of the most efficient farmer. The most allocative inefficient farmer would enjoy an efficiency gain of 60.31 percent found from  $(1 - 0.385848 / 0.971973) * 100$  to attain the level of the most technically efficient farmer.

The mean economic efficiency also showed that there was a significant level of inefficiency in the production process. That is the producer with an average economic efficiency level could reduce current average cost of production by 49.80 percent to achieve the potential minimum cost level without reducing output levels. It can be inferred that if farmers in the study area were to achieve 100 percent economic efficiency, they would experience substantial production cost saving of 49.80 percent. This implied that reduction in cost of production through eliminating resource use inefficiency could add about 49.80 percent of the minimum annual income. Moreover, the result also means that the farmer with average level of economic efficiency would enjoy a cost saving of about 23.14% derived from  $(1 - 0.5022105 / 0.6533746) * 100$  to attain the level of the most efficient farmer. The most economically inefficient farmer would have an efficiency gain of 68.22 percent derived from  $(1 - 0.1596029 / 0.5022105) * 100$  to attain the level of the most efficient farmer (Table 4).

According to the result, efficiency scores show that there were wide ranges of differences in technical efficiency among sorghum producer farmers in the study area. The mean technical efficiency of sample households during the survey year was 78.01 percent. The technical efficiency among farmers ranged from 39.86 to 96.64 percent. This shows that there is a wide disparity among sorghum producer farmers in their level of technical efficiency which may in turn indicate that there is a room for improving the existing level of sorghum production through enhancing the level of farmers' technical efficiency (Table 4). This wide variation in farmer

technical efficiency levels is consistent with study of (Jema, 2016; Mussa, 2013; Mohamed, 2012; [40]).

On the other hand, mean level of technical efficiency further tells us the level of sorghum output of the sample respondents which can be increased on average by about 21.87 percent if appropriate measures are taken to improve the efficiency level of sorghum growing farmers. This point out that presence of an opportunity to increase yield of sorghum approximately by 21.87 percent using the existing resources at their disposal in an efficient manner without introducing any other external inputs and practices.

### 3.4 Actual and Potential Levels of Output

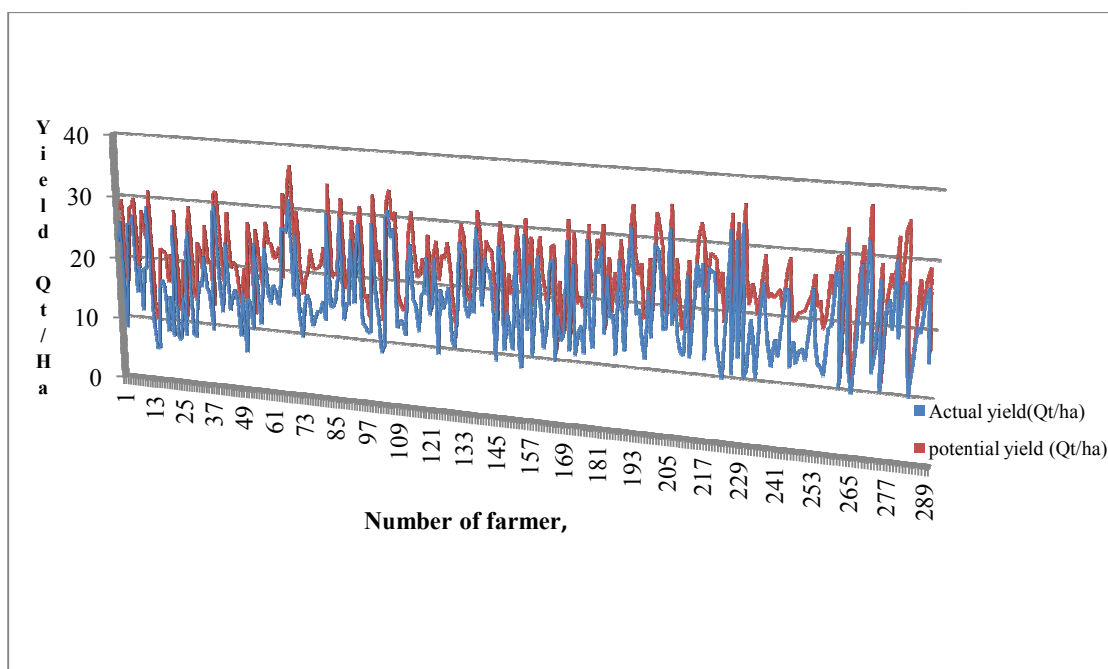
The knowledge of the individual farmer efficiency level and their corresponding actual output enables us to determine how much yield is lost because of inefficient use of existing resources. From the current production practice of the existing resources, it is possible to find out the potential attainable level of sorghum output or yield. Either the farmers had used the available resources in an efficient way was calculated using the actual observed individual level sorghum output and predicted individual TE from the frontier model.

From the relationship of technical efficiency in a given period of time as the ratio of the actual output  $(Y_i; \exp(X_i\beta + v_i - \mu_i))$  to the potential output  $(Y_i^*; \exp(X_i\beta + v_i))$  described in equation, the potential sorghum production of each individual farmer is calculated as follows:  $TE_i = Y_i / Y_i^* = \exp(-\mu_i)$  which gives  $Y_i^* = Y_i / TE$ . The mean level of both actual and potential output during the production year were 18.35qt/ha and 23.16 qt/ha with standard error of 6.48 and 5.86 respectively. Using the t-test method, the mean difference of the actual and the potential output was found to be statistically significant at 1% provability level. The result is similar with the results found by Haileselesse (2006), [40] and Gosa (2016).

**Table 4. Efficiency score of sorghum producers**

Types of efficiency	Non participants		Market participants		Both		t-test
	Mean	Std	Mean	Std	Mean	Std	
Technical	0.757	0.138	0.785	0.128	0.780	0.129	-1.32
Allocative	0.624	0.093	0.657	0.083	0.652	0.085	-2.46
Economic	0.461	0.035	0.510	0.073	0.502	0.071	-4.49





**Fig. 1. Comparison of actual and potential levels of output**

### 3.5 Stochastic Frontier Cost Function (SFCF)

The parameters of the stochastic frontier production function are actually used to derive the parameters of the dual cost function. Adjusted output is used to derive allocative and economic efficiencies employing the dual cost frontier function. Where C is the minimum cost of production of the  $i^{th}$  farmer,  $Y^*$  refers to the index of output adjusted for any statistical noise and scale effects, W stands for input prices [41], Bravo-Ureta and Rieger, 1991 and [23]. On account of inadequate farm level price data coupled with little or no input price variation across farms in the study area precludes any econometric estimation of a cost or profit frontier function. Therefore, the use of self-dual production frontier functions allows the cost frontier to be derived and used to estimate economic efficiency in situations where producers face the same input prices.

$$\ln C_i = 2.832 + 0.256 \ln W_1 + 0.049 \ln W_2 + 0.086 \ln W_3 + 0.157 \ln W_4 + 0.112 \ln W_5 + 0.085 \ln W_6 + 0.838 \ln Y^*$$

### 3.6 Determinants of Efficiency Disparities among Farmers

After measuring levels of efficiency and determining the presence of efficiency variation

among farmers, the main interest behind measuring efficiency level was to know the factors that determine the efficiency level of individual farmers. The parameters of the various hypothesized variables in the efficiency effect model that were expected to determine efficiency differences among farmers were estimated using second stage estimation procedure. The determinants of technical, allocative and economic efficiencies in a given period differ considerably depending on the demographic, socioeconomic, farm characteristics, institutional and environmental conditions of the study area.

The result of regression model also showed that among the total variables age, age<sup>2</sup>, education, off farm income, amount of credit obtained, total livestock holding, training and extension service significantly affects the level of technical efficiency. Whereas age, age<sup>2</sup>, education, off farm income, amount of credit obtained, extension service and frequency of farm visit significantly influence allocative efficiency of sorghum production. Additionally age, age<sup>2</sup>, education, off farm income, amount of credit obtained, extension service and frequency of farm visit factors were important in influencing economic efficiency of households in the study area.

### 3.7 Determinates of Technical Allocative and Economic Efficiency of Sorghum Production

#### 3.7.1 Age of household head

Age of household head had significant and positive effect on technical and economic efficiency of sorghum producing farmers at one percent level of significance. This indicates that as the age of farmers increases their inefficiency decreases which leads to improvement in the level of technical and economic efficiency. This may be due to the fact that age can serve as a proxy variable of farming experience, in which farmers with more years of experience are expected to be less inefficient. The result is in conformity with the results of Gosa (2016), Mustefa (2014) on Barley and Mohammed (2012) sorghum in Nigeria. However, this may diminish, as the household head gets older. The result shows that the age and age-square have positive and negative signs, respectively and both are significant (Table 5). Thus, middle aged farmers are more efficient than the very young and older ones. Since farming as any other professions need accumulated knowledge, skill and physical capability, it is decisive in determining efficiency. The result is similar with Haileselasse (2006).

However, the negative coefficient of age of household head, which is significant in allocative

efficiency, indicates that efficiency in resource allocation is deteriorating when the household gets older at 1 percent significance level. Age contributed negatively to the allocative efficiency in this study; in other words, younger farmers were relatively more efficient than older farmers. The reason could be younger farmers had more contacts with extension agent services, plot demonstration and agricultural meetings. This result is in line with Gosa (2016) in Habro and Tukelaet al (2014) in Sidama on sorghum and maize respectively.

Age and age-square have negative and positive effect in allocative efficiency respectively. In addition to this age changes the general farming experience and physical capacity of farmers, which in turn bring differences in abilities of decision making and laborious farming practices. These efforts again could create efficiency differential across the different age. The reason could be because of the accumulated experiences that have been gathered over time. They become skillful as they get older and may have an interest in the use of new methods of production. The estimated coefficients of age square for allocative were also positive and significant at 1 percent significance level. This may be because allocative efficiency requires greater knowledge and skill gained over time, which builds the capacity of farmers for optimal allocation of resources and technology.

**Table 5. Factors influencing technical efficiency, allocative efficiency and economic efficiency**

Variables	Technical efficiency		Allocative efficiency		Economic efficiency	
	Marginal effect	Std. Error	Marginal effect	Std. Error	Marginal effect	Std. Error
Age	0.02159***	0.00441	-0.00841*	0.00482	0.01209***	0.00286
Age <sup>2</sup>	-0.00023***	0.00005	0.00009*	0.00005	-0.0001***	0.00003
Education	0.00624***	0.00225	0.00714***	0.00242	0.00359*	0.00215
Family size	-0.00175	0.00218	-0.00017	0.0024	-0.00194	0.00142
Sex	0.00461	0.01162	0.02023	0.01276	0.00708	0.00755
Lnoff income	0.00425***	0.00066	-0.00359*	0.00195	0.00185***	0.00043
LnCredit	0.00545***	0.00092	-0.00595***	0.00101	0.00131**	0.0006
Livestock (TLU)	-0.01238**	0.00679	0.00212	0.00387	-0.00161	0.00229
Extension contact	0.03711***	0.00349	-0.00979*	0.00383	0.03343***	0.00227
Training	0.02143*	0.01125	-0.00248	0.01236	-0.00836	0.00731
FSize other	0.00277	0.00179	-0.00223	0.00197	0.00126	0.00116
Frequency farm visit	0.00714	0.00485	0.00916*	0.00478	0.01203**	0.00283
Constant	0.37585**	0.15280	0.67698***	0.11965	0.63531***	0.10634

NB: \*, \*\*, \*\*\*, Significant at 10%, 5% and 1% level of significance

### 3.7.2 Frequency of extension contact

It had statistically significant positive relationship with technical and economic efficiency at one percent significance level. This implies that frequent extension service facilitates the flow of new ideas between the extension agent and the farmer thereby giving a room for improvement in farm efficiency. Advisory service provides to the farmer to improve their average performance in the overall farming operation. As the service widens the household's knowledge with regard to the use of improved agricultural inputs and agricultural technologies will increased. This result is also conformity to those results obtained by Mohammed (2012) in Nigeria, Chepng'etich (2013) in Kenya and opposite to Kusse (2016) and Haileselesse (2006) on sorghum. However, the negative coefficient of extension contact which is significant at ten percent in allocative efficiency indicates that efficiencies in resource allocation is hindering as the frequency of extension service increases. This may be due to the fact that extension workers are only interested in maximizing output at any cost. This result is similar with result obtained by Jema [20] on vegetable, Musa (2013) on maize and Ermias et al. (2015) and Hika (2016) on sesame.

### 3.7.3 Education

Education is believed to enhance the managerial and technical skills of farmers. It had significant and positive effect for all efficiencies. The positive and significant effect of education on all types of efficiencies verifies the importance of education in increasing the efficiency of sorghum production. Education can be a proxy variable for managerial ability of the farmer and improves the ability of the household to make better decision about production inputs. Because of their better skills, access to information and good farm planning; literate farmers are better to manage their farm resources and agricultural activities and willing to adopt improved production technologies than illiterate one. Education increases technical efficiency of sorghum producer farmers in the study area. This result is in line with early study of, Solomon (2014) on major crop; Assefa (2012) on crop producing smallholder farmers and Zalkuwi et al., (2014) on sorghum.

Additionally, educated farmers have also relatively better capacity for optimal allocation of inputs. This result is in line with result obtained by Endalkachew (2012) on barely and Sisay

(2015), Gosa (2016) and Kifle et al., (2017) on maize. This result indicates that access to better education enabling farmers to enhance their managerial ability in resource use in order to produce optimum level of output. This indicates education capacitating human capital that enhances the productivity of farmers by allocating homemade and purchased inputs, select the appropriate quantities of purchased inputs and choose among available techniques.

### 3.7.4 Off/non-farm income

It had statistically significant positive relationship with technical and economic efficiency at one percent significance level. This implies that off/non-farm income occupation enhances the technical and economic efficiency of sorghum producers. Off/non-farm occupation may affect the technical efficiency positively for the reason that the income obtained from such activities could be used for the purchase of agricultural inputs and enhances financing of household expenditures which would entirely dependent on agriculture. This result is in line with previous results of Haileselesse (2006), Jema [20], Ababayehu (2011) and Hasen et al. (2012).

It is also positive and significant at 1 percent for economic efficiency. This may be because; the availability of off/non-farm income shifts the cash constraint outwards and enables farmers to make timely purchases of those inputs which they cannot obtain from on farm income. Therefore, it may enable farmers in maximizing their output at low cost of production. This result is also in conformity to results obtained by Ermiyas (2013) on sesame and Kifle (2014) on maize. The negative and significant effect of off-farm income on allocative efficiency indicated that farmers engaged in off-farm income earning activities tend to exhibit lower level of allocative efficiency. According to this study, involvement in non-farm activities were accompanied by reallocation of time away from farm related activities, such as adoption of new technologies and gathering information that is essential for enhancing allocative efficiency. This result is in line with results found by Bealu et al., (2013) on maize and Ermiyas (2013) on sesame.

### 3.7.5 Credit

Credit utilization is an important element in agricultural production systems. It allows producers to satisfy their cash needs induced by the production cycle in different agricultural

practices. Credit increases farmer's efficiency because it temporarily solves shortage of liquidity/working capital. In this study, credit is found to have positive and significant relation with technical and economic efficiency, which indicates that farmers with access to credit tend to exhibit higher levels of efficiency. Credit availability shifts the cash constraint outwards and enables farmers to make timely purchases of those inputs that they cannot provide from their own sources. This result is in line with Hasan [31]; Jude et al., (2011) and Gbigbi (2011). However, the negative coefficient of credit utilization which is significant in allocative efficiency indicates that as compared to those households who credit utilizes it reduces allocative efficiency. This may be because of fearing repayment which did not consider risk, Changing weather condition, non-existence of agricultural insurance and level of loan diversion problem and inappropriate use of funds by farmers for agricultural production purpose. This result is in line with the argument of Ibrahim (2018) in Sudan on sorghum and millet.

### 3.7.6 Livestock holding (TLU)

Livestock in a mixed farming system have importance in the supply of animal power for plowing and threshing, provide draught power, manure, fire energy, and they are sources of income and food for the family. It can also be a proxy variable for the wealth status of the farmer. As livestock could have both competitive and complementary relationship with crop production, the direction of influence on production and efficiency depends on which form of the relationship outweighs under the considered study area. The result indicated that there was a negative sign and significant impact of total livestock holding on TE. The negative effect of total livestock holding indicates that a farmer with large populations of livestock ownership were less efficient in the study area. The reason might be that livestock husbandry may compete for resource with crop production and hence did not improve production. This result is in line with the argument of Fekadu (2004), Kinde [22] and Bealu et al., [39].

### 3.7.7 Training participation

The coefficient of training participation in sorghum production was significantly affecting the technical efficiency at households' level in Kafta-Humera woreda. It was a dummy variable and significant at 1% significance level. May the

reason was giving training increases the awareness of farmers and exposes to new ideas and information about productivity of inputs, opportunities, input and output management and prudent handling of cash. Those households who attend trainings on various sorghum production skills can easily adopt various sorghum production technologies. Farmers who received training were technical more efficient than those who did not received training. This result was related with the result found by Fekadu (2004) on wheat, Hagos (2014) on major crops and Bealu et al., [39] on maize.

### 3.7.8 Frequency of sorghum farm visit

It is found that this variable significantly and positively determines the allocative and economic efficiency of sorghum production at 10% and 5% significance levels respectively. This result indicates that as the frequency of farm visit increases the efficiency level of farmer increases. This may be the reason follow up it enables farmers to understand and quickly solve the possible solutions which boosts productivity.

## 4. CONCLUSION

The study aimed at analyzing production efficiency of sorghum in the Kafta-Humera district of Tigray region Ethiopia. The study was undertaken with the specific objective of analyzing levels of technical, allocative and economic efficiency as well as, determinants of inefficiency of sorghum. The study area was selected purposively based on the level of sorghum production in the region. To address the objectives of the studies stochastic frontier approach, Tobit and simple descriptive statistics were employed.

In this study, both purposive and a two stage random sampling procedures were adopted to select a sample of 289 sorghum producer households that represent the population. The data were collected from both primary and secondary sources. The primary data were collected through household survey from sample households using a semi-structured questionnaire. Besides, primary and secondary data from different sources were collected and organized. Data analysis was carried out using descriptive statistics and econometric models.

The Cobb-Douglas stochastic frontier production function result shows that all input variables except seed had significant positive effect on

sorghum production. The input elasticity indicated that labor, land, DAP, urea, tractor plow power and chemicals (herbicides) inputs are organized based on their elasticity respectively. This implies that sorghum production was responsive to inputs utilization (especially labor and land). The return to scale of sorghum production in the study area was 1.19 and from neoclassical theory of economics, sample farmers faced increasing returns to scale. This implies that production was in the irrational zone of production (stage I), where resource uses and production is believed to be inefficient. That is, inputs were not efficiently allocated and utilized while producing the output.

The Cobb-Douglas stochastic frontier production model was used to estimate the production and cost functions. The estimated stochastic production frontier model illustrates that land, DAP and urea, labour and tractor plow power positively and significantly affected sorghum production. The study also indicated that 78.01%, 65.21% and 50.22% were the mean levels of TE, AE and EE, respectively. This in turn indicates that farmers can increase their sorghum production on average by 21.92% when they were technically efficient. Similarly, they can reduce their cost by 68.22% without any change from optimum level of output. This implies that, using the subsisting resource base, improved efficiency can still be achieved and there was great potential for increasing the gross output and profit with the existing level of resource base.

In the second step of the analysis, Tobit model was used to identify factors determining relationships between TE, AE and EE. The Tobit model results indicated that age, education, off/non-farm income, credit, extension contact and training positively and significantly affected TE. Age square, education and frequency of farm visit had positive and significant effect on AE. Age, education, off/non-farm income, credit, extension contact and farm visit had positive and significant effect on EE.

However, age square and livestock (TLU) negatively and significantly affected TE. Age, off/non farm income, credit and extension contact had negative and significant effect on AE. Age square had negative and significant effect on EE. These findings indicated appropriate policy formulation and implementation on factors that enable farmers to improve their existing level of production efficiency and quantity of sorghum

supply. Development programs should act upon these variables. Therefore, the following important recommendations are given below based on the study results.

## 5. RECOMMENDATIONS

Age of household head had a significant positive effect on technical and economic efficiency of sorghum production. The local government should arrange field days, cross-visits, creating forum for experience sharing elder households and provision of short-term training programs so as to share the knowledge of elder households to young farmers. Using best practices of the efficient farmers as a point of reference would help setting targets in improving efficiency levels and finding the feebleness of the present farm practices. The relatively efficient farms can also improve their efficiency more through learning the best resource allocation decision from others.

The study also revealed that farm visit had a significant positive influence both allocative and economic efficiency of smallholders. Therefore, farmers should have more frequent follow his farm and effectively manage their farm activities to overcome the positive relation to efficiency. So, it is important to strengthen the initiatives for producers to visit their farm frequently during the production period. To address the constraints and improved the level of production efficiency.

Education was very important determining factor that has significant effect on production in the study area. It is central to adopt and use modern agricultural technologies and practices, agricultural information and institutional accessibilities which in turn increase and improve farm household's efficiencies. Thus government has to give due attention for training farmers through strengthening and establishing both formal and informal type of farmers education, farmers training centers, technical and vocational schools as farmer education would improve production efficiencies.

The result of the study reveals that farmers who have more frequency of extension contact were more efficient than farmers with less contact both in technical and economic efficiency. However, extension contact has negative and significant contribution to allocative efficiencies. Therefore, extension agents have to give due attention in training farmers in optimal input allocation. This could be done by designing appropriate capacity building program to train additional development

agents to reduce the existing higher ratio of farmers to development agents as well as to provide refreshment training for development agents. This calls for the need to more effective policy support for extension services and additional efforts need to be devoted to upgrade the skills and knowledge of the extension agents.

In this study training it was found to have a positive and significant effect on technical efficiency. Providing continuous training to smallholders and follow-up smallholders' farming activities about input usage during sorghum production is very important. Extension service centers should give trainings to the farmers to increase technical efficiency. This will substantially help smallholder sorghum producers to survive and achieve food security. This requires more effort from government and NGOs to increase farmers' training and education on better use of inputs.

Even though non-farm income was negatively related to allocative efficiency, it had a positive effect on technical and economic efficiency. This indicates a need to introduce activities that could enhance the non-farm/off farm income of households without affecting their farm time allocation so that the farmers would be in a position to invest the required amount of resources in sorghum production. Therefore, encouraging farmers to involve them self in both activities to improve their livelihood is required.

The study indicated that utilization of credit affects technical and economic efficiency positively. But it also affected allocative efficiency negatively. Therefore, better credit facility has to be facilitated via the establishment of adequate rural financial institutions and strengthening of the available micro-finance institutions and agricultural cooperatives to assist farmers in terms of finance. Additionally, improvements in farm efficiency rely on institutional capacity building for farmers. As a result, policy makers need to focus on providing institutional support to farmers rather than focusing on introducing new technologies. If the necessary technical and managerial skills are not in place, it may result in continued inefficiencies in sorghum production.

Livestock size affected technical significantly and negatively. This might be due to the fact that increase in livestock in TLU diverts farmers' efforts away from sorghum production and hence reduces efficiency of smallholder sorghum producers. This might be the case if the type of

off-farm activity deprives the farmers from running his/her farm. There for it is better to design appropriate policy and strategies for improving livestock production systems by solving the shortage of feed and providing various technical and advisory support services, which in turn would time spent in livestock management and enhance the efficiency of sorghum production.

## CONSENT

As per international standard or university standard, participant's written consent has been collected and preserved by the author(s).

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Minten B, Barrett CB. Agricultural technology, productivity, and poverty in Madagascar. *World Dev.* 2008;36(5):797–822.
2. MoA (Ministry of Agriculture). Ethiopia animal health year book. Addis Ababa: Federal ministry of agriculture animal and plant health regulatory directorate; 2010.
3. UNDP. African economic outlook: Ethiopia; 2015. Available:[http://www.africaneconomicoutlook.org/fileadmin/uploads/aeo/2015/CN\\_data/CN\\_Long\\_EN/Ethiopia\\_GB\\_2015.pdf](http://www.africaneconomicoutlook.org/fileadmin/uploads/aeo/2015/CN_data/CN_Long_EN/Ethiopia_GB_2015.pdf)
4. CSA (Central Statistical Agency) .2015. Agricultural sample survey report on area and production of major crops (private peasant holdings Meherseason 2014/2015 (2007 E.C.) Addis Ababa, Ethiopia, the FDRE statistical bulletin 578, Volume I.
5. UNDP (United Nations Development Program). Ethiopia: Quarterly ECONOMIC BRIEF. Third Quarter, Addis Ababa, Ethiopia; 2014.
6. Parvan A, Agricultural technology adoption. *Review.* 2011;5.
7. Mohammad Hassena, Farah H, Mwangi W, Belay Kassa. Factors influencing technical efficiency of barely production in Assassa District of Southern Ethiopia, *Ethiopian Journal of Agricultural Economics.* 2000;4 (1/2):1-22.
8. Jon P. The adoption and productivity of modern agricultural technologies in the Ethiopian highlands: A cross-sectional

- analysis of maize production in the west Gojam zone, Proceeding of the 2nd International Symposium on Economic Theory, Policy and Applications, 6-7th August 2007. Athens, Greece; 2007.
9. Rehima M, Belay Kassa, Dawit Alemu, Rashid S. Factors affecting farmers' crops diversification: Evidence from SNNPR, Ethiopia. *International Journal of Agricultural Sciences*. 2013;3(6):558-565.
  10. FAO. Food and agriculture organization of the United Nations database of agricultural production. Italy: FAO Statistical Databases; 2017. Available:<http://faostat.fao.org/site/339/default.aspx> [Google Scholar]
  11. DiMarcantonio F, Demeke M. Analysis of incentives and disincentives for sorghum in Ethiopia; 2013.
  12. CSA (Central Statistical Authority). Agricultural sample survey, area and production of crops. Addis Ababa: Central Statistical Authority. *Statistical Bulletin* 532. 2018;14-63.
  13. CSA (Central Statistical Agency). Ethiopian statistical abstract for the year 2016/17. Volume I. Report on area and production of major crops. Volume I. *Statistical Bulletin* No.584. Addis Ababa, Ethiopia. [Google Scholar]; 2017.
  14. Bravo-Ureta B, Evenson RE. Efficiency in agricultural production: The case of peasant farmers in Eastern Paraguay. *Agricultural Economics*. 1994;10:27-37.
  15. Sinafikeh Asrat, Getawork Getachew, Alemayehu Seyoum. Trend and determinants of cereal productivity: Econometrics analysis of nationally representative plot-level data. *International Food Policy Research Institute: Development Strategy and Governance Division Discussion Paper*, Addis Ababa, Ethiopia; 2010..
  16. Yu B, Nin-Pratt A. Fertilizer adoption in Ethiopia"s cereal production. *Journal of Development and Agricultural Economics*. 2014;6(7):318-337.
  17. Arega D, Rashid MH. The efficiency of traditional and hybrid maize production in eastern ethiopia: An extended efficiency decomposition approach. *Journal of African Economics*. 2005;15:91-116.
  18. Assefa Admassie. Analysis of production Efficiency and the use of modern technology in crop production: A study of Smallholders in the Central Highlands of Ethiopia, *Arbeiten Zur Agrarwirtschaft in EntwicklungsLandern*; 1995.
  19. FAO and WFP (Food and Agricultural Organization and World Food Programme), crop and food security assessment mission to Ethiopia. *Special Report of Food and Agriculture Organization and World Food Programme*; 2012.
  20. Jema Haji. Economic efficiency and marketing performance of vegetable production. In the Eastern and Central parts of Ethiopia: Faculty of natural resources and agricultural sciences department of economics uppsala, doctoral thesis no.2008:17. Swedish University of Agricultural Sciences, Department of Economics, Uppsala; 2008.
  21. Fekadu G, Bezabih E. Analysis of technical efficiency of wheat production: A study in MachakelWoreda Ethiopia. *Journal of Agricultural Economics*. 2009;7(2):1-34.
  22. Kinde Teshome. Technical efficiency of maize production: A case of smallholder farmers in AssosaWoreda. Unpublished M.S.c. Thesis Presented to School of Graduate Studies of Haramaya University; 2005.
  23. Aigner DJ, Lovell CK, Schmidt P. Formulation and estimation of stochastic frontier production function models. *Journal of econometrics*. 1977;6:21-37.
  24. Meeusen W, van Den Broeck J. Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review*; 435-444.
  25. Battese GE, Corra GS. Estimation of a production frontier model: with application to the pastoral zone of Eastern Australia. *Australian Journal of Agricultural Economics*. 1977;21(3):169-179.
  26. Bravo-Ureta BE, Pinheiro AE. Technical, economic and allocative efficiencies in peasant farming: Evidence from the Dominican Republic. *Developing Economies*. 1997;35(1):48-67.
  27. Xu X, Jeffrey R. Efficiency and technical progress in and modern agriculture: Evidence from rice production in China. *Agricultural Economics*. 1998;19:157-165.
  28. Battese GE, Coelli TJ. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*. 1995;20(2):325-332.
  29. Arega Demelash, Rashid MH. The Efficiency of traditional and hybrid maize production in Eastern Ethiopia: An

- extended efficiency decomposition approach. *Journal of African Economics*. 2005;15:91-116.
30. Arega Demelash, Rashid M. The efficiency of traditional and hybrid maize production in eastern Ethiopia: An extended efficiency decomposition approach. *Journal of African Economies*. 2005;15(1):91-116.
31. Arega Alene, Hassan RM. The efficiency of traditional and hybrid maize production in eastern Ethiopia: An extended efficiency decomposition approach. *Journal of African Economies*. 2006;15(1):91-116
32. Ogundari K, Ojo SO, Ajibefun IA. Economies of scale and cost efficiency in small scale maize production: Empirical evidence from Nigeria. *Journal of Social Sciences*. 2006;13:131-136.
33. Greene WH. *Econometric Analysis*. 5th Edition, Prentice-Hall, Pearson Education, Inc., Upper Saddle River, New Jersey, New York University; 2003.
34. Amemiya T. *Advanced Econometrics*, Harvard University press, Cambridge, Massachusetts; 1985.
35. Coelli T, Rahman S, Thirtle C. Technical, allocative, cost and scale efficiencies in Bangladesh Rice Cultivation: A Non-parametric Approach. *Journal of Agricultural Economics*. 2002;53(3):607-626.
36. Greene WH. *Econometric Analysis*, 5<sup>th</sup> ed. Pearson Education Inc., Upper Saddle River, New Jersey. 2003; 1024.
37. Bravo-Ureta BE, Solfs D, Lopez VHM, Maripani JF, Thiam A, Rivas T. Technical efficiency in farming-a meta-regression analysis. *Journal of Productivity Analysis*. 2007;27:37-72.
38. Mussaa EC, Obare GA, Bogale A, Simtowe F. Resource use efficiency of smallholder crop production in the central highlands of Ethiopia; 2011.
39. Tukela Bealu, Endrias Geta, Tadesse Ababu. Factors affecting economic efficiency in maize production: The case of BorichaWoreda in Sidama Zone, Southern Ethiopia; 2013.
40. Essa C. Mussa, Gideon A, Obare, Ayalneh Bogale, Franklin P. Simtowe. Resource use efficiency of smallholder crop production in the Central Highlands of Ethiopia. JEL Classification: C21, C61, Q12; 2011.
41. Sharma K, Leung RP, Zaleski HM. Technical, allocative and economic efficiencies in swine production in Hawaii: A comparison of parametric and non-parametric approaches. *Agricultural Economics*. 1999;20:23-35.

© 2021 Meleaku et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*  
*The peer review history for this paper can be accessed here:*  
<http://www.sdiarticle4.com/review-history/62253>