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Technical Efficiency of Lowland Rice Production in Northwest of Ethiopia

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Abstract

This study employed the Cobb-Douglas stochastic frontier production function to measure the level and determinants of technical efficiency of smallholder rice producers in the Fogera district of Amhara Region, Ethiopia. A multistage sampling procedure was used to select 202 rice producers sample farmers in 2016. The result of the analysis showed that the mean technical efficiency was 85 %, with a minimum and maximum efficiency level of about 22% and 99%, respectively. By operating at full technical efficiency levels, rice productivity could increase, on average, from the current 3.2 tons ha^{-1} to 3.7 tons ha^{-1}. Therefore, the future direction should trigger towards enhancing rice productivity per hectare by improving technical efficiency at the farm level in addition to technological progress. Efficiency gains could be realized by designing better institutional support, improving soil fertility, focusing on livestock production and ensuring an adequate provision of research and extension support to rice farmers.

Introduction

Rice is a recent introduction in Ethiopia; an attempt to the introduction of rice had started in Ethiopia when the wild rice was observed in the swampy and waterlogged areas of Fogera and Gambella Plains in the 1970s (Gebey *et al.*, 2012). Italian's and North Korean introduced Rice to Ethiopia specifically in Gambella in the 1970s by Dutch's and in the 1980s to Pawe and Fogera respectively. Rice cultivation was started in the South Gonder zone in the 1980s through the technical support of North Korean experts in Jigna *kebele* farmers' cooperative. However, the crop is a recent introduction; its importance in terms of food security, nutrition, employment creation, and export substitution is being well recognized by the Ethiopian government as the area coverage has shown a drastic increase in the past ten years. For example, the area planted under rice production has increased from 6,100 ha in 2007 to 48,484 ha in 2017, showing an increase of 795% (FAOSTAT, 2019).

Rice production has brought a significant change in the livelihood of farmers and has created job opportunities for a number of citizens along the rice value chain. Total cultivated land, production, and productivity of rice have been significantly increased (Fig.1) within the period of the two decades and still, it is increasing. In the productivity base, rice is the second highest productive cereal crop next to maize (CSA, 2018). It has shown promise as to be among the major crops that can immensely contribute towards ensuring food security in Ethiopia.

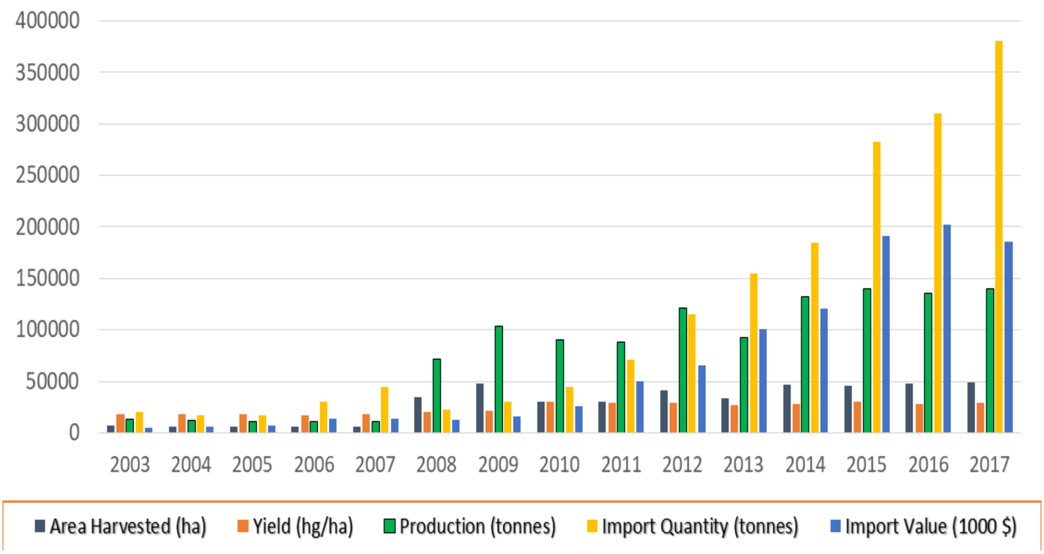

Figure 1. Trends of rice production, productivity, and imports in Ethiopia, 2001-2017
Source FAOSTAT, 2019 & USDA, 2019

Even though rice production has been increasing for the last ten years, the supply could not satisfy the entire domestic market due to low quality and demand increment so that the country is importing more than two-fold of its rice production (USDA, 2019). To fill this mismatch, the country has been importing rice from abroad. For instance, the country imported 380 877 tons of rice in 2017, mainly from three countries, India (95%), Pakistan (3%) and Thailand (1%). What is of concern is the drastic increase in imports since 2014. Rice imports doubled from 187 741 tons in 2014 to 380 877 tons in 2017 (ITC, 2019). Thus, in order to reduce import burden and ensuring the country's development plan of import substitution, it is critical to focus more on increasing the productivity of rice production per hectare at the farm level).

Despite the urgent need to address the above-mentioned constraints, the country has huge future growth potential for increasing rice productivity and production for several reasons. First, there is a substantial potential for Ethiopia to increase the cultivation area of rice. According to the report of the Ministry of Agriculture (MoA, 2010), the potential rain-fed rice production area is estimated to be 30 million hectares, of which more than 5 million hectares are highly suitable. So far, only 0.8% of this potentially arable rice land is being used for rice production compared with the potential. Second, rice production could improve with time. Since rice production is a new crop, its production, and productivity are expected to improve over time as farmers get more experience in producing the crop. Thirdly, the country is endowed with several conducive resources to improve irrigated lowland rice production such as wetland, lakes, perennial rivers, and man-made reservoirs. Finally, there is a scope for improving the productivity of rice through availing required improved varieties and by fostering the adoption of new techniques of agronomic management.

Understanding the existence of efficiency differentials and different factors contributing to the inefficiency in advance is a factor that helps to improve efficiency with a view to bringing a desired change in the sector. Although there exists extensive evidence on technical efficiency analysis in the Ethiopian agricultural sector (see Endrias *et al*. 2010, Essa, 2011, Mustefa 2014, Ermias *et al*.,2015), there is limited information in rice production efficiency analysis. In view of this, this study aims to fill the paucity of information pertaining to the level and determinants of farm-level technical efficiency of a sample of smallholder rice producers in Ethiopia by taking the case of the Amhara region, which accounts 64% the national rice production (CSA, 2016).

Methodology

The study area

This study was conducted in the Fogera district of South Gondar Zone, which is located in the Amhara Regional State of Ethiopia. The study area is situated between 11^0 46 to $11^0$59N latitude and 37^0 30 to 37^0 52E longitude. The altitude ranges from 1774 to 2410 meter above sea level with a mean annual rainfall of 1216 mm and mean annual temperature of 19^0c. It is bordered on the south by Dera district, on the west by Lake Tana, on the North by Gondar Zuria district, and on the East by Farta and Ebenat districts (FWOA, 2018).

Data collection and Analysis

Both primary and secondary data were used for this study. The primary data were collected from sample households in the district using structured questionnaire through the interview method. The 2016 rice production data are used in the estimation. Relevant secondary data were also collected from different organizations including the Ministry of Agriculture and Natural Resources, CSA, FAOSTAT, Fogera districts Agricultural office, among others.

A multi-stage random sampling technique was applied to select the study sample Kebele’s and households. In the first stage, Fogera district was selected purposely and three rice-producing kebeles were selected randomly from the district. Then, 202 rice producing farm household heads were selected randomly using simple random sampling.

To address the objectives of the research, both descriptive and econometric model were employed. Descriptive statistics such as mean, percentages, frequencies, and standard deviations were utilized to analyze the data and summarize the information. The econometric model, stochastic frontier approach (SFA) that takes the log-linear Cobb-Douglas production form was used to estimate the production function.

Specification of the econometric models

Following Aigner, Lovell and Schmidt (1997) and Meeusen and van den Broeck (1977), the stochastic production frontier for sample rice producers can be modeled as follows:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j lnX_{ij} + \varepsilon i \qquad (1)$$

where:
ln = denotes the natural logarithm
j = represents the number of inputs used
i = represents the i^{th} number of households in the sample
Y_i = represents rice production of the i^{th} households in 2016 production year.
X_{ij} = denotes j^{th} input variables used in rice production of the i^{th} households
β_0 = stands for the vector of unknown parameters to be estimated
$\mathcal{E}_i$ = is a disturbance term consists of two elements (v_i and u_i)
V_i = accounts for the stochastic effects beyond the farmers' control, measurement errors as well as other statistical noises
U_i = captures the technical inefficiency in production

Concerning technical efficiency, determination farmers have different characteristics that make them attain different levels of technical efficiency. Given a particular technology to transform physical inputs into outputs, some farmers are able to achieve maximum output while others are not. These factors need to be identified in order to define the problem of inefficiency and eventually search for a remedial measure to solve the problem. So to capture the possible effect of the exogenous variables that affect technical inefficiency, the following model is specified (Battesse and Coelli, 1995).

$$U_i = \delta_0 + \sum_{j=1}^{13} \delta_j Z_{ij} \qquad (2)$$

Where:
U_i = technical inefficiency score of the i^{th} household
$\delta_0 .. \delta_j$ = are parameters to be estimated that assumed to affect inefficiency;
Z_{ij} = are factors determining the inefficiency of rice producers and specified as: Z_1 = is a dummy variable for sex of a household head (1=male and 0=female);
Z_2 = is a continuous variable to represent the age of household head in years;

Z_3 = is a continuous variable of education level of the household head
Z_4 = is a discrete variable stands for a household size of the household;
Z_5 = is a continuous variable for the number of extension contacts;
Z_6 = is proximity (plot distance) from the homestead of farmers (in km);
Z_7 = is a dummy variable for received credit or not (1=Yes, 0=No);
Z_8 = is a continuous variable stands for the number of rice plots;
Z_9 = is a continuous variable for distance to the nearest market measured in km;
Z_{10} = is a continuous variable for livestock holding in TLU;
Z_{11} = is proximity (rice plot distance) from homestead (in km)
Z_{12} = is a dummy variable for soil fertility status (1=fertile and 0=otherwise);
Z_{13} = is a discrete variable for farmers experience in rice farming measured in a number of years.

The technical efficiency of the i^{th} farm household is estimated by the ratio of the observed output to maximum possible output, where the latter is provided by the stochastic frontier production function. The output produced with full efficiency and each farm household's performance is then compared with the estimated frontier. Estimating this frontier is served to estimate the level of technical efficiency (TE) of each farmer that is given as:

$$TE_i = \frac{Y_i}{Y^*} = \frac{f(X_i, \beta_i)\ \exp(V_i - U_i)}{f(X_i, \beta_i)\ \exp(V_i)} \tag{3}$$

$$TE_i = \exp^{(-U_i)} \ \ (\textit{where } 0 \leq TE_i \geq 1) \tag{4}$$

Where; Y_i is the level of output observed, Y^* *is* the stochastic production frontier and $\exp^{(-U_i)}$ takes values between zero and one and is inversely related to the level of the technical inefficiency effect.

The parameters of the stochastic frontier production function (SFPF) model and determinants of inefficiency were estimated by the method of maximum likelihood. The variance parameters are expressed in terms of the parameterization:

$$\delta^2_s = (\delta^2_v + \delta^2_u)] \tag{5}$$

$$\gamma = \delta^2_u / \delta^2_s = [\delta^2_u / (\delta^2_v + \delta^2_u)] \tag{6}$$

Where;
γ = parameter has a value between 0 and 1. A value of γ of zero indicates that the deviations from the frontier are entirely due to noise, while a value of one would indicate that all deviations are due to technical inefficiency.
δ^2_u = is the variance parameter that denotes deviation from the frontier due to inefficiency.
δ^2_v = is the variance parameter that denotes deviation from the frontier due to noise.
σ^2_s = is the variance parameter that denotes the total deviation from the frontier.
These parameters were analyzed using the computer program, STATA version 14.2 by employing a one-stage estimation procedure.

Description of variables for efficiency measurement

Production function variables

The production function variables are the dependent and independent variables measured in physical and monetary terms. The dependent variable that was used in the stochastic frontier model was the quantity of lowland rice produced in the year 2016 while the independent variables that were used in the model were input variables and inefficiency variables. The variables were specified based on economic theory, literature from previous studies and socioeconomic conditions of the study area. The variables are described in Table 1.

Table 1: Definition of variables included in the model

Variable	Description	Values	Expected sign
Output (Y)	Quantity of rice produced in 2016	kg h	+
Input function variables			
Labor	Labor (hired, family and exchange) used in rice production	person-days	+
Fertilizer	Amount of chemical fertilizers used	kg	
Seed	Quantity of rice seed used	kg	
Oxen Labor	Number of oxen days used	Oxen-days	
Land	Total land allocated to rice production	Hectare	+
Inefficiency factors			
Age	Age of the head of the farm HH	Years	+
Education	Educational level of the HH head	Years of schooling	+
Rice_exp	Experience of HHs in growing rice	Years	+
Dist_mkt	Distance to the nearest main market	km	-
TLU	Number of livestock owned	TLU	+
HH_size	Number of household size	Number	
Soil_fert	Perception of farm households on fertility status of the soil	value of 1 if perceives as fertile, 0 otherwise	+
Proximity	The distance between the farm where rice was cultivated and the residence of the respondents	km	-
Credit	Received credit	value of 1 if received credit, 0 otherwise	+

Results and Discussion

Descriptive analysis results

For this study, essential information was collected from 202 sampled households. Demographic, socio economic and institutional factors of the farm households are presented as follow (Table 2).

Table 2: Demographic, socio economic and institutional characteristics

Variable	Mean	SD	Minimum	Maximum
Sex (Male)	0.856	0.35		
Education status	0.609	0.49		
Age	44.4	14.06	20	80
Household size	5.29	2.14	1	11
Total Own Landholding (ha)	1.001	0.599	0	3
Total Own land rain-fed	0.886	0.511	0	3
Total Own land irrigated	0.116	0.281	0	2
Total Land	1.248	0.637	.125	4.5
Livestock holding (TLU)	4.575	2.517	0.000	10
Livestock income (Birr)	4662.03	5534.07	0	27800
Extension contact	5.07	5.44	0	15
Distance from the market (km)	3.85	2.04	0	7
Use of credit (user)	0.21	0.41		

Source: Survey result

Use of inputs

The average rice output obtained by the sample household in the 2016 production year was 3217 kg. The minimum and the maximum output levels ranged between 200 and 8700 kg with a standard deviation of 16 (Table 3). These amounts of output are often obtained when there is sufficient rainfall. In addition to the natural factors, the farmers' water management style plays a crucial role in determining the output level of lowland rice. Weed management, crop rotation, frequency of plowing and application of fertilizer are the important factors that affect rice yield, among others (MoA, 2010).

The majority of farmers uses inorganic fertilizer, farmers are aware of the deteriorating fertility status of their plot and the tendencies to use soil fertility improvement mechanism is common in the study area. Sample households used more UREA than DAP. The use of improved rice seed varieties in the study area was not common since the improved variety of rice seeds is not delivered to farmers by any organization (Table 3).

Plowing, water management, weeding, harvesting, and threshing are the major farming activities in the production of rice. The main source of labor is family labor, hired labor, and exchange labor. The amount of exchange labor in the study area is very low as compared to the source of labor. Weeding and harvesting take a higher share of labor consumption.

Table 3. Variables used to estimate the production function

Variable	Mean	SD	Min	Max
Total seed	149.73	74.51	25	350
Fertilizer used	91.16	78.38	0	400
Rice area	0.925	0.430	0.0625	2.75
Labor	188.45	146.01	16	774
Oxen labor	20.84	22.79	12	256
Rice prod	32.17	16.40	2	87

Source: Survey result

Econometric Results

Table 4. Stochastic frontier approach to measure efficiency

Variable	Coefficient	SE
ln Labor	0.0624*	0.0335
ln Oxen day	0.0881***	0.0218
Ln fert	-0.0058	0.0064
ln Area	0.5345***	0.0521
ln Seed	0.1106*	0.0294
Constant	2.6478***	0.3351
Likelihood function	-54.17	
Gamma	0.7875***	0.0164
Lamda	1.9253***	0.0611
Sigma square	0.209***	0.0315

Source Survey result

The ratio of the standard error of u (σu) to the standard error of v (σv), known as lambda (λ), is 1.92. Based on λ, gamma (γ) which measures the effect of technical inefficiency in the variation of observed output can be derived (i.e. γ= λ2/ [1+λ2]). In this case, the value of this discrepancy ratio (γ) calculated from the maximum likelihood estimation of the full frontier model was highly significant and close to one (γ= 0.79). The coefficient for the parameter γ can be interpreted in such a way that about 79% of the variability in rice output in the study area in the year 2016 was attributable to technical inefficiency effect, while the remaining 21% variation in output was due to the effect of random noise. This indicates that there is room for improving the output of rice by first identifying those institutional, socioeconomic, and farm-specific factors causing this variation (Table 4).

Elasticity estimates

The parameter estimates from MLE for the Cobb-Douglass model indicates the elasticity of the input variables with respect to rice production. The respective output elasticity is presented in Table 5 below.

Table 5. Output elasticity of input variables

Input variable	Elasticity
Labor	0.0624*
Oxen day	0.0881***
Fertilizer	-0.0058
Area	0.5345***
Seed	0.1106*
Returns to scale	0.79

Source: Survey result

On average, as we increase area allocated to rice, human labor, oxen labor and rice seed for the production of rice by one percent each, we could increase the level of rice yield by 53.45%, 6.24%, 8.81%, and 11.06% respectively. The sum of the parameter estimates in the frontier production function gives estimates of the returns to scale of the Cobb-Douglass production function. The sum is less than one thus indicating the farmers are operating at decreasing returns to scale.

Estimating household level technical efficiency

The mean level of technical efficiency of rice producing sample households was about 85%, with the minimum and maximum efficiency level of 22% and 99%, respectively. This shows that there is a disparity among rice producer households in their level of technical efficiency, which may in turn indicate that there is a room for improving the existing level of rice production through enhancing the level of households' technical efficiency. The mean level of technical efficiency further tells us that the level of rice output of the sample respondents could be increased, on average, by about 15% using the resources at their disposal in an efficient manner without introducing any other improved (external) inputs and practices. Thus, by operating at full technical efficiency levels, rice Productivity could increase, on average, from the current 3.2 t/ha to 3.68 t/ha.

It was observed that about 28% of the sample households were operating below the overall mean level of technical efficiency while about 25 % of the households were operating at the technical efficiency level of more than 95%. However, as illustrated in Figure 6 below the majority of rice producers (72 %) were able to attain above the overall mean level of technical efficiency. This might imply that in the end improving the existing level of technical efficiency of households alone may not lead to a significant increment in the level of rice output. So in the end, further efforts are required to introduce other best alternative farming practices and improved technologies in order to boost the overall rice production level.

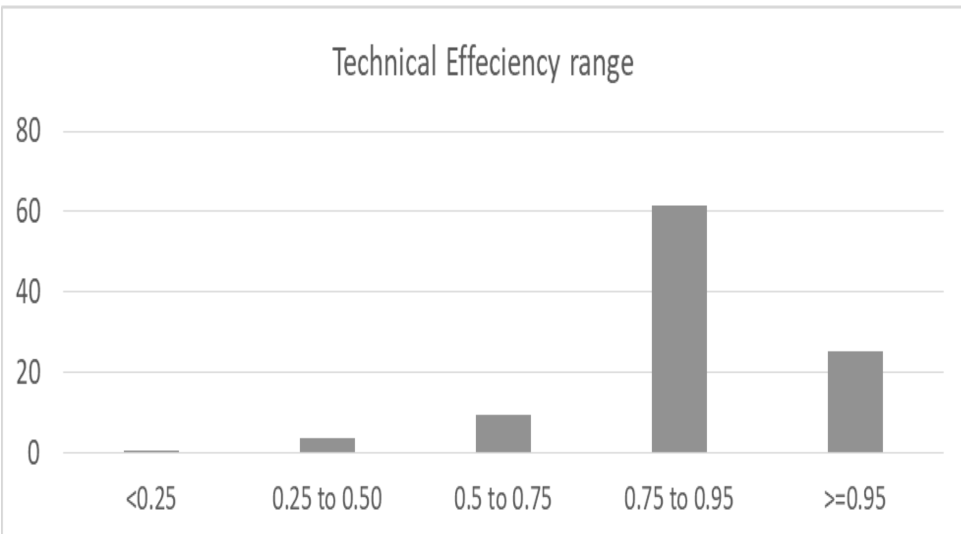

Figure 3. Frequency distribution of efficiency score of rice producers in 2016

Sources of technical inefficiency

The coefficients of those socio-economic and institutional variables included in the model were estimated using one stage stochastic production frontier with the input variable. Hence, the coefficients should be read as the effect of each input variable on the level of inefficiency instead of efficiency. However, one can read the estimated coefficients directly as the effect of the variable on technical efficiency by taking the opposite sign of the respective coefficients.

It was observed that the variables fertility of the soil, tropical livestock unit and frequency of extension contact were significant and appeared with negative signs indicating that these variables positively determine the level of technical efficiency of rice production. On the contrary, the positive sign of education level of the household and proximity of the plots shows that these variables affect the efficiency level negatively.

The education level of the household head was hypothesized to determine efficiency positively. However, the result shows that the coefficient of education is negative and statistically significant at ten percent level of significance with technical efficiency. As the education level of the household head increases by one percent, the probability of technical efficiency decrease by 72% keeping other factors constant. This might be due to educated farmers' are more exposed to the external environment and accumulated knowledge through formal learning that might enable them to shift their production from rice to other cash crops like vegetables. The other possible reason might be educated farmers spent their time on village administration and social responsibilities than rice farming.

Table 6 Maximum likelihood estimates of the factors determining technical inefficiency

Inefficiency variable	Coefficient	SE
Education	0.7184*	0.0165
Rice experience	0.0153	0.0704
Household size	-0.0089	0.0998
Total Asset Value	-0.0002	0.0002
TLU	-0.2118**	0.0877
Credit	0.1171	0.3262
Market distance	-0.0960	0.0707
Extension contact	-0.1094***	0.0358
Proximity	0.1026***	0.0165
Soil fertility	-0.0203***	0.0077
Constant	-1.3112	1.4769

, **and*Significant at 10%, 5% and 1%, significance level, respectively*
Source: Survey result

The advisory service rendered to the farmers in general can significantly help farmers to improve their average performance in the overall farming operation (source). From the result, it was observed that contact with extension workers was found to influence the technical efficiency of households positively. As extension contact increases by one unit, ceteris paribus, the probability of technical efficiency could increase by 11%.

Our result is in line with the findings of Mohammed (2011), and Abdulai et al. (2018). The result shows that having extension either contact with the advisory service through a visit from the farm advisor or participating in any training courses has a significant effect in explaining farmers' level of technical efficiency.

The result indicates that the coefficient of the fertility of the soil was positive and statistically significant at one percent level of significance, which confirms with a prior expectation. The result is an indication that the fertility of the soil is an important factor in influencing the level of efficiency in the production of rice. As the households produce rice in fertile soil, the probability of technical efficiency increases by 2%, keeping other factors constant. Improving and maintaining the fertility of land will have a positive impact on raising efficiency as pointed out in Ermiyas *et al.* (2015) and Tadele et al. (2017).

Livestock ownership is considered as an indication of household wealth status in rural Ethiopia. It is believed that livestock ownership may positively influence the technical efficiency of a household in two ways. Firstly, income generated from livestock off-takes and its products (selling milk and milk products) is expected to finance necessary agricultural inputs such as chemical fertilizer, pesticides, etc. Secondly, households having a large size of livestock can have a better chance to get more oxen draught power and serves for organic fertilizer. As mentioned above, ownership of livestock influenced technical efficiency positively and statistically significant at five percent level of significance. As the tropical livestock unit increases by one percent, the probability of rice technical efficiency could increase by 21% keeping other factors constant. This finding is consistent with what Shumet (2012) found in Tigray region and Tadele et al (2017) found in the wheat producing area of Ethiopia.

Finally, the study showed a negative relationship between technical efficiency and the distance between the cultivated rice plot and residence of the household measured in km. As the distance of rice plot increased by one kilometer, the probability of the technical efficiency of rice could decrease by 10%. This might be related to soil fertility and water availability of the land. Farmers often select land that has no or minimum flooding for their homestead.

Conclusion and Recommendations

Farmers’ in Fogera district in the Amhara region have been cultivating rice as a major crop for the last 20 years. However, there is no empirical evidence pertaining to the technical efficiency of rice producing farmers in the study area. Therefore, this study examined the level of technical efficiency of rice producing smallholder farmers, and factors affecting the variation of technical efficiency among smallholder farmers in the Fogera district.

The estimated Cobb-Douglas stochastic production frontier shows that there was a considerable inefficiency gap among households in rice production. It was observed that the mean efficiency level of rice production was 85%, indicating that production can be increased by 15 percent. The findings also revealed that there was a substantial difference in technical efficiency level among rice producers' households. Hence if inputs are used to their maximum potential, there will be considerable gain from improvement in technical efficiency. If rice farmers produced at full technical efficiency level, the rice production could, on average, increase from 3200 kg ha^{-1} to 3680 kg ha^{-1} The efficiency gains would come from improvements in technology outreach activities, especially the extension service. Since rice is a new introduction to the country, availing accessible extension services and providing better production management techniques for all rice farmers is expected to enhance rice production in the country.

The results of the study showed that soil fertility is a crucial factor in determining the technical efficiency of rice producers. Therefore, there is a need to encourage households to improve the fertility status of their soil. This can be achieved by applying fertilizers that are suitable for the farm and fostering the practice of soil conservation on rice plots.

Utilizing available resources and technology efficiently side by side with introducing new agricultural technologies could help to address the food security problem and enhance the commercialization of rice. So to achieve this, extension services should expand to reach each and every farmer and there is also a need to modernize extension services provided so that it can face new challenges and transfer the latest technologies in an efficient way. It is evident from the result of the study that the effect of extension service on the technical efficiency of rice production was statistically significant. Therefore, Efficiency gains could be realized by designing better extension and institutional support and ensuring an adequate provision of research and extension support to rice farmers.

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