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Analysis of Technical Efficiency of Smallholder Irrigated Cotton Producers in Middle Awash Valley, Northeastern Ethiopia

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Abstract

This study estimated the level of technical efficiency and its determinants of smallholder irrigated cotton farmers in the Middle Awash Valley of Northeastern Ethiopia. A multi-stage purposive random sampling procedure was employed to select 74 irrigated cotton farmers from Amibara district of Afar region. A structured questionnaire and field observations were employed to collect relevant information. Data were analyzed using stochastic production frontier approach. Results showed a mean technical efficiency level of irrigated cotton farmers to be 71%; indicating that there was 29% possibility of increasing cotton production in the valley given the current state of technology and inputs level. The results indicated that elasticities of the mean output for the cotton area, labor cost, and irrigation frequency were positive while those of seed and pesticide costs were negative. Further, the empirical results from the inefficiency effects model revealed that experience in cotton farming, extension service, credit access, tenancy status, salinity level, and distance to the main irrigation water canal were found to be important in explaining farmers' technical inefficiency in the study area. The study recommends that government efforts are vital in increasing cotton output through improvement in technical efficiency by ensuring timely delivery of optimal quantities of inputs, such as cotton seed and chemicals. Provision of short-term credit service and promotion of research findings through extension services would also be crucial.

Keywords: Stochastic Frontier Analysis; Technical efficiency; Irrigated cotton farmers; Middle Awash Valley; Northeastern Ethiopia.

Introduction

Agriculture has consistently been the center of economic activities in Ethiopia. It contributes about 36% of the country's Gross Domestic Product (GDP), 73% of employment and 70% of export earnings (Getachew *et al*., 2018; NBE, 2018) as well as important providers of raw materials (inputs) for other production activities, especially the manufacturing sector. Moreover, the government development policies propose agriculture to be the main source of capital to be accumulated for the process of establishing future industrialized Ethiopia. This again shows the importance of agriculture sector in bringing sustainable economic development for the country in the years to come. Thus, the growth of other sectors of the economy in the country by and large depends on the growth and development of the agricultural sector.

In this context, the Government of Ethiopia (GOE) has planned textile/garment industry as one of the economic engines of growth. This is because the sector has the potential to not only transform Ethiopia's agrarian economy into industry but also create massive employment opportunities both at the farm and off-farm levels. Consequently, cotton is the major supplier of raw materials and becomes one of the strategic cash crops central to the development of the textile and garment industries. In Ethiopia, cotton production has gained much significance because it also serve as the dual purpose of providing raw materials to the apparel and textile industry as well as creating massive employment opportunities.

Ethiopia has a long tradition of cultivating cotton, and the crop is growing in many parts of the country. Many regions of the country have favorable environmental conditions suitable for the cultivation of cotton both under rainfed and irrigation conditions. Several estimates have shown that Ethiopia has 2.6 to 3 million hectares of land suitable for cotton cultivation (MoA, 2011; EIA, 2012). Areas, such as Omo-Ghibe, Wabi Shebele, Awash, Baro-Akobo, Blue Nile, and Tekeze river basins lie within the optimal altitude range for growing cotton: between 300 meters and 1,400 meters above sea level (Bayrau *et al*., 2014).

Even though Ethiopia has ideal conditions for growing cotton and a significant amount of land potentially suitable for its production, the cotton sector and its related industry have failed to reach their potential. This is related to sub-optimal yields, poor marketing and processing, and limited improvement of livelihoods involved along the cotton value chain. Cotton production in Ethiopia has consistently fallen below domestic demand from the textile and apparel sector, thus resulting in a deficit, which is often catered through importation. The current seed cotton production level of the country neither meets the cotton sector's potential nor satisfies the domestic industry's demand and the yield is far less than other countries (Seboka, 2020).

Production and productivity of cotton vary considerably from farm to farm. Productivity of commercial varieties under research-managed conditions is about 3.5 to 4 tons per hectare. The same varieties yield 2-3 and 1-1.2 tons per hectare under irrigated and rainfall-grown commercial farms, respectively (Seboka, 2020; Nicolay *et al*., 2020). The yield under farmers' production systems (0.3-0.7 tons per hectare) is far below the national average of 1.36 tons per hectare (Terefe and Mohammed, 2010). Thus, there is a wide yield gap between the attainable and actual yield of seed cotton among producers. This means that current technologies have a big potential to increase the yield of seed cotton. The gap between commercial farm yield and the national average yield represents the untapped yield potential existing at the current level of technology and the availability of appropriate technologies best suited to production systems. Therefore, to increase cotton productivity, there is a need to understand the technical efficiency of producers. Hence, it is necessary to enhance the productivity of farmers by helping them to reduce their inefficiency in production.

Improving agricultural productivity among cotton farmers has a multiplier effect on the sector. It can improve the income of cotton farmers and subsequently help to reduce poverty. It can also improve the profitability of lint production among ginning companies and consequently contribute to the national economy. Therefore, improving the Technical Efficiency (TE) of cotton farmers is a key step in achieving the national cotton development strategy of making Ethiopia one of the world's top producers of sustainable quality cotton by 2032 (SOFRECO, 2017). This strategic goal can be achieved through increasing cotton production, investing in the textile and apparel domains to transform Ethiopia's agrarian economy into industry and creating employment opportunities. Given the importance of cotton and the opportunities arising in the cotton industry, it is expected that cotton is one of the strategic cash crops in the country. Thus, it is vital that policymakers, researchers, and other actors along the value chain understand the efficiency of cotton production.

Population growth and expansion of industrialization are the main reasons for increased demand for cotton fabric and this has pushed cotton-producing countries including Ethiopia to meet this demand. Accordingly, boosting production and productivity is crucial. Despite cotton sector plays indispensable role in enhancing economic transformation and poverty reduction, no study has been conducted to estimate the production efficiency of cotton in Ethiopia. Many empirical studies on efficiency were geared towards food crops. Over time, cotton-related research has focused on the agronomic and/or breeding aspects, ignoring important aspects of cotton production along the value chain such as resource use efficiency and enterprise profitability. This study is, therefore, undertaken in the Middle Awash Valley, representing the major irrigated cotton-producing areas of Ethiopia with the objectives of assessing the level of technical efficiency and identifying sources of inefficiency among smallholder irrigated cotton producers.

Methodology of the Study

The Study Area

The study was conducted in the Amibara district of the Middle Awash Valley, which stretches between the towns of Awash and Gewane. Geographically located between 9°12′8″ to 9°27′46″ North latitude and 40°5′41″ to 40°15′21″ East longitude. The climate of the area is characterized as semi-arid bimodal (long and short rainy seasons) with rainfall of about 533mm annually. The long rainy season occurs from July to September with 49% of the total rain. The short rainy season extends from February to April and accounts for about 29% of the total rain. The mean minimum temperature of the area is 15°c in December and 23°c in June, while the mean maximum temperature is 33°c in December and 38°c in June.

Sampling Technique and Data Sources

The sampling frame of this study was all farmers who produced cotton under irrigation in the Amibara district. A multi-stage sampling technique was used in selecting respondents for this study. The first stage involved the purposive selection of the Amibara district based on the volume of cotton cultivation and the availability of a well-established irrigation scheme for the regular supply of irrigation water for crop production. In the second stage, four local *kebeles* were purposively sampled based on the intensity of cotton cultivation (*Badhamo, Bonta, Waydulalie* and *Bedulalie*). In the third stage, a random sampling technique was used to select farmers from the list of cotton-producing farmers at each *kebele* with the help of Agricultural Extension agents. A total of 74 cotton farmers were sampled for the study. The primary data for this study were collected using structured questionnaires administered through face-to-face interviews with the sampled farmers. Field observations and key informant interviews were also employed in collecting data.

Analysis Techniques

Descriptive and econometric statistical methods were employed to analyze the primary data collected from the field survey. Descriptive statistics such as frequency distribution, mean, percentage, and standard deviation were used to describe the socio-economic and farm-specific characteristics of the farmers obtained from field data. We adopted the parametric methodology (econometric model), Stochastic Frontier Analysis (SFA) approach to estimate the production function, determine the sources of inefficiency, and estimate the level of technical efficiency. Moreover, the Maximum Likelihood Estimation (MLE) technique was employed as the estimation procedure. We used Stata version 14 for the maximum likelihood estimation[1].

The Stochastic Frontier Analysis

In stochastic frontier analysis, the farm is constrained to produce at or below the deterministic production frontier. The approach is preferred for efficiency studies in agricultural production due to the inherently stochastic nature of the agricultural production systems. The stochastic production frontier function was first independently proposed by Aigner *et al.* (1977) and Meeusen and Van den Broeck (1977). A stochastic production frontier function comprises a production function

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[1] The maximum likelihood estimates can be estimated simultaneously using the computer program FRONTIER 4.1, Stata and Limdep (Coelli, 1994; Green, 2002)

of the usual regression type with a composed disturbance term equal to the sum of two error components. One error component represents the effects of statistical and random noise (for example weather, measurement error, etc.) the other is attributed to technical inefficiency. The major advantage of the stochastic production frontier model is the introduction of disturbance terms representing noise, measurement error and exogenous factors beyond the control of the production unit, in addition to the inefficiency component. Following the model proposed by Aigner *et al.* (1977), the general stochastic frontier production function can be expressed as:

$$Y_i = f(X_i, \beta) + \varepsilon_i = exp\ (X_i\beta + \varepsilon_i) \quad (1)$$

where i= 1, 2..., n

Y_i = output level of the i^{th} sample farm

f (χ_i, β) = a suitable function such as Cobb-Douglas or transcendental (translog) production functions

χ_i = vector of inputs

β = vector of unknown parameter to be estimated

ε_i = the double component error term ($\varepsilon_i = V_i - U_i$), v_i is assumed to account for random effects on production associated with factors such as measurement errors in production and other factors in which the farmer does not have control over and V_i is a non-negative random term associated with farm-specific factors, which leads to the i^{th} farm not attaining maximum efficiency of production. Thus, U_i measures the technical inefficiency effects variables which are under the discretion of the decision-making unit.

The stochastic frontier approach specifies the technical efficiency of an individual farm as the ratio of the observed output to the corresponding frontier output given the level of inputs and technology used by the farm. The Technical Efficiency (TE) of the i^{th} farm, defined relative to the estimated frontier output of an efficient farm using the same set of inputs, can be specified as:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(X_i;\beta)\ exp(V_{i-U_i})}{f(X_i;\beta)\ expV_i} = exp\ (-U_i)\ = exp(-Z_i\delta - w_i) \quad (2)$$

where Y_i is the actual (observed) output obtained by the sampled farmer and Y_i^* is the maximum (unobserved) possible output. According to Battese and Coelli (1995), the error term V_i is assumed to be identically, independently, and normally distributed with zero mean and constant variance, $N(0, \sigma_v^2)$. The non-negative random term, U_i, is also assumed to be distributed as truncation of the normal distribution with mean U_i and variance $N(U_i, \sigma_u^2)$ such that inefficiency error term can be explained by exogenous variables as:

$$U_i = \delta_0 + Z_i\delta + w_i \quad (3)$$

where Z_i is a vector of explanatory variables; δ_i is a vector of unknown parameters to be estimated and W_i is an unobservable random variable defined by the truncation of the normal distribution with a mean of zero and a variance δ^2.

In this study, a single-stage maximum likelihood approach was used to estimate the technical efficiency level of irrigated cotton farmers and the determinants of technical inefficiency simultaneously. This simultaneous estimation approach ensures that the assumption of the identical distribution of the error term U_i is not violated. The maximum likelihood estimates of the stochastic frontier model provide the estimates of β and the gamma (γ), where the gamma explains the variation of the total output from the frontier output. The gamma estimate is specified as:

$$\gamma = \frac{\delta_u^2}{\delta^2} \tag{4}$$

where γ has a value between zero and one, δ_u^2 is the variance of the error term associated with inefficiency and is the overall variation in the model specified as the sum of variance associated with inefficiency and that associated with random noise factors. Therefore:

$$\delta^2 = \delta_u^2 + \delta_v^2 \tag{5}$$

The closer the value of gamma (γ) to one, the more the deviation of the observed output from the deterministic output, which is the result of inefficiency factors. However, if the value is closer to zero, then the deviations are because of random factors.

Empirical model

In the stochastic production frontier model, the two most important functional forms widely used are Cobb-Douglas and Translog production functions. Though both functional forms have their strengths and shortcomings, the Cobb-Douglas production function was employed in this study for simplicity related to cotton production. The Cobb-Douglas has been widely used in efficiency studies on the agricultural sector of developed and developing countries (Chakraborty *et al*., 2002; Gebremedhin *et al*., 2009). The Cobb-Douglas stochastic production function is written as:

$$lnY_i = \sum_{n=1}^{N} \beta_0 + \beta_j lnX_{ji} + V_i - U_i \tag{6}$$

where ln is the natural logarithm, Y_i is the total output, X_i is vector of inputs, ji are positive integers ($i \neq j$), β is vector of parameters to be estimated, and V_i and U_i have been defined above. Following Battese and Coelli (1995), the model of technical inefficiency effects on the stochastic frontier equation (6), including socio-economic and farm-specific factors, can be specified as:

$$U_i = \delta_0 + \sum_{j=1}^{n} \delta_j Z_{ji} + w_i \quad (7)$$

where Z_i is a vector of socio-economic and farm specific characteristics, δ is a vector of parameters to be estimated, and W_i is unobservable random variables.

Descriptions of Variables Used in the Model

Table 1 summarizes the description of output, inputs and inefficiency variables used in the model and their priori expectation. In regression, all the independent variables for the production frontier model are in logarithm form along with the dependent variable, whereas variables in the TE model are in absolute values. The dependent variable, Y_i, is the seed-cotton[2] production in Kg for the i^{th} farm. The independent variables for the frontier model are defined as X_{1i} to X_{7i} as follows: X_{1i} indicates the natural logarithm of irrigated cotton cultivated area in hectares, X_{2i} is the quantity of cotton seed used (Kg). X3i and X4i show the monetary values of fertilizers and pesticide costs, respectively. X5i is the cost of hired labor[3]. The value of labor used in this study is the aggregate costs of all manually operated activities in the cotton production process. X6i represents machinery operating costs, measured as the monetary value of working hours for ploughing, leveling, and ridging. X7i shows the number of irrigations applied to the cotton area of production.

Table 1: Definition of variables used in the stochastic production frontier model

Variables	Coding system	Category	Expected sign
Production variables			
InX_{1i} = Cultivated cotton area	Hectares	Continuous	+
ImX_{2i} = Quantity of cotton seed	Kg	Continuous	+
InX_{3i} = Quantity of fertilizer	Kg	Continuous	+
InX_{4i} = Pesticide cost	Ethiopian Birr (ETB)	Continuous	+
InX_{5i} = Labor cost	ETB	Continuous	-
InX_{6i} = Machinery costs	ETB	Continuous	-
InX_{7i} = Irrigation frequency	Number of irrigations	Continuous	+/-
Inefficiency variables			
Z_{1i} = Age of household head	Number of years	Continuous	+/-
Z_{2i} = Education level of household head	1= literate, 0= otherwise	Dummy	+
Z_{3i} = Cotton farming experience	Number of years	Continuous	+
Z_{4i} = Extension access	1= yes, 0= otherwise	Dummy	+
Z_{5i} = Access to credit	1= yes, 0= otherwise	Dummy	+
Z_{6i} = Off-farm activities	1= yes, 0= otherwise	Dummy	+/-
Z_{7i} = Tenancy system of farmland	1= rented, 0= owner	Dummy	-
Z_{8i} = Salinity status of the farmland	1= saline, 0= otherwise	Dummy	-
Z_{9i} = Distance to water cannel	Kilometers	Continuous	-
Z_{10i} = Time of planting	1=Mid-April to Mid- May, 0= otherwise	Dummy	+

[2] Seed-cotton; raw cotton (lint + seed)

[3] This variable is measured in terms of monetary value due to the unavailability of quantity data as farmers in the study area hire labor on a contract basis.

The variables for the model of technical inefficiency effects are represented from Z_{1i} to Z_{10i}. Z_{1i} denotes the age of the household head. Z_{2i} is a dummy variable indicating the level of education of the household head. Z_{3i} represents cotton farming experience in years. Z_{4i} represents a dummy variable for the contact of extension for the cotton crop. Z_{5i} and Z_{6i} are dummy variables indicating access to credit service and participation in off-farm activities, respectively. The dummy variables, Z_{7i} and Z_{8i} help determine the impacts of tenancy and soil quality of the cotton farmland on technical efficiency, respectively. Z_{9i} represents the variable for the distance (km) from the farmland to the main irrigation canal, and Z_{10i} represents a dummy variable for timely sowing.

Results and Discussion

Descriptive Statistics

The general characteristics of household respondents of irrigated cotton farmers in the study area are presented in the following tables. These results refer to the descriptive analysis of the demographic and socio-economic characteristics of the sampled households. Table 2 shows the demographic characteristics of irrigated cotton farmers in the study area. The table shows that in all the villages, cotton production is dominated by male farmers (95% of the sampled respondents) compared to female (5%) counterparts. This result can be explained by socio-cultural factors, but not as the result of technical inefficiency. Most irrigated cotton farmers (64%) are below the age of 41 years with a mean age of 39 years. This implies that irrigated cotton farming is mainly practiced by younger farmers. The predominance of young farmers in the cotton farming implies that labor productivity is expected to be high as they are active and energetic. Education can make the farmer more skilled and efficient. Therefore, literacy level was asked from the selected cotton farmers in the study area. The study shows that 30% of the respondents have formal education ranging from primary to secondary and above, while 70% of the cotton farmers are illiterate.

Table 2: Demographic characteristics of respondents

Variable	Group	Frequency	Percentage
Gender	Male	70	94.59
	Female	4	5.41
Age	20-40	47	63.51
	41-60	25	33.78
	≥ 61	2	2.70
Level of education	Illiterate	52	70.3
	Literate	22	29.73
Household size	1-5	23	31.08
	6-10	49	66.22
	≥ 11	2	2.70

Source: Field survey data, 2018/19

In terms of household size, 31% of the sampled cotton growers had 1-5 family members, whereas 62% had 6-10 family members. Only 3% of the households had 11 family members or more. However, the mean family size was 6.82 members ranged from 1 to 13 members.

Table 3 describes some of the socio-economic and farm characteristics of cotton growers in the study area. In this study, experience includes knowledge or skills gained through involvement in cotton farming. The result shows that 93% of the respondents had more than 5 years of experience in producing irrigated cotton, while 7% of the respondents had 1-5 years of cotton farming experience. In terms of farmland size, the majority (98.64%) of the cotton farmers had less than 5 hectares of land, while only 1.36% owned farmland of more than 5 hectares.

The land within the Amibara Irrigation Scheme was owned by the state. However, after abolishing the state farms, the land around the irrigation scheme was reallocated to local farmers through their respective clans. The reapportioned plots become the permanent properties of the various clans and farm families. When the clan or farmers do not need the plot in a particular year, they often lease it for another user. Interaction with the farmers during the survey revealed that the status of land ownership in cotton production in the study area is of two types i.e., landowners and lessee/rent. About 55% of the cotton growers acquired land for irrigation farms through ownership while 45% of the cotton growers obtained land through renting. About 54% of the farmers who cultivate cotton have been involved in other income-generating activities to support both cotton farming and their livelihoods.

Table 3: Farm specific characteristics of sample respondents

Variable	Category	Frequency	Percentage
Cotton farming experience	1-5	5	6.76
	6-10	46	62.16
	≥ 11	23	31.08
Farmland size	0.5-2.0	55	74.32
	2.1-5.0	18	24.32
	≥ 5.1	1	1.35
Off-farm activities	Yes	40	54.05
	No	34	45.95
Land tenure system	Owner	41	55.41
	Lessee/rent	33	44.59
Farmland quality	Saline	39	52.7
	Non-saline	35	47.3
Extension contacts	Yes	5	6.76
	No	69	93.24
Source of capital	Own	6	8.11
	Investors	50	67.57
	Relatives	18	24.32
Source of seed	Research Centre	10	13.51
	Ginnery	17	22.97
	Investors	47	63.51
Cotton varieties planted	DP-90	66	89.19
	Stam	4	5.41
	Unknown	4	5.41

Source: Field survey data, 2018/19

Farmers were also asked about their farmland condition in terms of salinity status. Accordingly, 53% of the respondents reported that their farmland is affected by salinity.

Accessibility factors such as extension services, credit facilities and sources of cotton seed varieties of the respondents play vital roles in increasing the production and productivity of cotton. Extension service has the potential to increase farmers managerial skills which helps them combine productive inputs optimally and ensure the execution of agronomic practices appropriately. Table 3 presents farmers' access to extension services, credit facilities and availability of cotton seed sources in the study area. The results show that only 7% of the respondents had received extension services regarding cotton production in the study area. This implies how the cotton production is neglected by the public extension service. Similarly, only 8% of the growers have reported covering all the operational costs by themselves. The majority (92% of the producers) have almost no access to credit. They can only borrow cash from their relatives or investors at a very high-interest rate. These results, therefore, suggest that most smallholder cotton farmers lack the proper managerial knowledge and skills as well as essential resources to efficiently carry out production activities to optimize their output.

Table 3 also reveals the various sources of seed supply for planting. About 64% of respondents obtained cottonseed from private investors, 14% got from research centers and 23% got seeds from the private ginnery found in their vicinity. None of the farmers have reported the use of seeds from the previous production season. The descriptive results also show that the most popular commercial cotton variety grown by the farmers in the study area is DP-90. This variety was planted by 89% of the sampled farmers. The remaining 5% of the cotton land was covered by the variety called '*Stam*' while 5% of the cotton farms were covered by unknown cotton varieties. These results imply that cotton farmers in the study area are using old and obsolete cotton varieties. This is because the varieties they are currently using are more than 40 years old.

The mean, standard deviation, minimum and maximum values of the inputs, output and other variables included in the stochastic production frontier, as well as the inefficiency effects model, are presented in Table 4.

Table 4: Summary statistics of input, output, and other variables

Variables	Mean	Standard Deviation	Minimum	Maximum
Output (Kg)	4,455.41	3,785.70	1,100	200,000
Cotton area (Ha)	1.89	1.29	.50	7.00
Cottonseed (Kg)	56.35	35.87	15	225
Fertilizer (Kg)	26.68	35.68	0	150
Pesticides (ETB)	10,775.49	8,280.24	15,500.00	49,000.00
Manual labor (ETB)	22,680.29	17,367.27	5,300.00	104,730.00
Machinery operation (ETB)	10,603.38	7,493.53	2,725.00	42,700.00
Irrigation (Frequency)	8.20	1.20	7	12
Distance to water cannel (Km)	0.48	0.19	0.2	0.9

Source: Computed from survey data 2018/19

Irrigated cotton farmers in the study area harvested, on average, about 4,455 kg of seed cotton with a standard deviation of 3,786, indicating that there was high variability in the production of irrigated cotton among farmers in the study area. The mean size of land used to produce cotton was 1.89 hectares. The average quantity of seed used by the sample farmers was 56.35 kg with a minimum of 15 kg and a maximum of 225 kg. In the production process, on average, 27 kg of urea fertilizer was used with a high standard deviation of 36 showing the high variability of fertilizer use. The average cost of pesticides was ETB 10,776 while that of manual labor cost and machinery operation costs were ETB 22,680 and 10,603, respectively. On average, producers applied irrigation water eight times from sowing to physiological maturity of the crop. Meanwhile, the irrigation water travel about 0.5 kilometers to reach the cotton farmland.

Econometric Results

The choice of functional form plays an important role in empirical studies and could significantly affect the results of the model. Due to its easiness in estimation and interpretation, the Cobb Douglas production function was employed in this study. Generalized likelihood ratio statistics was carried out for the possibility of the existence of technical inefficiency. In the stochastic production frontier model, the sign of the coefficient estimate directly shows the direction of the effect. Contrarily, the sign and coefficients in the technical inefficiency effects model are interpreted in the opposite way such that a negative sign decreases inefficiency and positive sign increases inefficiency.

Stochastic Production Frontier Analysis

Table 5 presents the maximum likelihood estimates (MLE) of the stochastic production frontier model and inefficiency effects model. The results of MLE indicated that gamma (γ), which is the ratio of the variance of technical inefficiency effects (U_i) to the variance of random errors (V_i) has a coefficient of 0.83 and is significantly different from zero. The results indicate the stochastic nature of the cotton production function. These results indicate that about 83% of the variation in cotton output is attributable to differences in technical efficiencies among smallholder irrigated cotton farmers, while the random effect was only 17% which attributes to the random variation in cotton output among smallholder irrigated cotton farmers.

The Cobb-Douglas production function parameters can be interpreted directly as output elasticities. The maximum likelihood estimates results showed that all the input parameters, except the quantity of fertilizer used and land preparation machinery cost, were found statistically significant, which implies that these inputs are playing a significant role in cotton production (Table 5). There is a positive relationship between input variables of cotton area, labor cost, and irrigation frequency with cotton output. On the other hand, cottonseed and crop protection costs have a negative relationship with the cotton output.

The area under cotton cultivation had a positive coefficient (0.090) that met the priori expectation and statistically significant at 5% level. This result indicates that a 1% increase in area under cotton cultivation would lead to an increase (0.10%) in cotton output. These results appear to concomitant with the findings of Veronique and Renata (2014).

Seed rate determines the plant population in a field of certain crop and thus, is an important factor in determining cotton output. The maximum likelihood estimates of stochastic production frontier model revealed that coefficient of seed rate (quantity of seed used) had a negative sign with a value of -0.240 and was significantly significant at 5% level. This result shows that cotton seed is contributing negatively to cotton output. The implication is that farmers in the study area sow higher than the recommended rate for cotton. Negative coefficient of seed rate also implies that farmers use poor quality of seeds which have low germination rates that ultimately results in low crop production.

The production of conventional cotton requires excessive use of inputs in the form of pesticides, fertilizers, and irrigation. In Middle Awash Valley, the study area, herbicide use is not common and fertilizers use is still below average. Likewise, no defoliants are used as the produce is picked manually. Hence, pesticide here refers to insecticides only. The coefficient for pesticide costs was negative and significant at 1% level with a value of -2.087. The incidence of pests on cotton crop is a growing problem in all cotton growing areas of Ethiopia. Consequently, the adoption of chemical control methods are increasingly becoming popular among the cotton growers leading to the irrational use of insecticide. This indicates that farmers are not applying insecticides optimally for cotton production. The implication is that cotton output appears to decline in response to expenditures on plant protection measures (insecticide costs). Growers are spending too much and perhaps using too much insecticide each time they spray. The negative sign for elasticity of pesticide cost could be attributed to several types of pesticides applied because quality and efficacy of such chemicals would not fit for controlling pests in the study area.

Table 5: Maximum likelihood estimates of Stochastic Production Frontier model

Variables	Parameters	Coefficient	Std. Error	t-value
Stochastic production frontier				
Constant	β_0	-19.491	4.154	-4.690
Ln Cultivated cotton area	β_1	0.090	0.045	1.98**
Ln Cotton seed quantity	β_2	-0.240	0.031	-7.82**
Ln Fertilizer quantity	β_3	0.004	0.010	0.39
Ln Pesticides cost	β_4	-2.087	0.492	-4.24***
Ln Manual labor cost	β_5	0.946	0.097	9.75***
Ln Machinery operation cost	β_6	0.266	0.220	1.21
Ln Irrigation frequency	β_7	0.024	0.014	1.74*
Inefficiency effect				
Constant	δ_0	-5.972	2.686	-2.220
Age of the farmer	δ_1	0.060	0.064	0.940
Educational level	δ_2	-0.049	0.066	-0.740
Cotton farming experience	δ_3	-0.025	0.009	-2.720***
Extension access	δ_4	0.295	0.121	2.430**
Access to credit	δ_5	-0.024	0.009	-2.620***
Off-farm activities	δ_6	-0.003	0.003	-0.980
Tenancy status	δ_7	0.161	0.081	2.000**
Salinity level	δ_8	0.255	0.054	4.750***
Distance to main water canal	δ_9	0.298	0.128	2.320**
Time of planting	δ_{10}	-0.097	0.067	-1.450
Variance parameters				
Sigma square	δ^2	0.2945	0.0917	3.24***
Gamma	Γ	0.8310	0.3938	2.11**
Log likelihood function		39.5092		
Likelihood ratio	LR= 18.58***			

Source: Survey data, 2018/19

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

Moreover, the proliferation of substandard insecticides in the market, aggressive marketing by pesticide companies, and the limited knowledge of the farming households about pest control methods and practices as well as over reliance on chemicals and indiscriminate use of pesticides have led to inefficient use and high cost. However, Ahmad and Afzal (2012) have documented positive and significant effect of plant protection expenditures on cotton yield.

Labor plays a very important role in cotton production. Most activities in the farm require the use of labor e.g., land cleaning, sowing, weeding, hoeing, irrigating, spraying, picking, etc. In this study, labor costs are considered as costs incurred for all manually operated activities practiced in the cotton production process. From the analysis, the coefficient for cost of labor was positive and statistically significant at 1% level, with value of 0.946, indicating that the cotton output increases by 0.95% as labor cost increased by 1%. The higher elasticity of labor is also an indication that cotton farming is a labor-intensive venture. Similar findings have been reported in Abid *et al.* (2011) for cotton productivity.

Irrigation combined with integrated nutrient and pest management can enhance higher productivity and significantly affects crop production. Irrigation frequency had coefficient of 0.024, which was statistically significant at 10% level of significance. A relative increase of 1% in number of irrigations causes an increase of 0.024% in output of cotton.

Determinants of technical inefficiency

Results of the inefficiency effects model are quite interesting and attractive for policy making. The results revealed that variables such as cotton farming experience and access to credit were found to be negatively related with inefficiency and statistically significant. However, extension service for cotton, tenancy status, distance to main water canal and salinity level of the farmland were positively related with inefficiency and statistically significant. Thus, increase in the levels of these variables, reduces the technical inefficiency of the sample farms. These findings imply that farming experience, credit access, tenancy status, salinity level and distance to main irrigation water canal can increase technical efficiency in cotton production.

The coefficient for cotton farming experience with technical inefficiency was negative and statistically significant at 1% level. The result implies that experienced cotton farmers were more technically efficient than inexperienced ones. This is because farmers with many years of cotton farming experience are more likely to be familiar with the required skills needed for cotton production. That means that experienced farmers are more likely to have higher outputs and consequently become technically efficient.

The public agricultural extension service is still the most important player in terms of input delivery and technical advice to smallholder farmers in Ethiopia. Interestingly, the estimated coefficient for extension services on cotton production was found to be positive and statistically significant at 5% level. This implies that extension agents did not offer enough productive advice to farmers as they have little/no knowhow about the details of the crop. Ethiopia has one of the most densely staffed extension networks in the world but does not use it for cotton paradoxically. This could be taken as the hallmark of poor linkage between the research system and the producers in the cotton sector of the country.

The effect of credit access on technical inefficiency for irrigated cotton farmers was negative and statistically significant at 1% level. This was expected. The implication is that farmers with access to credit are more technically efficient than farmers without credit access. This is because smallholder farmers do not have adequate savings to purchase farm inputs. Thus, they apply sub-optimal quantities of inputs and, quite often, fail to apply them in time. Lower quantities of inputs than the recommended rates coupled with delayed application can result in low cotton output. Availability of credit can enhance farmers' capacity to purchase farm inputs well in-time and ensure timely application of optimal quantities. This is important for cotton production where input costs are quite high. Similarly, Assefa (2011) and Dessale (2019) reported that access to credit positively affects the technical efficiency of smallholders in Ethiopia.

Tenancy status had positive effect on the inefficiency and statistically significant at 5% level. It means that owners are less technically efficient than their renter counterparts in cotton production in the study area. The plausible reason for these findings would be that the owners of the land in the study area are Afar communities (native to the area) who are hitherto pastoralists and have little knowledge of farming activities.

Salinization is a major problem in semi-arid area where this study was carried out. In irrigated cotton production system, soil salinization occurs because of limited drainage combined with the application of saline or sodic water. The result indicated that salinity level of the soil was positive as expected and found to be statistically significant at 1% level. These findings revealed that farmers who have a farmland affected by salinity had high level of inefficiency. Thus, the malfunctioning of the existing drainage system and the poor quality of the irrigation water exacerbated soil salinization leading to production inefficiency. The other reason for salinization in the study area is associated with the type of irrigation application. In the study area, surface irrigation particularly furrow type of application is the most dominant practice for decades by producers.

Distance of the farmland to the main irrigation canal, which is directly related to access of the crop to water on time, had positive sign as expected. The coefficient for the distance from the source of irrigation to the farm was found to be 0.298, which was statistically significant at 5% level. A unit increase of this variable decrease efficiency of cotton farmers by 0.298 units. Thus, the farther the farmland from the main irrigation canal, the lower the probability of the crop to be irrigated on time, which results in shortage of water to the cotton crop. This, in turn, leads to production inefficiency of farmers. Technically, as the distance from source of irrigation to the farm increases, water losses increase due to water percolation and evaporation.

Technical efficiency level of irrigated cotton farmers

The frequency distributions of the technical efficiency scores of smallholders irrigated cotton farmers are presented in Table 6. The predicted technical efficiency level ranged from 40% and 99.99%; indicating that technical efficiencies considerably vary among the cotton farmers in the study area. The mean technical efficiency was estimated to be 71%, which implies that the average cotton farmers in the study area produces about 71% of the potential output given the current technology and levels of inputs. That is, cotton farmers in the study area produce at a level below 29% of the frontier output. The findings of the study indicated that irrigated cotton farmers are not making the right combination of available inputs and technologies to obtain maximum output. Thus, in the short run, there is much room for cotton farmers to increase their production by 29% through exploiting the available resources and without needing a new production frontier.

Table 6: Distribution of technical efficiency of irrigated cotton farmers

TE scores	Frequency	Percentage
$TE \leq 0.50$	8	10.81
$0.51 \leq TE \leq 0.60$	9	12.16
$0.61 \leq TE \leq 0.70$	18	24.32
$0.71 \leq TE \leq 0.80$	17	22.97
$0.81 \leq TE \leq 1.00$	22	29.73
Total number of observations	74	100
Mean		71.09
Minimum		40.09
Maximum		99.99
Standard Deviation		14.99

Source: Field survey data, 2018/19

These results are comparable with other technical efficiency studies on cotton sector. Using stochastic production frontier analysis, Veronique and Renata (2014) estimated the average technical efficiency score of 80% for West African cotton producers. Similarly, average technical efficiency of 85% and 66% were estimated for non-Bt cotton producers in North India and South Africa, respectively (Thirtle *et al*., 2003). There were no studies on cotton efficiency in Ethiopia to compare our estimates.

Conclusion and Recommendation

We estimated the technical efficiency levels of smallholder irrigated cotton farmers and identified the main determinants of inefficiency in the Middle Awash Valley of Ethiopia. Stochastic production frontier with technical inefficiency effect model was used for the analysis. The key results indicated that cotton area, labor cost and irrigation frequency have positive and statistically significant effect on cotton output. Quantity of seed and pesticide costs have negative and statistically significant effect on the cotton output.

We also investigated the factors affecting technical inefficiency of irrigated cotton farmers. Results showed that cotton farming experience, access to credit and sowing time were reducing production inefficiency. However, extension services to cotton, tenancy status, salinity level of the cotton farm and distance from the main irrigation water canal were increasing inefficiency. The mean technical efficiency level of the sample cotton farmers was estimated to be 71%. This indicates that there is a possibility of increasing cotton productivity in the valley, given the current state of technology and input levels. This can be achieved in the short run by increasing the technical efficiency level of the farmers by 29% through optimal combination of inputs and addressing production challenges in the cotton sector. Continuous government efforts are required to ensure an adequate and timely supply of critical inputs, adequate provision of credit facilities, extension services and research to generate quality technologies.

The current study mainly used cross-sectional data. It did not use farm-level panel data, as it was not available. Cross-sectional data fails to trace the dynamics of efficiency of farmers over time. Besides, the study focused only irrigated cotton whereas rainfed cotton production is growing in the country. Therefore, future research could undertake efficiency analysis using farm-level panel data both at irrigation and rainfed conditions to be able to track the dynamics of cotton farmers' efficiency over time.

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