The Determinants of Technical Efficiency of Farmers in *Teff*, Maize and Sorghum Production: Empirical Evidence from Central Zone of Tigray Region

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Abstract

This study is made to examine the technical efficiency of farmers in Teff, Maize, and Sorghum production in the Central Zone of Tigray. The study used primary data collected from a sample of farm households selected using a combination of probability and non-probability sampling techniques in the 2014 cropping season.

A single step stochastic frontier production model is used for Teff, Maize, and Sorghum production separately. Based on the regression output of the stochastic frontier models, there is no evidence of technical inefficiency of farmers in the production of Sorghum. Evidence of technical inefficiency is found in the production of Teff and Maize though the predicted level of inefficiency in Teff is infinitesimal (less than 1%). Therefore, the deviation of actual output from the frontier output in Teff and Sorghum production is the result of the stochastic factors beyond the control of the farmers such as bad weather, drought, and the like. The reason behind low level of output in Sorghum and Teff production is not technical inefficiency of farmers but the low level of the current technology available to the farmers. Therefore, increasing output in these two crops requires shifting the current level of technology. Only farmers in Maize production are found to be technically inefficient with a predicted possibility of 4.5% efficiency gains. The technical inefficiency of farmers in maize production significantly differs across the three Woredas; Werie-Lekhe with the highest

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inefficiency of about 11% followed by Lailai-Maichew and Kola-Temben with inefficiencies of 6% and 0% respectively.

The low level of technical inefficiency in Maize, bare evidence of inefficiency in Teff and the nonexistence of inefficiency in Sorghum production are against the preceding evidences. This might be due to the difference in the choice of the dependent and explanatory variables. Moreover, the farmers might have improved their input use over the last couple of years due to training and extension services. Moreover, labor input measured in man days is found to be positive and significant in contrast to the preceding evidences implying agriculture in the study area not subjected to excess labor with zero or negative marginal productivity.

Finally, suboptimal technology adoption [the use of fertilizers below or above the standard amount required] doesn't affect output in Teff and Sorghum production but it tends to reduce output in Maize production. Moreover, training on modern input use, access for credit, the dummy for main crop, and irrigation are found to be significant determinants of technical efficiency in Maize production. Therefore, farmers should use the standard amount of fertilizer in Maize production and specialization is superior to diversification in all crops.

Key Words: Technical Efficiency, Stochastic Frontier Model.
JEL Code: Q12

1. Introduction

1.1 Background

Rain fed, subsistence level, small land holding, and retrograde production technology characterize the agricultural sector in the Ethiopian economy. According to Zenebe and Yesuf (2013), significant portion of the population depends on food aid despite encouraging growth in agricultural production in recent years. Food aid has been about 10% of domestic food production in the last two decades and 10% of the population had been food dependent in the year 2009.

Despite the tremendous development endeavours towards the MDGs in recent years, Ethiopia is among the poorest countries, MoFED (2012), on its interim report on poverty analysis, has shown the existence of rural-urban and regional disparity in poverty indices in Ethiopia. As per the report, Tigray is among the poorest regions in the country with head count ratios of total poverty and food poverty reported to be 31.8% and 37.1% respectively. These figures are well above the national averages of 29.6% and 33.6% respectively. Moreover, the region has registered head count ratios of 36.5% and 40.2% in terms of total poverty and food poverty in the rural areas. These figures surpass the national averages of 30.4% and 34.7% respectively as well.

On top of the regional disparity in poverty, there is also huge regional disparity in crop productivity as well. Maize, Sorghum and *Teff* are among the major cereals produced in the country. According to the CSA Agricultural sample survey (2013/14), the region's productivity in *Teff* and Maize are found to be 13.30 qt/ha and 22.79 qt/ha which are well below the national averages of 14.65 qt/ha and 32.54 qt/ha respectively. The region's productivity in Sorghum is found to be 25.4 qt/ha which is higher than the national average of 22.83 qt/ha. The survey also indicates zonal disparity in the productivity of crops within Tigray region. The Central zone is found to have lower crop yields of 19.54 qt/ha and 17.22 qt/ha in Maize and Sorghum respectively which are much more below the regional averages. However, the zone is found to have better productivity of 13.43 qt/ha in *Teff* production and is a touch higher than the regional average.

Different evidences have also shown that Tigray is one of the most inefficient regions in cereal production. For instance, Gezahegn *et al*. (2006) revealed that technical inefficiency of farmers in the production of *Teff*, Maize, and Wheat in Tigray was estimated to be 35% and was higher than that of Amhara, SNNPR, and Oromia with estimated inefficiencies of 29%, 19%, and 10% respectively. Similarly, Shumet (2012) had also revealed that the average efficiency of farmers in crop production is estimated to be 60% which indicates a need for about 40% improvement. Gebrehaweria *et al*.

(2012) also estimated average technical efficiency of rain-fed and irrigated farming to be 82% and 45% respectively.

Based on the above reports and empirical evidences, the incidence of food poverty in Tigray might be attributed to low level of agricultural productivity which in turn might be affected by improper input usage, soil infertility, drought, low access for irrigation, low efficiency in production, and the like.

This study is, therefore, designed to investigate whether there is input use inefficiency of *Teff*, Maize and Sorghum producers in the Central Zone of Tigray using data collected from farm households. A single step stochastic frontier model is estimated in the outset and the level of technical efficiency of the farmers is predicted.

1.2 Research Questions

The study is mainly concerned with estimating the level of technical efficiency of farmers and the determinants of technical efficiency. Suboptimal technology adoption, extension services, and sex are among the major determinants chosen by the author. Suboptimal technology adoption might have positive or negative impact on technical efficiency depending on its nature. If farmers sub-optimally adopt technology (use fertilizer below or higher than the standard) because of failure to afford prices, it might negatively affect efficiency otherwise not. The author has also given special attention to extension services and sex as a policy variable and gender issue respectively. Therefore, the following research questions are developed in this study.

- How much technically efficient are farmers in Maize, Sorghum, and *Teff* production?
- How does suboptimal technology adoption affect the technical efficiency of farmers?
- How do policy variables such as extension programs affect the technical efficiency of farmers?

- Is there a gap in technical efficiency between female headed and male headed farm households?

1.3 Objectives of the Study

The general objective of the study is to examine the technical efficiency of cereal production and the determinants of technical efficiency of farmers in the study area.

Specific objectives of the study are:

- To estimate and investigate technical efficiency differences of farmers
- To examine the factors affecting the technical efficiency differences of farmers

1.4 Research Hypothesis

Based on the research questions posed, the author has developed the following hypotheses:

- At least one farmer is technically inefficient in *Teff*, Maize or Sorghum production
- Suboptimal technology adoption is expected to have negative impact on technical efficiency because using fertilizers below or above the standard required is more likely to reduce output
- Policy variables such as extension programs are expected to have positive impact on technical efficiency of farmers
- There exists efficiency gap between female headed and male headed farm households

1.5 Significance of the Study/Contribution to Current Literature/

For a country of highly agrarian based economy, high population growth rate, and significant number of food insecure population. Ethiopia, research findings on agriculture and food production are crucial inputs for decision making. For the ever mounting nature of food demand and food items' prices in the country, increasing the productivity of farmers has indispensable contribution to solve the problem. Increasing productivity of farmers is possible through the implementation of sound agricultural policies and strategies. The effectiveness of the policies in turn is promising if they are backed by researches and empirical evidences.

This research has its own contribution to policy makers in terms of identifying the nature of the most inefficient farmers and identifying the socio-economic and policy variables that have significant effect on efficiency of farmers. This would help them recognize future policy concerns and devise sound agricultural policies. On top of this, it can be used as a benchmark study for comparisons with improvements attributed to the second cycle Growth and Transformation Plan period. The research can also be used as a reference material for those who are keen to do researches on similar areas in the future.

Moreover, the research has its own contribution to the existing literature. Different researches have been done in Ethiopia and Tigray in a similar topic. Although, some of the researches done in other regions of Ethiopia are done at zonal levels, the researches done in Tigray are conducted at regional level. These regional level research findings might suffer from small sample sizes which might not represent the characteristics of farmers all over the region. Therefore, this research can solve the problem of sample size by increasing the sample size and improve the representativeness of the sample by focusing at Zonal level analysis. Moreover, there is a difference on the choice of explanatory variables and hence the structure of the models in this research and the previous researches done in Tigray region. For instance, the variable “compulsory technology adoption” was not used; the input variables of pesticides and insecticides were not used in the previous researches. Moreover, the dependent variable was taken as a market value of all crops whereas this study uses the physical quantity of each crop as dependent variable.

2. Literature Review

According to Page (1980), Shih *et al*. (2004), and Zamorano (2004), technical efficiency is defined as producing the maximum possible amount of output using a given sets of inputs or producing a given level of output using minimum possible combinations of inputs. In a world of scarce resources, especially in the developing countries, technical efficiency in production is indispensable.

According to Farrell (1957), efficiency can be explained in terms of technical efficiency, allocative efficiency and economic efficiency. Technical efficiency refers to the minimum combination of inputs required to produce a given level of output. Allocative efficiency refers to the least cost combination of inputs required to produce a given level of output. Determination of allocative efficiency, in this case, requires knowledge of the market prices of all inputs used in the production process. A technically efficient way of production is not necessarily allocatively efficient and an allocatively efficient way of production is not necessarily technically efficient. If the production method is both technically and allocatively efficient, we call it economically efficient.

According to Abate *et al*. (2013), poverty alleviation and ensuring food security of small holder farmers is possible through augmenting productivity and commercialization. Improving productivity of small holder farmers can be achieved through better access to technology and extension services. Extension services enhance productivity of farmers through improving technical efficiency of farmers.

The stochastic frontier production model has been widely used to estimate the technical efficiency of farmers in agricultural researches. Several technical efficiency/inefficiency researches have been conducted in Ethiopia and other countries. For instance, Bamlaku *et al*. (2007) have analyzed technical efficiency of farmers in three ecological zones in Ethiopia. Access to credit, literacy, proximity to market and livestock are found to have positive and significant effect while age, sex, extension service and off-farm activities are found to have insignificant effect on technical efficiency of farmers. Moreover, Endrias *et al*. (2012) have examined technical efficiency of maize farmers in Wolaita and Gamo Gofa zones. Based on their estimation, agro-ecology, oxen holding, farm size and use of improved maize variety are found to be significant whereas age, education, family size and access to credit are found to be insignificant determinants of technical efficiency.

Different researchers have also examined technical efficiency of small holder farmers in Tigray region. For instance, Zenebe and Yesuf (2013) and Shumet (2012) have examined technical efficiency of farmers in the region. Moreover, Gebrehawaria *et al*. (2012) have estimated technical efficacy of farmers in irrigated lands and rain-fed lands. Based on the findings of Zenebe and Yesuf (2013), off farm participation (negative) and irrigation (positive) are the only variables to have significant effect on the technical efficiency of farmers while gender, age and education are found to be insignificant.

Shumet (2012) revealed age, education, household size, and credit as positive and significant determinants whereas livestock and off-farm activity as negative and significant determinants of technical efficiency of farmers. Moreover, irrigation and gender are found to have no significant effect on technical efficiency of farmers. Gebrehawaria *et al*. (2012) found access to credit, literacy, road distance as negative and significant variables whereas age as insignificant variable in determining technical efficiency.

As we can see from the above empirical evidences, the effect of some variables such as education, age credit and extension services is found to be indefinite; a mixture of positive and insignificant effects. However, the basic problem of the researches is the choice of the dependent variable and the input variables. All of the above researches except Endrias *et al*. (2012) have used the market value of all crops produced by farmers as the dependent variable. This might lead us to a wrong conclusion because technical efficiency of farmers can differ by crop type. Therefore, crop specific technical efficiency is more plausible than a combination of all crops in to one. Moreover, in most of the researches, the choice of input variables suffers from omission of important inputs such as local seed, improved seed, compost, herbicides and insecticides. Moreover, the technical efficiency determinants used in the models are limited in number especially in the models of Zenebe and Yesuf (2013), and Gebrehawaria *et al*. (2012). Therefore, this research can solve some of these limitations of the preceding researches by carefully incorporating the possible input and exogenous variables for each crop type.

3. Research Methodology

3.1 Method of Data Collection and Sampling Techniques

This study used a primary data collected from farm households of the Central Zone of Tigray in the 2014 cropping season. In the outset, the author prepared a structured questionnaire and the data is collected using interview method. The interview method is chosen in view of expecting significant number of illiterate farm households.

According to CSA (2007) data, the Central Zone contains 10 Woredas, 187 Kebeles/Tabias and 225,343 farm households. Each Tabia contains smaller residential places called *Kushets*. The author has employed a combination of non-probability and probability sampling techniques under a general multi stage sampling framework. Initially, 3 Woredas namely ***Kola-Temben, Werie-Lekhe and Lailai-Maichew*** are selected using purposive sampling in terms of their population size and main crops cultivated. This technique is chosen to address the problems of majority of the population in the production of their main crops. Next, 3 Tabias from Werie-Lekhe [*Maychekente, Maekelawi, and Endachewa*], and 2 Tabias each from Kola-Temben [*Begashekha and Dr. Atakilti*] and Lailai-Maichew [*Dura and Hatsebo*] woredas are selected randomly. Then, 2 Kushets from each Tabia are selected using simple random sampling technique. Finally, the sample farm households are taken from the sampled Kushets. Initially, the author has selected a total of 500 sample farm households. From these sampled households, 10 respondents have refused to participate in the interview and 490 samples are used in this study. The samples were equally distributed among the sampled "Tabias".

3.2 Method of Data Analysis

Analysis of the data is made using both descriptive and econometric tools of data analysis. Under descriptive method, the author used simple statistical measures such as percentages and means. Besides, the author used tabular and graphical presentations of these statistical tools. Under the econometric analysis, the author employed a single step stochastic frontier model to estimate the level of technical efficiency of farmers and the determinants of technical efficiency. The stochastic frontier model is estimated using STATA software version 11.

3.3 Analytical Framework

Aigner, Lovell and Schmidt (1977); and Meeusen and Van den Broeck (1977) have developed a stochastic frontier production function for the purpose of estimating the level of technical efficiency of firms in production. The stochastic frontier production function can be given by;

$$Y_i = f(X_i.\beta) + \varepsilon_i \qquad (1)$$

Where, Y is output, f (.) is the production technology. X represents vector of inputs, and β is vector of parameters to be estimated. Moreover; ε is the error term of the model consisting of two components v and u such that;

$$\varepsilon_i = v_i - u_i;\ u_i \geq 0 \qquad (2)$$

Where v_i is a symmetric error term that captures deviations of actual production from the frontier because of favourable or unfavourable factors beyond the control of the producers such as drought, weather, luck, measurement error, etc. It is independently and identically distributed as $N(0, \sigma^2_v)$. The frontier production function is said to be stochastic because of this error term and producers can produce beyond the frontier when the value of v_i is positive and large. On the other hand, u_i shows the inefficiency of farmers from factors under their control such as technical and economic inefficiency, the will and effort of the farmers, and possibility of defective and damaged products. The error term u_i is assumed to be independent of vi and assumed to have half normal distribution of the form $N^+(0.\sigma^2_u)$.

Following Battese and Coelli (1995), the model can be estimated using maximum likelihood technique and one can find consistent estimators of $\beta . \sigma.$ and ª such that $\pm^2 = \pm_u{}^2 + \pm_v{}^2$ and ª $= \pm_u / \sigma_v$. Moreover, the technical efficiency level of firms can be given by;

$$TE_i = \frac{Y_i}{f(X_i.\beta)exp\{v_i\}} = \frac{f(X_i.\beta)exp\{\varepsilon_i\}}{f(X_i.\beta)exp\{v_i\}} = \frac{f(X_i.\beta)exp\{v_i - u_i\}}{f(X_i.\beta)exp\{v_i\}} = exp\{-u_i\} \qquad (3)$$

From Equation 3, technical efficiency is given as a ratio of the observed output to the maximum feasible (frontier) output level. However, it is the ε_i not the u_i and v_i observed in Equation 3. Therefore, the technical efficiency of firms can be estimated using the expectation of u_i conditional on ε_i after Jondrow *et al.*, (1982). Then, we can have;

$$TE_i = \exp(-\hat{u}_i) = expE\left\{\frac{-u_i}{\varepsilon_i}\right\} \qquad (4)$$

Where the estimator of u_i is given by:

$$\hat{u}_i = E\left(\frac{u}{\varepsilon}\right) = \left[\frac{\pm ª}{1 + ª^2}\right]\left[z_i + \frac{\phi(z_i)}{\Phi(z_i)}\right] \qquad (5)$$

Where $z_i = \frac{-\varepsilon_i \lambda}{\sigma}$ and ª $= \pm_u / \sigma_v$, ϕ (.) is the standard normal density function and Φ (.) is the distribution function. The existence of technical inefficiency can be tested by the parameter λ such that the null hypothesis ª $= 0$ is tested against the alternative hypothesis ª > 0. The level of technical efficiency lies between 0 and 1.

The Model

For the purpose of estimating individual farmer's level of efficiency in cereal production, the researcher has employed the Cobb-Douglas type of stochastic frontier production function. There are two ways of estimating stochastic frontier models; the two step procedure and the direct or single step procedure. In the two step procedure, the Cobb-Douglas production function relating farm inputs to output is estimated at first and the level of technical efficiency is predicted from this model. In the second step, the predicted technical efficiency is regressed on the variables affecting technical efficiency. In the single step method, both the farm inputs and the variables affecting technical efficiency are incorporated in the production function and a single model is estimated.

According to Kumbhakar and Lovell (2000), the two step procedure has a problem with respect to failure in assumptions. The level of technical efficiency of farmers is predicted from the half normally distributed term, u_i, with zero mean value and a constant variance of $\pm_u^2$. A variable with zero mean value can, therefore, not be regressed on other variables otherwise, it yields biased and inconsistent estimates. Moreover, unless the Z variables and the X variables are true orthogonal, the two step procedure yields biased and inconsistent estimates. The solution for this problem is to use the single step approach. Therefore, the author has also chosen the single step approach in this study as well. The stochastic frontier model, in this case, is given by:

$$lnY_{ji} = lnf\left(X_{ji}, Z_{jq}; \beta\right) + v_{ji} - u_{ji} \qquad (6)$$

Where j=1, 2, 3 represents the frontier production function for *Teff*, Maize and Sorghum farmers respectively. Therefore, $\boldsymbol{Y_{1i}}$ represents *Teff* production, $\mathbf{Y_{2i}}$ represents Maize production and $\mathbf{Y_{3i}}$ represents Sorghum production. Moreover, $\mathbf{X_{ji}}$ are the input variables, $\mathbf{Z_{jq}}$ are the exogenous variables affecting technical efficiency, $\boldsymbol{\beta}$ are the parameters, $\mathbf{v_{ji}}$ is the symmetric error term and $\mathbf{u_{ji}}$ is the half normal error term capturing the discrepancy of actual output from potential output due to inefficiency.

Description of Variables

Table 1: Description of variables used in the model

Category	Variable Name	Description
Dependent	Output	Output in quintals
X-Variables or Farm Inputs	Oxen days	
	Man days	
	Compost	Compost in quintal
	Fertilizer	Dap+Urea in quintal
	Improved seed	In quintal
	Local seed	In quintal
	Land	In hectare
	Insecticide	Insecticide in liters
	Herbicide	Herbicide in liters
Z-Variables or Efficiency Variables	Sex	1 if household head is male 0 if female
	Age	Age of household head
	Age2	
	Education	Years of schooling of the household head
	Main crop	1 if main crop 0 otherwise
	Market distance	Distance to nearest market place in minutes
	Irrigation	1 if yes and 0 if no irrigation
	Training[2]	1 if took training on modern input use and 0 otherwise
	Suboptimal adoption[3]	1 if farmers use lower or higher amount of fertilizer than the standard amount of fertilizer required and 0 otherwise
	Land distance	Distance of farm land from home in minutes
	Credit	1 if took credit and 0 otherwise
	Off-farm income	Off-farm income in Birr
	DKolatemben	1 if a farmer lives in Kola-Temben and 0 otherwise
	DWerielekhe	1 if a farmer lives in Werie-Lekhe and 0 otherwise

[2]Most of the farmers are beneficiaries of extension services. Therefore, training on modern input use is used as a policy variable to determine efficiency instead of extension service.

[3]Farmers who use fertilizers less than or greater than the standard are considered as suboptimal adopters and most of the farmer respondents in this study have used lower amount of fertilizer than the standard amount of fertilizer required. The standard amount of fertilizer required is 50 kg per 0.25 hectares of land.

4. Discussion and Data Analysis

4.1 Descriptive Analysis

From the total of 490 respondents, 219 (44.7%) are from Werie-Lekhe, 148 (30.2%) are from Kola-Temben, and the rest 123(25%) are from Lailai-Maichew Woreda.

Table 2: Background of the respondents

Variable	Obs	Mean	Std. Dev.	Min	Max
Sex	490	0.78	.4135603	0	1
Age	490	47	10.7359	24	82
Education	490	3.25	3.164734	0	13
Household Size	490	5.8	2.001711	1	10
Livestock Wealth	490	22596.34	12555.37	0	119300
Off-farm Income	490	3506.962	4891.08	0	50000
Distance to main market	490	89.24898	43.66281	5	225

Source: own survey data, 2015.

From Table 2, 78% of the respondents are male headed and the rest 22% are female headed farm households. The average age, year of schooling, and household size of the respondents is 47 years, 3.25 years, and 5.8 respectively. This indicates how much uneducated the farm households are in the study area. Moreover, the average livestock wealth and average off-farm income of the households in 2015 are found to be 22596 Birr and 3507 Birr respectively. The average distance from the respondents' home to the main market place is 89 minutes, i.e, the farmers have to travel for about 1 hour and 30 minutes to reach the nearest main market place on average.

Table 3: Characteristics of respondents by main crop, irrigation, technology adoption and credit

Variables	Obsn	Frequency	Percent
Teff Main Crop	490	230	47
Maize Main Crop	490	134	27.3
Sorghum Main Crop	490	126	25.7
Irrigation Users	490	120	25
Agriculture Extension	490	479	98.3
Training on Modern Input Use	490	422	86
Suboptimal Adoption	490	215	43.9
Credit Access	490	320	65.4

Source: own survey data, 2015

As we can see from Table 3, majority of the respondents are producers of *Teff* as main crop (47%) followed by Maize (27.3%) and Sorghum (25.7%). Moreover, 25% of the respondents have access for irrigation, 98.3% and 86% of the respondents are beneficiaries of agricultural extension services and have taken training on modern input use. Finally, 44% of the respondents have used suboptimal fertilizer (lower or higher fertilizer than the standard required) and 65.4% of the farmers have taken credit from microfinance.

Table 4: Mean values of the output and input variables by crop type

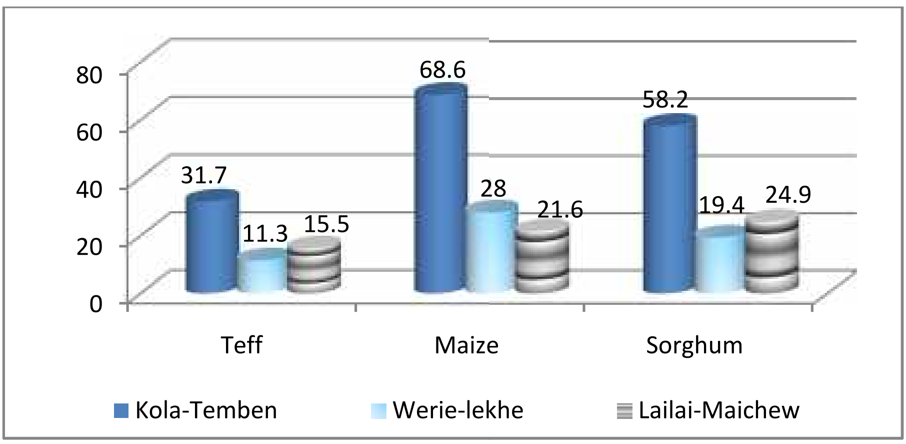
Variables	***Teff*** **Mean Values: N=457**	**Maize Mean Values: N=291**	**Sorghum Mean Values: N=268**
Output (in qt)	6.41	9.60	8.60
Yield (qt/ha)	17.73	46.70	34.40
Land (ha)	0.45	0.24	0.32
Land Distance (minutes)	26.30	5.27	17.45
Local Seed (qt)	0.15	0.06	0.14
Improved Seed (qt)	0.06	0.058	0.02
Fertilizer (qt)	0.58	0.32	0.27
Compost (qt)	3.93	8.59	4.81
Herbicide (liters)	0.18	0.002	0.013
Insecticide (liters)	0.22	0.114	0.07
Man Days	18.68	13.47	14.41
Oxen Days	5.38	3.02	3.68

Source: Own survey data, 2015

As we can see from Table 4, Maize yields are found to be higher than that of Sorghum and *Teff*. The average yields of *Teff*, Maize and Sorghum are 17.73 qt/ha, 46.70 qt/ha, and 34.40 qt/ha respectively. The average yields in all crops of the Central Zone of Tigray region have been increased as compared to the 20113/14 CSA reports of 13.4 qt/ha, 19.5 qt/ha, and 17.2 qt/ha for *Teff*, Maize, and Sorghum respectively. *Teff* farms are found far from the farmers' homes whereas Mize farms are nearest to the farmers' homes. On average, the farmers have to travel 26.5, and 17 minutes from their home to the *Teff*, Maize, and Sorghum farms respectively. Moreover, farmers tend to use more quintals of seeds, fertilizer, land, man days, oxen days, herbicides, and insecticides in *Teff* production as compared to the other two crops. However, they tend to use more compost in maize production than any other crop.

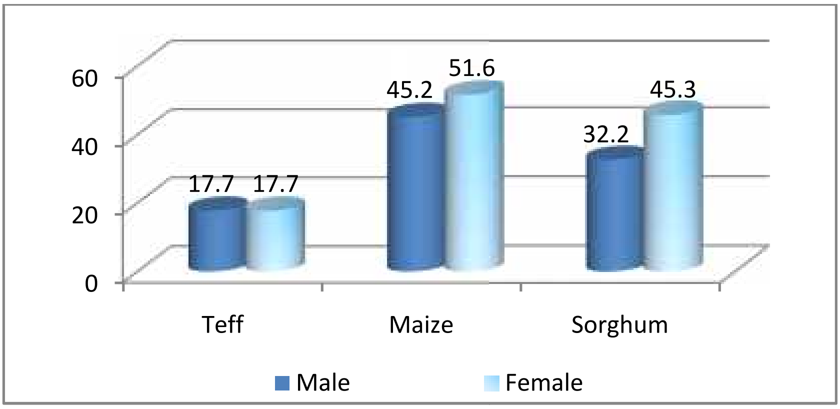
There is considerable difference in crop yield across the three sampled Woredas and across sex of household heads. Crop yield across Woredas and sex of household heads are given in the following successive figures respectively.

Figure 1: Average crop yield by Woreda



From Figure 1, Kola-Temben Woreda is found to have the highest yield in all crops with yields of 31.7 qt/ha, 68.6 qt/ha, and 58 qt/ha in *Teff*, Maize, and Sorghum respectively. Lilai-Maichew Woreda has the second highest yield in *Teff* and Sorghum with 15.5 qt/ha and 24.9 qt/ha respectively and the least yield of 21.6 qt/ha in Maize production. On the other hand, Werie-Lekhe has the second highest yield of 28 qt/ha in Maize and the least yields in *Teff* and Sorghum production with 11.3 qt/ha and 19.4 qt/ha respectively.

Figure 2: Average crop yield by Sex



From Figure 2, female headed households are found to have higher yields in Maize and Sorghum production with yields of 51.6 qt/ha and 45.3 qt/ha respectively than their male counterparts with yields of 45.2 qt/ha and 32.2 qt/ha respectively. On the other hand, female headed and male headed households have similar yield in *Teff* production of 17.7 qt/ha.

4.2 Model Estimation

A single step stochastic frontier mode is estimated to examine whether the farmers are technically efficient or not. Before estimation, pairwise correlation coefficients of the variables are examined. Based on the correlation coefficients, Oxen Days and Land are found to have high correlation in all crop types. The correlation between these two variables is found to be 0.947. 0.933. and 0.887 in *Teff*, Maize and Sorghum production respectively. This high correlation has significantly disturbed the regression outputs of for all crops in terms of magnitude and sign. Thus, the variable

Land is dropped from the models. The pair wise correlations of variables incorporated in the models are given in Appendix 1.

Table 4: Regression output of the stochastic frontier model by crop type

Crop Type	***Teff*: N=457**	**Maize: N=291**	**Sorghum: N=268**
X-Variables (Inputs)	**Coefficient**	**Coefficient**	**Coefficient**
Oxendays	0.2755649***	0.3024668***	0.3640958***
Mandays	0.1848228**	0.2149374***	0.2583911***
Compost	0.0079744	0.0221437**	0.0299424***
Fertilizer	0.133586***	0.0620407*	0.0662829**
Improvedseed	0.0952313***	0.0421137	0.1391927***
Localseed	0.0951763***	0.1854429***	0.2023589***
Insecticide	0.0606021***	0.0309678*	0.0554487**
Herbicide	0.0840701***	0.0798451	-0.0875173*
Z-Variables [Efficiency Determinants]			
Sex	0.0813734	0.0501357	-0.0302528
Age	0.0016136	0.2901372	0.5028591***
Age2	(omitted)	(omitted)	(omitted)
Education	-0.014189	0.0163711*	0.0170808
Maincrop	0.1706371***	0.4262037***	0.1945057**
Distance to market	0.0275611	-0.1257748*	0.0004059
Irrigation	0.1277673*	0.1504732**	-0.0582976
Training	0.2241505***	0.3787265***	0.0143335
Suboptimal adoption	0.0745929	-0.0946952*	0.08549
Land distance	-0.0479504	0.1312072***	-0.0387757
Credit	0.2349411***	0.0612902	0.1151666*
Off-farmincome	-0.0101675**	-0.0109974**	-0.0126212**
DKola-Temben	0.3581391***	0.7908351***	0.4514125***
DWerie-Lekhe	-0.1500244**	0.114353	-0.4432852***
_cons	1.778571***	0.7659075	0.176119
/lnsig2v	-2.670632***	-1.89396***	-1.957292***
/lnsig2u	-0.6915435***	-10.17787***	-2.12298
sigma_v	0.2630751	0.3879107	0.3758195
sigma_u	0.707674	0.0061646	0.3459399
sigma2	0.570011	0.1505127	0.2609147
lambda	2.690008***	0.0158917***	0.9204947

Source: Own estimation, 2015

***, **, and * indicate significant variables at α=1%. α=5% and α=10% respectively

In the stochastic frontier model, we have two sets of variables; the X-variables or the farm inputs and the exogenous Z-variables or the determinants of technical efficiency. Interpretation of the Z-variables can be viewed in terms of their effect on the production function and on the technical efficiency of the farmers. i.e On the one hand, they can shift the production function either outwards or inwards; on the other hand, they can affect the technical efficiency of the farmers either positively or negatively. However, the magnitude of the effect on technical efficiency is not directly known from the regression outputs.

From the regression Table 4, the variance of the half normal term, $\pm_u^2$, and the technical inefficiency parameter, Lambda, are found to be significant in *Teff* and Maize production. This shows the existence of technical inefficiency of farmers in the production of these two crops. However, the predicted level of technical efficiency of farmers in *Teff* production, as shown in Figure 3, is found to be 99.2% and thus the technical inefficiency of farmers is infinitesimal. Moreover, the technical inefficiency parameter, Lambda, is found to be insignificant and thus farmers are found to be technically efficient in Sorghum production. This indicates that the deviation of actual output from frontier output in *Teff* and Sorghum production is dominated by stochastic factors such as drought, bad weather condition and others beyond the farmers' control. The reason behind the low level of output in *Teff* and Maize production is, therefore, the low level of current technology available to the farmers. This implies that increasing *Teff* and Sorghum output requires shifting the current technology rather than urging farmers to change their practices. Finally, the average level of technical efficiency of Maize producers is found to be 95.5% which indicates a room for about 4.5% efficiency gains.

From the group of the input variables, Oxen days, Man days, Fertilizer, Improved seed, Local seed, Insecticide and Herbicide are found to have positive and significant effect on *Teff* output. Similarly, Oxen days, Man days, Compost, Fertilizer (at 10%), Local seed and Insecticide (at 10%) are found to have positive and significant effect on Maize output. However, improved seed and herbicide in Maize production and Compost in *Teff* production are found to be insignificant. In Sorghum production, herbicide (at 10%) is found to have negative and significant effect and the rest input variables are found to have positive and significant effect on output. Therefore, Sorghum farmers better to weed-out the herbs than trying to kill those using chemicals. In most of the preceding studies, Man Days is found to have insignificant effect on output. The highly significant Man Days in this study indicates that the agricultural sector is not subjected to excess labor with zero marginal productivity in the study area. This might be attributed to rural-urban migration of the rural youth for education and job search which leaves the agricultural sector with less availability of labor.

From the group of exogenous variables affecting efficiency, the dummies for Main crop, Irrigation (at 10%), Training, and credit are found to be positive and significant in *Teff* production. Besides, the dummy for Kola-Temben is positive and significant whereas the dummy for Werie-Lekhe is found to be negative and significant. This implies that *Teff* output in Kola-Temben is higher than Lailai-Maichewand *Teff* output in Werie-Lekhe is lower than Lailai-Maichew. On the other hand, Off-farm income is found to have negative and significant effect on *Teff* output. The higher the farmers get income from off-farm activities, the lesser the quantity of *Teff* output they produce. The remaining determinants such as Sex, Age, Education, Distance to market, Land distance and suboptimal adoption are found to be insignificant in *Teff* production. By suboptimal adoption, we mean the use of chemical fertilizers lower than or higher than from the standard amount required. Therefore, *Teff* output is not affected whether the farmers use the standard amount of fertilizer or not.

In Maize production, Education, the dummy for Main crop, Irrigation, Training, Land distance and the dummy for Kola-Temben are found to be positive and significant. However, Distance to market (at 10%), suboptimal adoption (at 10%). and Off-farm income are found to be negative and significant. The remaining variables Sex, Age, Credit and the dummy for Werie-Lekhe are found to be insignificant. Therefore, longer market distance and higher off-farm income reduces technical efficiency of farmers in Maize production. Suboptimal technology adoption or using fertilizers below or above the standard is also likely to reduce technical efficiency of farmers. Moreover, technical efficiency of farmers in Kola-Temben is found to be higher than that of farmers in Lailai-Maichew. But, there is no significant difference in technical efficiency of farmers in Lailai-Maichew and Werie-Lekhe. On the other hand, the positive and unexpected effect of land distance on Maize output might be due to the fact that maize cultivated near the farmer's home is eaten during spiking and before harvesting.

In Sorghum production, the exogenous variables Age, Main crop, Credit (at 10%), and the dummy for Kola-Temben are found to be positive and significant whereas Off-farm income and the dummy for Werie-Lekhe are found to be negative and significant. Once more, farmers in Kola-Temben produce higher output than Lailai-Maichew and farmers in Werie-Lekhe produce lower output than Lailai-Maichew. The exogenous variables Sex, Education, Distance to market, Irrigation, Training, suboptimal adoption and Land distance are found to have insignificant effect on Sorghum output.

Finally, the estimated coefficients are elasticities and their interpretation can be made in terms of percentage changes. For instance, the coefficient of oxen days in *Teff* production can be interpreted as "1% increase in oxen days leads to a 0.27% rise in *Teff* output". Similarly, the coefficients of the dummy variables show a percentage difference in output between the categories. For instance, the coefficient of the dummy for Training in *Teff* production can be interpreted as "Output of farmers who took training is higher than output of farmers who didn't take training by 0.22% in *Teff* production". The coefficients of other variables can be interpreted in a similar way.

As we have seen in the regression output, farmers are found to be technically inefficient in the production of *Teff* and Maize though the predicted average level of technical inefficiency in *Teff* production is infinitesimal. The levels of technical efficiency of farmers in *Teff* and Maize production are summarized in the following table.

Table 5: Levels of technical efficiency of farmers in *Teff* and Maize production

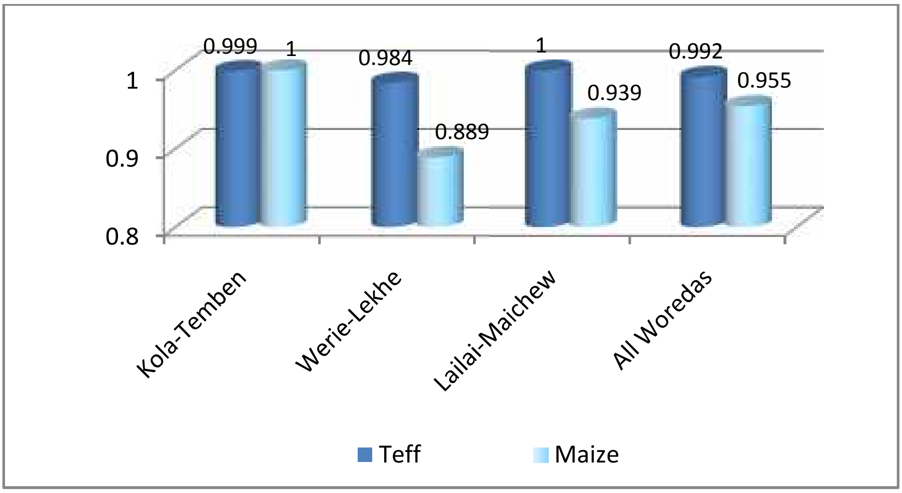
Efficiency Levels	*Teff*		Maize	
	Frequency	Percent	Frequency	Percent
[0.000-0.100)	1	0.22	0	0
[0.100-0.200)	0	0	0	0
[0.200-0.300)	0	0	2	0.7
[0.300-0.400)	0	0	3	1.03
[0.400-0.500)	0	0	4	1.37
[0.500-0.600)	0	0	5	1.72
[0.600-0.700)	1	0.22	7	2.4
[0.700-0.800)	4	0.87	6	2.06
[0.800-0.900)	5	1.1	5	1.72
[0.900-1.000)	7	1.53	7	2.4
1	439	96.06	252	86.6
Total	**457**	**100**	**291**	**100**

Source: Own computation, 2015.

As we can see from Table 5, only 18(4%) *Teff* producing farmers are found to be technically inefficient and the remaining 439 (96%) farmers are found to be efficient. Moreover, except one farmer whose level of efficiency is in the range [0.000-0.100), the level of efficiency of majority of the inefficient farmers is above 0.600. Moreover, 39 (13.4%) Maize producers are found to be technically inefficient and the rest 252 (86.6%) farmers are found to be efficient. Majority of the inefficient farmers have efficiency levels of above 0.6000 in Maize production as well. As we can see from Figure 3 below, the predicted level of technical efficiency in *Teff* and Maize production are found to be 99.2% and 95.5% respectively. The technical inefficiency of farmers in *Teff* is negligible while there is about 4.5% room for improvement from efficiency in Maize production.

There is no evidence of technical inefficiency in Sorghum. negligible inefficiency in *Teff* and only 4.5% inefficiency in Maize production in contrast to the findings of the preceding studies made by Shumet (2012), Zenebe and Yesuf (2013), and Endrias *et al.,* (2012). This might be attributed to the differences in the choice of the input variables, the exogenous variables, sample sizes, and model specifications between this study and the preceding ones. Moreover, efficiency of farmers over the last couple of years might have improved with all the trainings and extension services provided to the farmers.

Figure 3: Average technical efficiency of *Teff* and Maize production by Woreda



The technical efficiency of farmers in *Teff* and Maize production also differs across the sampled Woredas. As we can see from Figure 3, all farmers in Kola-Temben are found to be technically efficient in both *Teff* and Maize. Farmers in Lailai-Maichew are technically efficient in *Teff* but not in Maize production. Farmers in Lailai-Maichew have a possibility of about 6% room for improvement in Maize production. Finally, farmers in Werie-Lekhe are found to be the least technically efficient producers in both *Teff* and Maize production with a possibility of 1.6% and 11% room for improvement respectively.

5. Conclusions and Recommendations

5.1 Conclusions

As per the preceding empirical evidences and annual reports of the government, Tigray region is reported to have low level of crop productivity and farmers technical efficiency. On the other hand, the region is reported to be one of the poorest regions in terms of food poverty and total poverty in Ethiopia. Having this in mind, the author is motivated to carry out this study with the objective of examining the technical efficiency of farmers in the production of *Teff*, Maize, and Sorghum which are the major cereals produced in the central zone of Tigray. To this end, the author has collected a primary data from the farm households in the 2014 cropping season and found encouraging results. This study differs from the preceding ones in three ways. First, it is more comprehensive in terms of the choice of the input variables and the exogenous variables affecting the technical efficiency of farmers. Secondly, unlike the preceding similar studies, a stochastic frontier model is estimated for the production of *Teff*, Maize and Sorghum separately rather than using market value of the cereals and estimating a single stochastic frontier model for the aggregated output. Thirdly, the sample size is more representative in view of the geographical scope and the size of respondents used in the study.

Based on the stochastic frontier regression output, there is evidence of technical inefficiency in *Teff* and Maize but not in Sorghum production. However, the predicted level of technical inefficiency in *Teff* production is infinitesimal. The deviation of actual output from frontier output in *Teff* and Sorghum production is, therefore, said to be dominated by factors beyond the control of the farmers. In other words, *Teff* and Sorghum producers are technically efficient under the current technology and increasing output is possible through shifting the current level of technology rather than urging farmers to change their activities. Only Maize producing farmers are found to be technically inefficient with a possibility of 4.5% efficiency gains.

As far as the input variables are concerned, all of them except compost in *Teff*, Improved seed and Herbicide in Maize and Herbicide in Sorghum, are found to be significant and with the expected positive sign. Compost is not significant in *Teff*. Improved seed and Herbicides are not significant in Maize and herbicide is negative and significant in Sorghum production. The most important finding in this study is the significant effect of Mandays or labor on output of all crops. This indicates that the farms are not characterized by excess labor with zero or negative marginal productivity in the study area in contrast to the findings of the preceding studies where labor was found to be insignificant.

When we come to the exogenous variables, the dummy for Main crop positively affects output while Off-farm income negatively affects output of all crops. Moreover, Irrigation and Training positively affect *Teff* and Maize whereas Credit positively affects *Teff* and Sorghum output. Suboptimal technology adoption is insignificant in *Teff* and Sorghum and negative and significant in Maize production. In other words, *Teff* and Sorghum output are not affected whether farmers use fertilizers according to the standard set or not. Interestingly, there is no significant difference in output between male headed and female headed households across the three crop types. Finally, farmers in Kola-Temben produce significantly higher output in all crops followed by farmers in Lailai-Maichew and Werie-Lekhe.

5.2 Recommendations

Based on the empirical findings presented above, the author has the following recommendations to the farmers in the Zone and the concerned policy makers at Regional or Zonal levels.

- Except the low level of technical inefficiency in Maize production, farmers are found to be efficient producers. Any deviation of actual output from the potential (frontier) output is dominated by random factors such as drought, flooding, bad weather and other shocks which are beyond their control. Moreover, the low level of output is attributed to the backward technology with which the farmers are producing. Therefore, the government and other concerned bodies should emphasize in introducing new production technology to push the current production frontier outwards and increase output.

- Farmers who took training on modern input use are found to have significantly higher output in *Teff* and Mize production. Therefore, the government should give further training on modern input use to the farmers who didn't take training.
- Compulsory technology adoption doesn't affect output in *Teff* and Sorghum production. This implies that farmers have the knowledge about their land characteristics and the weather condition which helps them fix the amount of fertilizer to use. Therefore, it might not be fruitful urging the farmers to use the standard amount of fertilizer unless the standard is set based on the agro-ecological characteristics of their farm land.
- The government and other concerned bodies should create conducive environment on credit access for the farmers. Purchase of modern inputs such as fertilizers and improved seeds require higher outlay which might be difficult for the farmers to afford. These costs can be covered through credit only.
- The government and other concerned bodies should expand irrigation access for the farmers. Irrigation increases output because it helps the farmers produce more than once a year and creates sustainable water source for their crops.
- Farmers in Werie-Lekhe Woreda need special attention in terms of their technical inefficiency and lower productivity as compared to those in Lailai-Miachew and Kola-Temben in the production of the three crops.
- Herbicides tend to increase output in Maize and *Teff* production while they tend to reduce output in Sorghum production. Therefore, Sorghum farmers have to weed-out the herbs rather than using chemicals to avoid them.
- Farmers should not be reluctant in using the standard amount of fertilizers in Maize production for economic reasons such as higher

prices. Because, using fertilizer less than the standard amount tends to reduce output.

- Farmers producing as a main crop have higher output as compared to the farmers producing as a subbed crop. This calls for the superiority of specialization in crop production over diversification to increase their output and efficiency.
- Off-farm activities negatively affect output in all crops. Therefore, farmers should pay full attention to farming especially during the rainy season. Off-farm activities should be done whenever the farmers are free from farming activities.

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Appendix

Appendix 1: Pairwise Correlation of Variables

A) *Teff*

pwcorr Totallandteff Oxendaysteff Mandaysteff Insecticideteff Herbicideteff Compostteff Fertilizer Improvedseed Localseed Landistanceteff Distancemarket Offarmincome

Variables	Land	Oxen days	Man days	Insecticide	Herbicide	Compost	Fertilizer	Improved seed	Local seed	Land distance	Distance market	Off-farm income
Land	1											
Oxen days	**0.9473**	1										
Man days	0.6791	0.6734	1									
Insecticide	0.3349	0.3618	0.0925	1								
Herbicide	0.2149	0.2294	0.0298	0.4896	1							
Compost	0.2612	0.2615	0.0653	-0.0081	-0.0777	1						
Fertilizer	0.5736	0.5901	0.3641	0.3539	0.1881	0.2373	1					
Improved seed	0.2915	0.285	0.1062	0.1279	0.1174	0.184	0.2603	1				
Local seed	0.5773	0.5552	0.5179	0.1394	0.14	0.1955	0.239	0.1467	1			
Land distance	0.056	0.0546	0.0299	0.1966	0.244	-0.129	0.0112	-0.03	0.0588	1		
Distance market	-0.1345	-0.0935	-0.009	0.1686	0.2592	-0.2155	-0.0472	0.0346	0.0037	0.2146	1	
Off-farm income	-0.1968	-0.1544	-0.0803	0.0571	0.1776	-0.2323	-0.1269	-0.0222	-0.0711	0.0684	0.3508	1

B) Maize

pwcorr Totallandmaize Oxendaysmaize Mandaysmaize Insecticidemaize Herbicidemaize Compostmaize Fert imp loc Landistancemaize Distancemarket Offarmincome

Variables	Land	Oxen days	Man days	Insecticide	Herbicide	Compost	Fertilizer	Improved seed	Local seed	Land distance	Distance market	Off-farm income
Land	1											
Oxen days	**0.9335**	1										
Man days	0.4675	0.5031	1									
Insecticide	0.2019	0.1864	-0.0643	1								
Herbicide	0.2086	0.2038	0.0695	-0.0055	1							
Compost	0.2616	0.2141	0.0743	0.5404	0.0166	1						
Fertilizer	0.361	0.3848	0.5961	-0.0749	0.1313	0.0498	1					
Improved seed	0.4463	0.4545	0.5717	0.164	0.0575	0.1954	0.6098	1				
Local seed	0.3254	0.3119	0	0.3726	0.1482	0.4169	-0.1003	-0.1892	1			
Land distance	0.1485	0.1512	-0.0845	0.0013	0.0436	0.0905	-0.0185	-0.0935	0.1486	1		
Distance market	0.3206	0.301	0.413	0.1845	0.0864	0.352	0.2708	0.3492	0.2385	-0.0517	1	
Off-farm income	0.2345	0.2799	0.2873	0.1762	0.195	0.2738	0.2952	0.365	0.1271	-0.1729	0.3508	1

C) Sorghum

pwcorr Totallandsorghum Oxendayssorghum Mandayssorghum Insecticidesorghum Herbicidesorghum Compostsorghum Fertilizer Improvedseed Localseed Landistancesorghum Distancemarket Offarmincome

Variables	Land	Oxen days	Man days	Insecticide	Herbicide	Compost	Fertilizer	Improved seed	Local seed	Land distance	Distance market	Off-farm income
Land	1											
Oxen days	**0.8877**	1										
Man days	0.5115	0.5024	1									
Insecticide	-0.0707	-0.0466	0.0766	1								
Herbicide	-0.0593	-0.0547	0.0034	-0.0474	1							
Compost	-0.068	-0.0588	-0.0059	0.1503	0.0462	1						
Fertilizer	0.0789	0.1353	0.0545	0.1241	-0.0106	0.2798	1					
Improved seed	-0.0361	-0.0719	0.0241	0.0007	0.2727	0.1162	0.0753	1				
Local seed	0.382	0.3745	0.3159	0.0498	-0.1304	0.0714	0.209	-0.1912	1			
Land distance	0.1369	0.1194	-0.0709	-0.3268	-0.0279	-0.1257	-0.0031	0.014	0.138	1		
Distance market	-0.0903	0.0817	0.1462	-0.1491	0.0882	-0.2717	-0.2695	0.2219	0.0488	0.2476	1	
Off-farm income	-0.1559	-0.0369	0.0579	0.0283	0.0825	-0.1607	-0.0956	0.2109	-0.0438	0.1417	0.3508	1

Appendix 2: Regression Outputs

A) *Teff*

frontier LNOutput LNOxendays LNMandays LNCompost LNFertilizer LNImprovedseed LNLocalseed LNInsecticide LNHerbicide Sex LNAge LNAge2 LNEducation Maincrop LNDistancemarket Irrigation Training Compulsoryadoption LNLandistance Credit LNOffarmincome DKolatemben DWerielekhe. vce(robust)

note: LNAge2 omitted because of collinearity

Iteration 0: log pseudolikelihood = -321.56194

Iteration 1: log pseudolikelihood = -317.48356

Iteration 2: log pseudolikelihood = -317.26084

Iteration 3: log pseudolikelihood = -317.26031

Iteration 4: log pseudolikelihood = -317.26031

Stoc. frontier normal/half-normal model Number of obs = 457

Wald chi2(21) = 1282.83

Log pseudolikelihood = -317.26031 Prob > chi2 = 0.0000

Robust						
LNOutput	**Coef.**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**
LNOxendays	0.2755649	0.0712645	3.87	0	0.135889	0.415241
LNMandays	0.1848228	0.0755695	2.45	0.014	0.036709	0.332936
LNCompost	0.0079744	0.0089902	0.89	0.375	-0.009646	0.025595
LNFertilizer	0.133586	0.0334867	3.99	0	0.067953	0.199219
LNImprovedseed	0.0952313	0.020143	4.73	0	0.055752	0.134711
LNLocalseed	0.0951763	0.0330981	2.88	0.004	0.030305	0.160047
LNInsecticide	0.0606021	0.015996	3.79	0	0.029251	0.091954
LNHerbicide	0.0840701	0.0162193	5.18	0	0.052281	0.115859
Sex	0.0813734	0.053785	1.51	0.13	-0.024043	0.18679
LNAge	0.0016136	0.1319018	0.01	0.99	-0.256909	0.260136
LNAge2	(omitted)					
LNEducation	-0.014189	0.0093106	-1.52	0.128	-0.032437	0.004059
Maincrop	0.1706371	0.0537577	3.17	0.002	0.065274	0.276
LNDistancemarket	0.0275611	0.043408	0.63	0.525	-0.057517	0.112639
Irrigation	0.1277673	0.0720853	1.77	0.076	-0.013517	0.269052
Training	0.2241505	0.0746064	3	0.003	0.077925	0.370376
Compulsoryadoption	0.0745929	0.0510048	1.46	0.144	-0.025375	0.174561
LNLandistance	-0.0479504	0.0349318	-1.37	0.17	-0.116416	0.020515
Credit	0.2349411	0.0472117	4.98	0	0.142408	0.327474
LNOffarmincome	-0.0101675	0.0041663	-2.44	0.015	-0.018333	-0.002
DKolatemben	0.3581391	0.1114513	3.21	0.001	0.139699	0.57658
DWerielekhe	-0.1500244	0.0725417	-2.07	0.039	-0.292204	-0.00785
_cons	1.778571	0.5846233	3.04	0.002	0.63273	2.924412
/lnsig2v	-2.670632	0.331558	-8.05	0	-3.320473	-2.02079
/lnsig2u	-0.6915435	0.1824869	-3.79	0	-1.049211	-0.33388
sigma_v	0.2630751	0.0436123			0.190094	0.364075
sigma_u	0.707674	0.0645706			0.591789	0.846252
sigma2	0.570011	0.0738484			0.425271	0.714751
lambda	2.690008	0.1032994			2.487545	2.892471

B) Maize

frontier LNOutput LNOxendays LNMandays LNCompost LNFertilizer LNImprovedseed LNLocalseed LNInsecticide LNHerbicide Sex LNAge LNAge2 LNEducation Maincrop LNDistancemarket Irrigation Training Compulsoryadoption LNLandistance Credit LNOffarmincome DKolatemben DWerielekhe. vce(robust)

note: LNAge2 omitted because of collinearity

Iteration 0: log pseudolikelihood = -137.37981
Iteration 1: log pseudolikelihood = -137.37764
Iteration 2: log pseudolikelihood = -137.36039
Iteration 3: log pseudolikelihood = -137.35923
Iteration 4: log pseudolikelihood = -137.35521
Iteration 5: log pseudolikelihood = -137.35505
Iteration 6: log pseudolikelihood = -137.35378
Iteration 7: log pseudolikelihood = -137.35353
Iteration 8: log pseudolikelihood = -137.35331
Iteration 9: log pseudolikelihood = -137.35321
Iteration 10: log pseudolikelihood = -137.35313

Iteration 11: log pseudolikelihood = -137.35313
Iteration 12: log pseudolikelihood = -137.35311
Iteration 13: log pseudolikelihood = -137.3531
Stoc. frontier normal/half-normal model Number of obs = 291
Wald chi2(21) = 1779.64
Log pseudolikelihood = -137.3531 Prob > chi2 = 0.0000

Robust						
LNOutput	**Coef.**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**	**Interval]**
LNOxendays	0.3024668	0.0775165	3.9	0	0.1505373	0.4543963
LNMandays	0.2149374	0.0675049	3.18	0.001	0.0826303	0.3472444
LNCompost	0.0221437	0.0089916	2.46	0.014	0.0045205	0.039767
LNFertilizer	0.0620407	0.0351236	1.77	0.077	-0.0068002	0.1308817
LNImprovedseed	0.0421137	0.0304755	1.38	0.167	-0.0176172	0.1018447
LNLocalseed	0.1854429	0.0294671	6.29	0	0.1276885	0.2431974
LNInsecticie	0.0309678	0.0176276	1.76	0.079	-0.0035816	0.0655172
LNHerbicide	0.0798451	0.0765632	1.04	0.297	-0.0702159	0.2299062
Sex	0.0501357	0.0534559	0.94	0.348	-0.054636	0.1549074
LNAge	0.2901372	0.2032547	1.43	0.153	-0.1082347	0.6885092
LNAge2	(omitted)					
LNEducation	0.0163711	0.0089927	1.82	0.069	-0.0012542	0.0339965
Maincrop	0.4262037	0.0891983	4.78	0	0.2513783	0.6010292
LNDistancemarket	-0.1257748	0.0664409	-1.89	0.058	-0.2559966	0.004447
Irrigation	0.1504732	0.0654442	2.3	0.021	0.022205	0.2787414
Training	0.3787265	0.1062283	3.57	0	0.1705229	0.5869301
Compulsoryadoption	-0.0946952	0.0531922	-1.78	0.075	-0.1989501	0.0095597
LNLandistance	0.1312072	0.0373624	3.51	0	0.0579783	0.2044361
Credit	0.0612902	0.0553617	1.11	0.268	-0.0472167	0.1697971
LNOffarmincome	-0.0109974	0.0054372	-2.02	0.043	-0.0216542	-0.0003406
DKolatemben	0.7908351	0.1199272	6.59	0	0.555782	1.025888
DWerielekhe	0.114353	0.1032893	1.11	0.268	-0.0880903	0.3167963
_cons	0.7659075	0.7658658	1	0.317	-0.7351618	2.266977
/lnsig2v	-1.89396	0.1220755	-15.51	0	-2.133224	-1.654696
/lnsig2u	-10.17787	0.1784056	-57.05	0	-10.52754	-9.828204
sigma_v	0.3879107	0.0236772			0.3441727	0.4372071
sigma_u	0.0061646	0.0005499			0.0051758	0.0073423
sigma2	0.1505127	0.0183703			0.1145076	0.1865179
lambda	0.0158917	0.0235985			-0.0303604	0.0621439

C) Sorghum

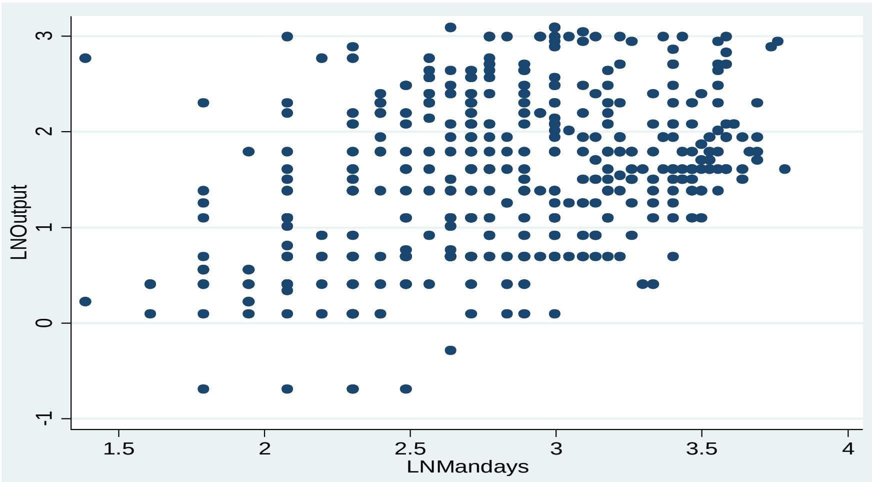
frontier LNOutput LNOxendays LNMandays LNCompost LNFertilizer LNImprovedseed LNLocalseed LNInsecticide LNHerbicide Sex LNAge LNAge2 LNEducation Maincrop LNDistancemarket Irrigation Training Compulsoryadoption LNLandistance Credit LNOffarmincome DKolatemben DWerielekhe. vce(robust)
note: LNAge2 omitted because of collinearity

Iteration 0: log pseudolikelihood = -153.81422 (not concave)
Iteration 1: log pseudolikelihood = -153.7828
Iteration 2: log pseudolikelihood = -153.76078
Iteration 3: log pseudolikelihood = -153.72906
Iteration 4: log pseudolikelihood = -153.72829
Iteration 5: log pseudolikelihood = -153.72554
Iteration 6: log pseudolikelihood = -153.72549
Iteration 7: log pseudolikelihood = -153.72549
Stoc. frontier normal/half-normal model Number of obs = 268
Wald chi2(21) = 640.98
Log pseudolikelihood = -153.72549 Prob > chi2 = 0.0000

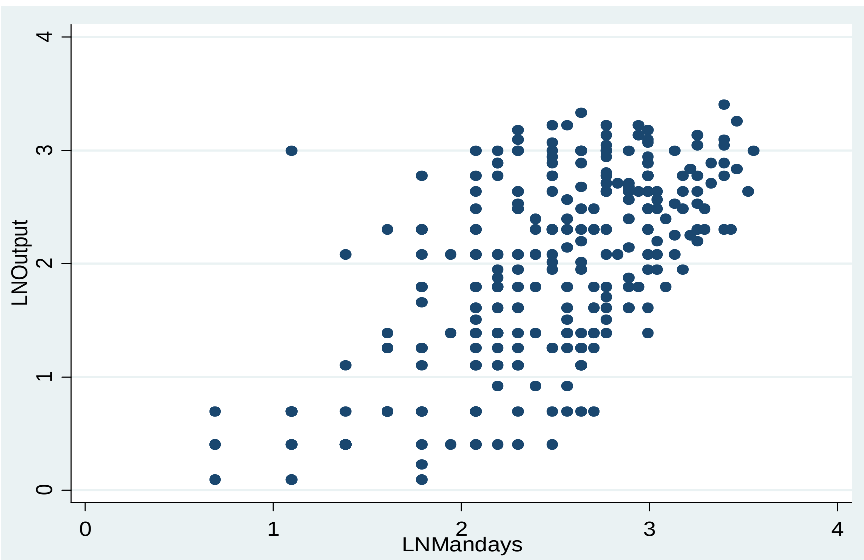
Robust					
LNOutput	**Coef.**	**Std. Err.**	**z**	**P>z**	**[95% Conf.**
LNOxendays	0.3640958	0.0821833	4.43	0	0.2030195
LNMandays	0.2583911	0.0837066	3.09	0.002	0.0943291
LNCompost	0.0299424	0.0092365	3.24	0.001	0.0118392
LNFertilizer	0.0662829	0.027751	2.39	0.017	0.011892
LNImprovedseed	0.1391927	0.0497851	2.8	0.005	0.0416157
LNLocalseed	0.2023589	0.0521265	3.88	0	0.1001927
LNInsecticide	0.0554487	0.0244152	2.27	0.023	0.0075958
LNHerbicide	-0.0875173	0.0459822	-1.9	0.057	-0.1776407
Sex	-0.0302528	0.0712561	-0.42	0.671	-0.1699121
LNAge	0.5028591	0.1846007	2.72	0.006	0.1410484
LNAge2	(omitted)				
LNEducation	0.0170808	0.0126728	1.35	0.178	-0.0077575
Maincrop	0.1945057	0.0825639	2.36	0.018	0.0326834
LNDistancemarket	0.0004059	0.0591524	0.01	0.995	-0.1155307
Irrigation	-0.0582976	0.0969167	-0.6	0.547	-0.2482508
Training	0.0143335	0.0835807	0.17	0.864	-0.1494816
Compulsoryadoption	0.08549	0.0603641	1.42	0.157	-0.0328214
LNLandistance	-0.0387757	0.0382323	-1.01	0.31	-0.1137096
Credit	0.1151666	0.0695694	1.66	0.098	-0.0211868
LNOffarmincome	-0.0126212	0.0050257	-2.51	0.012	-0.0224715
DKolatemben	0.4514125	0.1546374	2.92	0.004	0.1483289
DWerielekhe	-0.4432852	0.1108593	-4	0	-0.6605655
_cons	0.176119	0.7850109	0.22	0.822	-1.362474
/lnsig2v	-1.957292	0.5518952	-3.55	0	-3.038987
/lnsig2u	-2.12298	1.71436	-1.24	0.216	-5.483064
sigma_v	0.3758195	0.1037065			0.2188227
sigma_u	0.3459399	0.2965327			0.0644715
sigma2	0.2609147	0.1302647			0.0056006
lambda	0.9204947	0.3983485			0.1397459

Appendix 3: Scatter Diagram between Output and Man-days

A) *Teff*



B) Maize



C) Sorghum