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Abstract

Using sample data collected from 384 sample households in Eastern Amhara, North Shewa Zone, Ethiopia, and this study analyzes the technical, allocative and economic crop production efficiency of farmers as well as the key factors influencing it. A combination of descriptive and econometric methodologies were used to analyze the data. With the exception of oxen, all input variables (improved seed, cultivated land size, chemical fertilizer and labor days) had a positive and 1% significant effect on production, based on the maximum likelihood parameter estimates obtained from the stochastic frontier analysis. According to the analysis, crop-producing farmers' mean technical efficiency was 62.48%. This suggests that by operating at full technical efficiency, production in the study area can be raised by 35.2% at the current level of inputs and technology. Farmers in the research area had an average allocative efficiency of 86.47%, with ranging from 27.44% to 98.76%. This suggests that crop producer farmers can reduce their present input costs by 13.53% by using resources efficiently. The sample households' average economic efficiency was 54.11%, with the lowest and maximum efficiency ratings being 6.25% and 82.21%, respectively. The Tobit model's result indicated that technical efficiency was affected significantly by age of the head of the family, access to social networks, cultivated land area, irrigation involvement, agricultural experience, and alternative revenue sources. Additionally, the number of oxen, age of household head, access to social networks, agricultural experience, irrigation use, extension services, and other sources of income were significant variable impacting the economic efficiency of crop-producing farmers in the study area. The amount of the cultivated area and agricultural experience both have a major significant factors for allocative efficiency. According to the study's findings, smallholder farmers in Ethiopia's Eastern Amhara region may greatly increase the productivity of their crops by implementing new technology and better land management practices. This will improve their earnings and general standard of living, since farming is the community's primary source of livelihood. It is important that development organizations and governments back these initiatives aimed at raising the region's agricultural output.

*Keywords***: Crop, Production efficiency, stochastic frontier, tobit model, Amhara region and Ethiopia**

1. INTRODUCTION

The great majority of Ethiopians rely on agriculture as their main source of employment, income and subsistence, making it an integral part of the country's economy. A staggering 95% of agricultural production is produced by almost 12 million smallholder farming households, meaning that this industry is vital to the majority of Ethiopians [1]. Agriculture remains a crucial pillar of the Ethiopian economy, contributing significantly to various sectors, including employment, food security, foreign earnings, and industrial raw material supply. While its share of GDP has decreased from 41.1% to 33.3% between 2013/14 and 2017/18, in the nation's economy, agriculture continues to be the primary sector. It creates 81% of Ethiopia's foreign revenues, employs 80% of the population, meets 85% of Ethiopia's food demands, and supplies 70% of the country's raw materials. This highlights the interconnectedness of agriculture with other key economic activities and its vital role in Ethiopia's national development [2]. Small-scale farms account for over 90% of agricultural output in Ethiopia, despite covering only about 95% of the total farmland [3]. While agriculture remains vital to Ethiopia's economy, its contribution to GDP has been steadily decreasing. Furthermore, rising food demand and escalating food prices, key drivers of inflation, have emphasized the urgent need to enhance agricultural productivity. The Ethiopian government is actively implementing a range of measures to achieve this goal, including promoting the adoption of innovative and improved agricultural technologies. [4].

Despite its central role in the Ethiopian economy, agriculture has struggled to keep pace with the country's growing food demands. This shortfall is attributed to a combination of factors including high population growth, recurring droughts, natural disasters, pest outbreaks, irregular rainfall patterns, and a historical lack of technological advancement [5]. Growing Ethiopia's agricultural output, productivity, and efficiency remains a major developmental challenge in the country [2]. Ethiopia's 2.46% yearly population growth rate means that increasing food production is necessary to control pricing and intermittent food shortages [6]. Increasing agricultural productivity efficiency in all its forms is a critical policy priority for developing the sector and supplying data for resource allocation decisions that are well-informed.

Understanding the crop production efficiency levels of farmers, and the factors that affect their production, is crucial for developing effective agricultural strategies [7]. While global agricultural production efficiency is low overall, significant variations exist between regions and nations. Research suggests that factors influencing crop production efficiency vary widely, with their effects differing across locations. Developed regions often benefit from superior skills, knowledge, policies, institutional capacity, and technological advancements, enabling them to achieve higher levels of crop productivity. In contrast, developing nations frequently exhibit lower production efficiency performance, highlighting the need for targeted interventions to address specific challenges and support their agricultural development.[8].

In Ethiopia, agriculture has become more and more stagnant due to inadequate farm production and the growing population [9]. In the country, farmers work on plots of land measuring 1 hectare or smaller, and agricultural methods have seen minimal evolution over time. This has resulted in low productivity and has made farmers susceptible to the impacts of erratic climate patterns [10].Even if Ethiopia struggles to satisfy its needs for food production by boosting agricultural productivity through yield-enhancing agricultural technologies, still the country depends on food aids from Western nations [9]. Though a key objective in the process of implementation was not achieved, small-scale farming and agricultural intensification increased through the application of varieties and technology. This suggests that there are numerous implementation flaws in the policy as well as the difficulty with the policy itself. Moreover, political instability and misguided macroeconomic policies reduced the potential impact of rural development initiatives [11]. This study targets to assess the agricultural production efficiency of crop producing farmers in Ethiopia's eastern Amhara regional state (North Showa zone), who grow major crops such grains, legumes, and vegetables, based on the challenges and issues described above. The study takes into account a sizable sample size and focuses on how raising productivity and resource efficiency can improve the standard of living for numerous farm households in these important agricultural regions. The study intends to offer insights into possible areas for improvement in crop production and income generation for these farmers by an analysis of technical, allocative, and economic efficiencies.

The objective of this study was to analyze the crop production efficiency of farmers in North Shewa zone, eastern Amhara, Ethiopia.

Chapter 2:- Literature review

2.1. Concept of productivity and efficiency

"A volume measure of output divided by a volume measure of input use is a common definition of productivity" [12]. In its most basic form, productivity is the amount that a target group (a country, industry, sector, farm, or nearly any other target group) produces given a set of resources and inputs. Since this document has already explained production process efficiency, crop productivity is typically taken to represent it. But as [13]and others have pointed out, this is only valid if the farm (or enterprise) is efficient, which is arguably a strong supposition. It is helpful to remember that agricultural productivity is dependent on two factors in order to comprehend the relationship between these two ideas: the kind and caliber of inputs utilized in the production process, as well as the efficiency with which these inputs are combined. According to [14], the first component is the manufacturing technology, and the second is the production process' efficiency.

2.2. Types of efficiencies

The efficiency of a production function with a single input and output is what we actually defined above. Technical efficiency and allocative efficiency are two of the many components of efficiency. The efficiency term can be used in place of the technical efficiency term because it is more commonly employed in performance measurement studies [15].

Technical efficiency: - "If a producer needs to decrease one of the outputs or increase one of the inputs in order to increase its output, the situation is technical efficient," according to [16], is the formal definition of technical efficiency. It is also defined as follows: "The situation is technically efficient if a producer needs to increase one of the inputs or decrease one of the outputs in order to decrease its input." Technical efficiency can be studied using input-oriented or output-oriented methods, as the definition makes clear.

Allocative Efficiency: - Known also as price efficiency, allocate efficiency is a measure of how well an input set was chosen from the set of possible inputs, according to [17]. Using the definition provided by[18], formulate the allocative efficiency as follows:

Production plan: (Y^0, X^0) $\qquad \frac{fi(X0)}{fj(X0)} = \frac{Wi}{Wj}$ --(1)

Wj : input price of Xj,   fj : marginal product of Xj input

Economic efficiency: - It is the product of technical efficiency (TE) and allocative efficiency (AE) [17].

2.3. Measurement of efficiencies

Modern efficiency measurements date back to the research done by [17]. He divided efficiency metrics into two categories: allocative (price) efficiency and technological efficiency. Allocative efficiency measures a company's capacity to use resources in the best possible proportions given their different pricing, whereas technical efficiency measures a company's ability to produce the most from a given set of inputs. Economic or overall efficiency is obtained as the product of the two measures [19]. Moreover, purely technical (PTE) and scale efficiency (SE) are the two categories into which measures of technical efficiency are divided. The firm's optimal size is measured by SE [18]. A company that exhibits growing returns to scale (IRS) is too tiny in relation to its operational scale. A company with dimensioning returns to scale (DRS), on the other hand, is too big for the amount of business it engages in. Efficiency measurements can be roughly divided into input-oriented and output-oriented categories based on the research of Farrell [17]. This study employed an output-oriented methodology to evaluate the production efficiency scores of farms at the household level.

A firm's capacity to maximize output or production given the current level of input employment is implied by an output-oriented measure. It speaks to a company's capacity to grow output quantities proportionately while maintaining input employment levels ([20]. Tones (kilograms) is a physical unit of measurement that may not be the ideal option since the land can be used for a variety of crops. It is frequently necessary to assign a monetary value to each crop's yield in order to combine the output of many crops [14].

2.4. Conceptual framework of production efficiency

According to certain reports, developing countries' agricultural productivity increases dramatically when productivity-enhancing technology are implemented [21]. Agricultural transformation through the creation and application of

agricultural production technology is crucial to raising agricultural output in underdeveloped countries [22]. To solve the issue of little to no technology utilization, it is vital to identify the factors that impact producers' decisions to accept or reject new technologies that boost agricultural productivity. According to [23], these components are commonly separated into two groups: internal variables and external influences. A few examples of internal determinants are age, gender, family size, and level of education. Examples of external factors include the environment, cost of inputs and products, cultivation space, loan availability, and information availability.

Production efficiency can be defined as either the economical use of resources (allocative efficiency) or as achieving the maximum level of output with a particular set of inputs (technical efficiency). Economic efficiency is therefore created by combining allocative and technical efficiencies. Technical efficiency necessitates a farmer to be on the maximum productivity frontier, but allocative efficiency describes a balance or equality between the marginal value of input and product prices. Improved inputs (seeds, fertilizers, fungicides and herbicides, soil fertility management practices), internal factors (age, gender, and family size), external characteristics (cultivated area, input and output prices, climatic factors, membership in a farmer association, as well as access to credit, information, and infrastructure like roads and storage facilities), and other factor inputs, including land and labor, are the factors that influence economic efficiency (E), according to [24]. The relationships between the explanatory and dependent variables are depicted in this figure by the arrow directions. Figure 1 displays the relationships discussed above.
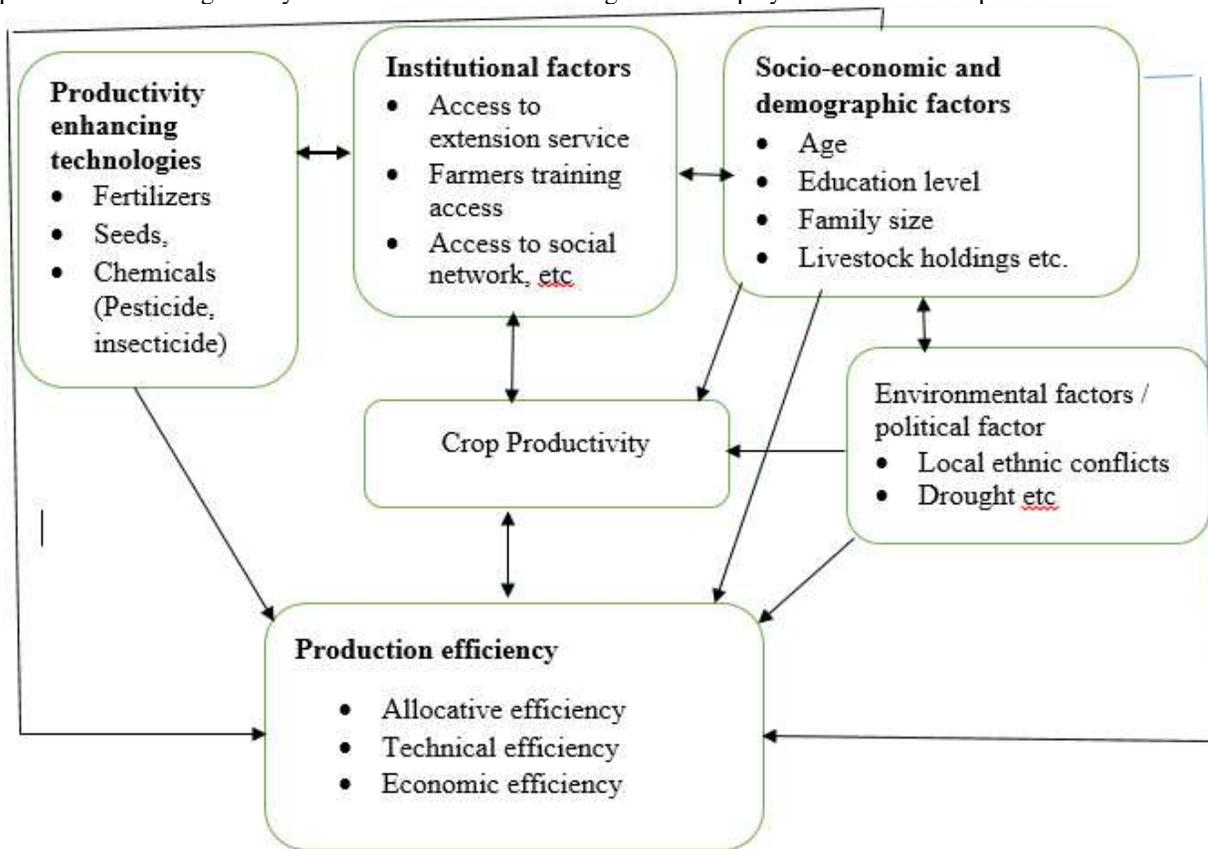

Figure 1 Conceptual framework (Authors design based on literature)

3. Research Methodology

3.1. Description of the study area

The study was conducted in the Amhara regional state in the North Shewa zone of Ethiopia. With 1,837,490 residents, the zone is 15,936.13 square kilometers in size. The study focused on three districts: Kewot, Tarmaber and Efrata and Gidim, where small-scale farming serves as the primary source of income for the local population. The zone has a mixed farming system, with the production of livestock and crops acting as the main sources of income. The primary crops farmed in the area include barley, teff, mung beans, sorghum, wheat, and onions. The research region has mixed agro-ecological zones, such as kolla, wina dega, and dega. The study districts are displayed in figure 2.
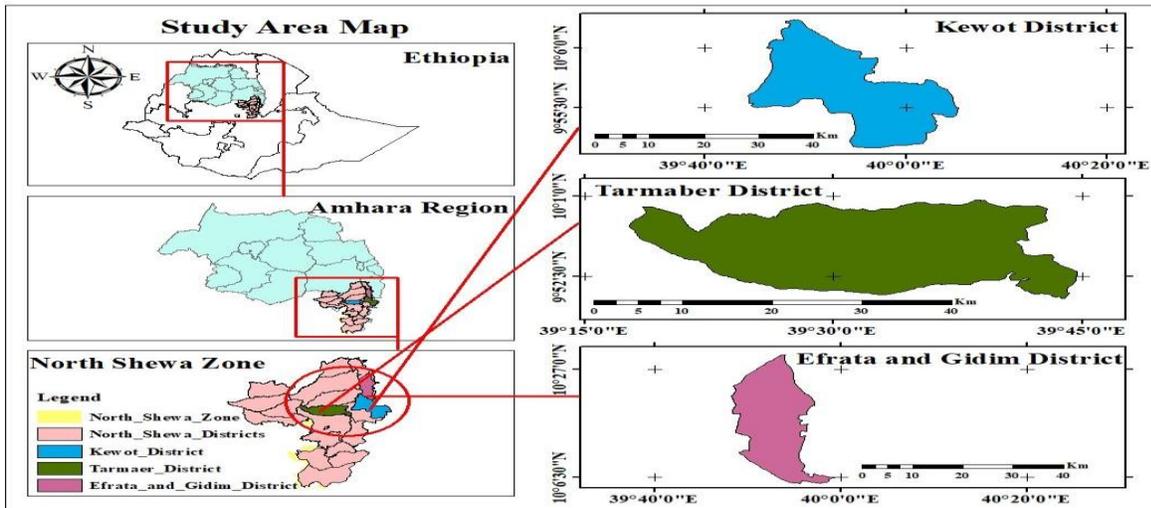
3

Figure 2 Map of the study area

3.2. Methods of data collection

Both primary and secondary data were employed in this study to accomplish its goals. Making the right methodological choices is essential to guaranteeing the caliber of scientific research. A semi structured interview, targeted group discussions, key informant interviews, and observation/transect walks were employed to gather primary data. Secondary sources from published and unpublished records of governmental agencies were reviewed in order to gather secondary data on the socioeconomic information of the districts.

3.3. Sample size and sampling procedures

A multiple-phase sampling technique was utilized to guarantee the identification of typical households. Because there are a lot of small-scale farmers in the research area, the North Shewa zone was initially specifically picked from the Amhara regional states. Three districts from the North Shewa zone were chosen for the second phase based on their rankings ascertained after consulting with the specialists from the zonal agricultural office. In the third step, nine kebeles were chosen at random from the designated districts. The agroecology of the selected districts addresses the heterogeneity of agricultural output through the use of kolla, wina dega, and dega. Once the kebeles were chosen, a straightforward random sampling procedure was applied to reduce heterogeneities and sampling mistakes [25]. A contingency sample of 20 families was included in the 384 households that made up the study's sample size. The following criteria were used to calculate the sample size [26]. The sample size is calculated using the following formula:

… ……………………………………………….(2)

$$n_0 = \frac{Z^2 pq}{e^2}$$

Where e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population, q is 1-p, Z is the normal curve that cuts off an area α at the tails $(1 - α,$ equals the desired confidence level, e.g., 95%), and no is the sample size. The area under the normal curve (AUC) in statistical tables contains the value for Z.

$$n = \frac{1.96^2(0.5)(0.5)}{0.05^2} = 384$$

3.4. Analytical model and theoretical aspects of production efficiency

In general, there are two primary approaches utilized to examine manufacturing efficiency. They are the parametric approach that makes use of the stochastic production frontier, which was independently established by [27], and the non-parametric strategy that computes production efficiency scores using data envelope analysis (DEA). The stochastic production frontier is used in this study because it accounts for firm-specific inefficiency and allows for stochastic mistakes caused by statistical noise or measurement errors [28]. The Cobb-Douglas functional form is used to specify the stochastic production frontier, despite its well-known drawbacks. As long as the focus is on measuring

efficiency rather than the analysis of the production technology's overall structure, this study offers a sufficient depiction of the technology. Consequently, the stochastic frontier approach may be used to express the Cobb-Douglas stochastic production function model as follows:

$$\ln(q_i) = X'_i\beta + v_i - u_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

In this case, yi is the total output generated by the ith household, which will be converted to logarithm (ln), and ui and vj are the (1xk) vectors of inputs utilized to produce the ith output and unknown parameters to be estimated, respectively. On the other hand, vi is a non-negative error term for the inefficiency effect in the production process, and vi measures random error for statistical noise.

Figure 3 illustrates the widely used diagrammatic form of the stochastic production frontier by [29]. With inputs and outputs measured along the horizontal and vertical axes, respectively, the graph assumes two enterprises, X and J. Because Vi > 0, the deterministic production function y=f(X, c) is observed above the firm X that uses Xi input. Conversely, because Vi < 0, the company J that uses the Xj input is seen to be below the deterministic production function. Stated simply, the variation is caused by the differing noise effects both positive and negative for the X and J firms. The observed values in both scenarios are less than the frontier production value, as shown in the diagram. Concurrently, a deterministic production function diagram has been designed to show that there are decreasing returns to scale in the production function.
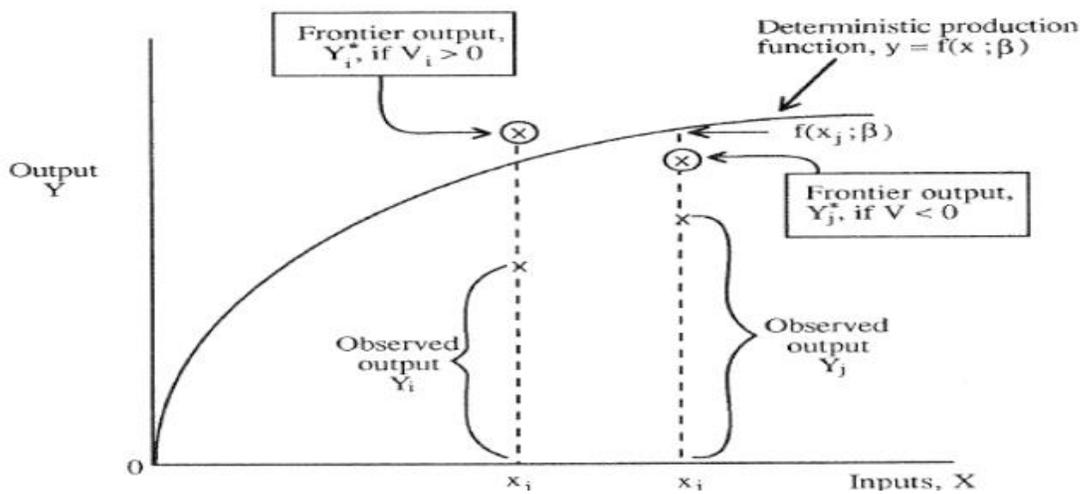

Figure 3.

Stochastic Production Frontier (Source:[29])

The application of frontier functions has been intimately linked to efficiency measurement. Considering the landmark study of [17] depicted that there are three components to the efficiency concepts: There are three different kinds of efficiency: technical (TE), allocative (AE), and overall (EE). The stochastic frontier technique inadvertently predicted the firm/farm household inefficiencies that are typically measured using output-oriented metrics. According to[19], it is the output divided by the matching stochastic frontier output.

Technical efficiency: - The value between zero and one, which denotes the lower and greater efficiency level, is used by the technical efficiency measurement (TEi). Measuring a firm's or family's efficiency in relation to the outputs that a fully-efficient firm or household could produce with the same inputs is helpful [30].

$$TE_i = \frac{q_i}{\exp(X'_i\beta + v_i)} = \frac{\exp(X'_i\beta + v_i - u_i)}{\exp(X'_i\beta + v_i)} = \exp(-u_i) \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Economic Efficiency: - The farm-specific economic efficiency is calculated as the ratio of the least observed total production cost (C*) to the actual total production cost (C) from the previously indicated dual cost:

$$EE_i = \frac{C_*}{C} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

Allocative efficiency:- The ratio of economic efficiency to technical efficiency can be used to derive the allocative efficiency index, per [17]:

5

$AE = \dfrac{EE}{TE}$ ……………………………………………………………………………(7)

The technical, allocative, and economic efficiency level derived from the stochastic production frontier was regressed on farm-specific independent variables using a censored Tobit model, exposing variations in farm efficiency. We used the Tobit model since the efficiency score is confined between 1 and 0. The Tobit regression is defined as follows:

$E^* = \delta_0 + \delta_m Z_{im} + \mu$

$v/z \approx$ normal $(0, \delta^2)$ …………………………………………………………… ………….(8)

where the technical, allocative, and economic efficiency scores of agricultural outputs in the study region obtained through the use of dual cost and stochastic production frontier methods are represented by the E * latent variable. The vector of unknown parameters to be estimated is denoted by δ. For farmers, Zim is a vector of explanatory variables m (m=1, 2,... n). μ is an error term with zero mean and variance, distributed independently and normally. Using Ei to represent observed variables,

$$\begin{Bmatrix} 1 & if & E_i^* > = 1 \\ 0 & if & E_i^* < = 0 \end{Bmatrix}$$ …………………………………………………………. (9)

Following McDonald (1980) and the likelihood function, the two-limit Tobit model for marginal effects is decomposed as follows: The dependent variable's unconditional expected value

$$\frac{\partial E(y)}{\partial X_j} = [\varphi(z_u) - \varphi(z_L)] . \frac{\partial E(y^*)}{\partial X_j} + \frac{\partial[\varphi(z_u) - \varphi(z_L)]}{\partial X_j} + \frac{\partial[1 - \varphi(z_u)]}{\partial X_j}$$ ………………….. (10)

The expected value of the dependent variable is conditional upon being between the limits

$$\frac{\partial E(y^*)}{\partial X_j} = \beta m . \left[1 + \frac{\{z_L \varphi(z_L) - z_u \varphi(z_u)\}}{\{\varphi(z_u) - \varphi(z_L)\}} \right] - \left[1 + \frac{\{\varphi(z_L) - \varphi(z_u)\}^2}{\{\varphi(z_u) - \varphi(z_L)\}^2} \right]$$ ………………….. (11)

The probability of being between the limits

$$\frac{\partial[\varphi(z_L) - \varphi(z_u)]}{\partial X_j} = \frac{\beta m}{\sigma} = [\phi(z_L) - \phi(z_u)]$$ ……………………………………………. (12)

where, φ(.) = the cumulative normal distribution,
Ø(.) = the normal density
$Z_L = Z_{(L)}$ and Zu = are standardized variables that came from the likelihood function given the limits of y* and σ = standard deviation of the model.

The production functions that are most frequently used in stochastic frontiers research are the translog (TL) or Cobb-Douglas (CD) versions. The Alkaike Information Criteria and the log-likelihood ratio test are the primary factors that determine which option is better. Consequently, the following specifications apply to the CD and TL functional forms, respectively:

$$ln(y_i) = \beta_0 + \beta_i \sum_{n=1}^{n} ln(x_i) + v_i - u_i$$ ………………………………………………. (13)

$$ln(y_i) = \beta_0 + \sum_{k=1}^{n} \beta_k ln(x_{ik}) + \frac{1}{2} \sum_{k}^{n} \sum_{j}^{n} \beta_{ij} ln(x_{ik}) * ln(x_j) + v_i - u_i$$ ………………… (14)

Where,
The natural logarithm of the monetary worth of the entire yearly crop output is - $ln(yi) =$; studies have suggested the monetary value of crop production because it helps to aggregate all crops produced by the farmer; this was proposed by[31];

The variables $\beta i's$ represent the coefficients of parameters that need to be estimated, vi represents the idiosyncratic measurement error, ui is a non-negative random variable used to gauge the household's technical efficiency, and $xi's$

represents significant elements or inputs of production. In efficiency analysis, choosing the right distribution for the non-negative error term ui is crucial. Although gamma, exponential, truncated, half-normal, and other distributions are commonly used, there is no clear-cut rule for selecting one over the other before estimate.

3.5. Variables Choice, Definition and Measurement

While there are no universal rules for variable selection in efficiency models, economic theory and prior empirical research provide valuable guidance. These resources help identify explanatory variables that are likely to influence the dependent variable, in this case, production efficiency and crop production [32]. As a result, based on empirical research on the factors influencing production efficiency carried out in Ethiopia and other countries, several socioeconomic, demographic, institutional, and geographic aspects are discovered and presented as follows.

The age of the family head, education, land size, land fragmentation, extension service, and off-farm income were found to be important variables in an Ethiopian study on maize output [31]. Every element that affected production efficiency was positive, with the exception of land area. This is primarily because agricultural production is context-specific, meaning that the socioeconomic, managerial, and environmental features of the study site may change the productivity of the production. The majority of sample research have shown that the more general categories of demographic, socioeconomic, institutional, and other managerial and environmental variables may have a positive or negative impact on the productivity of the farm household, as shown in Table 1 below.

Table 1 Definition of hypothesized explanatory variables in determinants of production efficiency

Variable	Type	Definition	Measurement	Expected sign
		Dependent		
Efficiency	Dummy	Efficiency		1 if efficient, otherwise 0
		Explanatory variable		
Acdt	Dummy	Access to credit	1 yes ,0 otherwise	+
AgEx	Continuous	Agricultural experience	Years	+
TLU	Continuous	Tropical Livestock unit	Numbers excluding oxen	-
Priri	Dummy	Participation in irrigation	1 yes ,0 otherwise	+
CLS	Continuous	Cultivated land size	Hectares	-
Exs	Continuous	Extension service	Number of days per year	+
Ox	Continuous	Number of oxen	Number	+
AgHH	Continuous	Age of household head	Years	+
Frtr	Dummy	Farmers training access	1 yes, 0 otherwise	+
Acsn	Dummy	Access to social network	1 yes, 0 otherwise	+
Altincm	Dummy	Alternative income source	1 yes, o otherwise	-
Lec	Dummy	Local ethnic conflicts	1 yes, 0 otherwise	-

Source: own definition, 2023

4. CHAPTER FOUR: - RESULT AND DISCUSIION

Crop output efficiency and production have both been covered in this section. First, the variables' descriptive findings are grouped under continuous and dummy variables based on descriptive analysis.

4.1. Descriptive results of respondents

4.1.1. Descriptive result of sample households for dummy variables

Table 2 revealed that the descriptive result of the independent variables that are used in the analysis of production efficiency in the study area. Based on the result, access to credit, participation in irrigation, and alternative income sources are relatively common which more than 50% of farmers reporting access to each. However, access to farmers' training and local ethnic conflicts present areas of concern. Only 53.13% of farmers reported access to training, indicating a potential knowledge gap that could be addressed through targeted interventions. The presence of local ethnic conflicts in 60.16% of cases shows the need for conflict mitigation strategies. Remarkably, access to social networks is predominant, with 72.92% of farmers reporting as they had access to social networks. This offers a valuable platform for disseminating information.

Table 2 Descriptive results of the sample households" characteristics for dummy variables

Variables	Yes (%)	No (%)	Total
Access to credit	210 (54.69)	174 (45.31)	384
Participation in irrigation	201 (52.34)	183 (47.66)	384
Farmers training	204 (53.13)	180 (67.66)	384
Access to social network	280 (72.92)	104 (27.08)	384
Alternative income source	210 (54.69)	174 (45.31)	384
Local ethnic conflicts	231 (60.16)	153 (39.84)	384

Source: Own survey result, 2024.

4.1.2. Descriptive result of continuous explanatory variables for sample households

The descriptive analysis result of key demographic and resource characteristics of smallholder farmers in Eastern Amhara, Ethiopia for the data collected from 384 sample households depicted in table 3. Based on the result, the average agricultural experience of farmers in the study area is 27.28 years, the average Tropical Livestock Unit (TLU) count, excluding oxen, stands at 3.56, the average cultivated land size was 0.97 hectares, farmers access to extension service was 70.1 per year on average, oxen ownership is common, with an average of 2.6 oxen per household and the average age of household heads is 44.69 years.

Table 3 Descriptive statistics of the sample households' characteristics for continuous variables

Variable	Observation	Mean	Std. Dev.	Min	Max
Agricultural experience	384	27.279	12.353	1.5	65
Tropical livestock unit (excluded ox)	384	3.563	1.339	0.7	8.3
Cultivated land size	384	0.973	1.244	0.25	10
Extension service	384	7.013	3.854	0	20
Number of oxen	384	2.596	1.433	1	8
Age of household head	384	44.693	12.216	21	80

Source: Own survey result, 2024

4.1.3. Descriptive results for crop outputs and inputs

Different factors that determine the productivity and efficiency of smallholder farmers. Hence, to understand these factors, it is important to know the descriptive statistics of the yield obtained from individual crops and inputs used during the production year 2022–23 as depicted in table 4. Generally, the strength of productivity and efficiency depends greatly on the allocation of production inputs such as land, quantity and quality of seed, the quantity of chemical fertilizer, amount of labor (in labor days), and amount of oxen power (oxen-day).

Quantity of outputs and inputs: The mean values of the patterns of outputs per hectare per birr were 170949.6. This implies that, on average, the sample farmers in the study area were generating this much income per hectare from all crops they cultivated during the agricultural season, as it was converted by using their market price in that production year.

Costs of production inputs: Production input costs were calculated based on the quantity and quality of inputs used, reflecting the costs of individual crops during the 2022-23 farming season. Land costs were determined using its rental value, obtained from individual farm households. The market prices during the production period were used for other input costs. Table 4 reveals a significant variation in land costs for different crops, largely driven by the differing size

and quality of land allocated by individual farm households. Overall, the data provides insights into the average values associated with key agricultural inputs and resources used by farmers.

Cost of improved seed used: refers to seeds of crop varieties that have been developed through plant breeding techniques to possess desirable traits and characteristics. The average value of improved seed was 1718 birr, indicating a significant investment in high-quality seed varieties that could potentially enhance crop yield and productivity. This value includes the seed of red bombe, which is highly produced in the study area.

Cost of land used: Land is a fundamental resource for crop production, and its suitability for agriculture depends on various physical, chemical, and biological characteristics. The average value of land was 10022.88 birr, highlighting the substantial value attributed to agricultural land as a critical resource for crop production.

Cost of Chemical Fertilizer Used: The value of chemical fertilizer used was birr 2171, suggesting that farmers recognize the importance of chemical fertilizers in increasing soil fertility and crop productivity. In the research area, urea and diammonium phosphate (DAP) are the two most used inorganic fertilizers. Nearly every member of the sample population employed chemical fertilizer for agricultural production, according to agricultural professionals in the research area. This does not imply, however, that they applied enough fertilizer. With a few exceptions arising from transportation and associated expenses, the expenses of chemical fertilizers are nearly identical.

Cost of labor used: According to the responses from the sample farm households, hired labor, non-cash exchange labor, and household labor were the main sources of labor inputs. Most of the time, it is challenging to put a price on domestic labor and non-cash exchange labor. Every attempt was made to adequately account for these labor costs. Ultimately, the cost of domestic work and non-cash exchange labor was determined using an average laborer's daily compensation. The average labor input expenditure for the sample households throughout the study agricultural season was birr 10355. The farmer paid birr 350 every labor day on average.

Cost of oxen power used: Oxen remains a valuable asset for farmers in many parts of the world, particularly in small-scale and subsistence agriculture. Their strength, adaptability, and cultural significance continue to make them an important part of agricultural systems in various regions. The average value of oxen power used was birr 10022, indicating that oxen remain a valuable asset for farmers, primarily for land preparation and other farm operations.

These values reflect the relative importance and cost of agricultural inputs and resources in the context in which the data was gathered. Farmers allocate their resources strategically, considering the value and potential benefits of each input, to maximize agricultural productivity and income. Agricultural production cannot necessarily be increased by expanding the farmland holding and accessing farmland for smallholder farmers, but the most important thing is the condition of the fertile farmland.

Table 4 Descriptive statistics of production input costs for individual crops (per birr)

Variables (n=384)	Average cost of input (mean)	Standard deviation
Cost of improved seed used	1718	818
Cost of land used	10022.88	7020
Cost of fertilizer used	2171	2437
Cost of labor used	10355	5008.8
Cost of oxen power used	10022	7031

Source: Own survey result, 2024

4.2. Estimation Maximum Likelihood Estimate

As table 5 displays that the stochastic frontier production function analysis identified four key input variables that significantly influenced crop productivity: improved seed, land, chemical fertilizer, and labor. A 1% increase in each of these inputs led to corresponding increases in crop production: 0.074%, 0.184%, 0.276%, and 0.295%, respectively, with other factors held constant. Decreasing returns to scale were found by the estimated scale coefficient of 0.84, indicating that output growth slows down as input levels rise. This indicates that an increase of one unit in all inputs results in an increase of just 0.84 units in output. In other words, output increases by 0.84 units when all inputs increase by one unit. The inefficiency component's diagnostic statistics show that, at 1%, sigma squared ($\delta 2$) = 0.6041 was statistically significant. This shows that the distributional shape predicted for the composite error component is true

and that the fit is good. Lambda (λ) is the ratio of the standard error of u (δu) to the standard error of v (δv). Depending on the value of lambda, the gamma value is derived using the formula ($\gamma = \frac{\lambda^2}{1+\lambda^2}$) 77.78%. It also demonstrates that inefficiency variables account for roughly 77.78% of the differences in farmers' production. The farmers had no control over random noise, which accounted for 22.22% of the fluctuation.

In order to estimate the production function, this work makes use of both OLS and MLE. Essentially, testing the study's hypotheses is crucial before delving into the econometric model results. Once inefficiency has been established, it is necessary to determine whether one or more variables could account for variations in production inefficiency. The LL ratio test can be computed as the LL ratio = -2(LLH$_0$ – LLH$_1$), where LLH$_0$ is the LL value of the restricted Cobb-Douglas SFP model (a model without explanatory variables of the inefficiency effect model) and LLH$_1$ is the LL value of the unrestricted model (a model with all explanatory variables of the inefficiency effect model), which is 75.78 and the critical value of chi2 is 21.062. On the other hand, since all calculated the LL ratio values are greater than the critical value of LL ratio, with an upper 5% level of significance, the null hypotheses that determinant variables in the inefficiency effect model are simultaneously equal to zero are rejected. In other words, there exists at least one explanatory variable that explains the variation in the technical inefficiency among plots.

Table 5 Results of Cobb–Douglas stochastic frontier production function.

Ln output	Coef.	Std. Err.	z	P>z
Ln improve seed	0.075***	0.0137	5.37	0.000
Ln oxen	0.021	0.064	0.33	0.738
Ln cultivated lad size (land)	0.169***	0.049	3.46	0.001
Ln chemical fertilizer	0.272***	0.066	4.14	0.000
Ln labor days	0.3007***	0.096	3.12	0.002
Constant	5.709***	0.661	8.63	0.000
sigma2	0.604	0.098		
Lambda	1.87	0.145		

Note: *** represents to 1% significance level.
Source**:** Stochastic frontier model result (2024).

4.3. Crop production Efficiency Scores

Farmers in the study area were comparatively good at allocative efficiency as opposed to technical and economic efficiency of crop production, based on the frontier model's results. With a mean technical efficiency level of 62.48% and a range of 9.63% to 91.46%, crop-producing farmers can effectively use resources and use current technology to boost crop yield by 35.52%. Farmers in the research area had an average allocative efficiency of 86.47%, with ranges spanning from 27.44% to 98.76%. This suggests that crop producer farmers can reduce their present input costs by 13.53% by using resources efficiently. As indicated in Table 6, the sample households' average economic efficiency level was 54.11%, with minimum and maximum efficiency scores of 6.25% and 82.21%, respectively. This implies that in order to reach the lowest feasible cost level without compromising output levels, a producer with an average degree of economic efficiency may lower the present average cost of production by 45.89%.

Table 6 Crop production efficiency scores.

Types of efficiency	Obs	Mean	Std. Dev.	Min	Max
Technical efficiency	384	0.6248	0.1593	0.0963	0.9146
Allocative efficiency	384	0.8647	0.0886	0.2744	0.9876
Economic efficiency	384	0.5411	0.1508	0.0625	0.8221

Source:- Own survey result of 2024

4.3.1. Factors that Determine Crop Production's Technical, Allocative, and Economic Efficiency and Their Marginal Effects

In order to create successful interventions to address the issues faced by farmers who raise crops, policymakers must have a thorough understanding of the elements that contribute to TE, AE, and EE. Consequently, the degree of inefficiency is thought to be influenced by institutional, farm-specific, socioeconomic, and demographic factors.

As a result, a multicollinearity test was carried out before the inefficiency model's parameters were estimated using the Tobit model. The variance inflation factor (VIF) was 2.87 at its highest and 2.24 at its mean. These numbers show that the dataset's multicollinearity is not a cause for concern. The presence of heteroscedasticity is implied by the Breusch-Pagan test for heteroscedasticity, which revealed that the null hypothesis of constant variance variables is rejected. The bias in standard errors is due to heteroscedasticity. Therefore, in the presence of heteroscedasticity, robust standard errors tend to be more reliable. The robust option deals with the problem of errors that are not independent and uniformly distributed. The coefficient estimates produced by ordinary least squares (OLS) remain same when robust standard errors are used, but the standard errors and significance tests may be affected. Robust regression, on the other hand, deals with the issue of outliers and reduces their impact on the regression coefficient estimates. Robust Tobit regression was employed in the analysis to address these problems.

Table 7 factors that determine technical, allocative and economic efficiency and their marginal effects.

Variables	TE		AE		EE	
	Marginal effect	*Z-value*	Marginal effect	*Z-value*	Marginal effect	*Z-value*
Access to credit	0.0085	0.54 (0.0158)	-0.0008	0.09 (0.0088)	0.0053	0.35 (0.0149)
Agriculture experience	0.0016***	2.97 (0.0006)	0.0010***	3.68 (0.0003)	0.0019***	3.78 (0.0005)
Tropical livestock unit	-0.0003	-1.02 (0.0003)	0.00005	0.50 (0.00009)	-0.0002	-0.71 (0.0003)
Participation in irrigation	0.0379**	2.45 (0.0155)	-0.0021	-0.24 (0.0088)	0.0283*	1.91 (0.0148)
Cultivated land size	0.0149**	2.45 (0.0061)	-0.0123***	-3.14 (0.0039)	0.0051	0.89 (0.0057)
Extension service	0.0039*	1.98 (0.0020)	0.0002	0.14 (0.0011)	0.0035*	1.88 (0.0019)
Number of oxen	-0.0069	-1.32 (0.0052)	-0.0039	-1.40 (0.0028)	-0.0092*	-1.87 (0.0049)
Age of household head	0.0012*	1.83 (0.006)	0.0002	1.04 (0.0003)	0.0013**	2.20 (0.0006)
Farmers training	0.0083	0.55 (0.0151)	-0.0103	-1.14 (0.0091)	0.0017	0.11 (0.0147)
Access to social network	0.0811***	4.32 (0.0188)	-0.0025	-0.23 (0.010)	0.0672***	3.80 (0.0177)
Alternative income source	-0.0373**	-2.48 (0.0151)	-0.0084	-1.02 (0.0082)	-0.0356**	-2.49 (0.0144)
Local ethnic conflict	-0.0052	-0.34 0.0155)	0.0043	0.46 (0.0092)	-0.0009	-0.06 (0.0148)

Note: *, **, and *** significant at 10%, 5%, and 1% level significance, respectively
Source: Own survey result, 2024

Finding the causes of inefficiency disparity among households was the most crucial phase in this study, which came after assessing the efficiency levels of farmers and establishing whether efficiency discrepancies existed among them. According to the Tobit model's results, cultivated land area, irrigation experience, age of the head of the household, extension service, social network accessibility, and alternative sources of income all had a substantial impact on TE. Furthermore, a number of significant parameters impacting the EE of crop-producing families in the study area included agricultural experience, irrigation involvement, the number of oxen provided by the extension service, the age of the household head, access to social networks, and alternative sources of income. AE was also significantly influenced by agricultural experience and cultivated land size (Table 7). The effects of the above significant variables are either negative or positive at different significant levels, as discussed as follows:

Agricultural experience: This independent variable positively and significantly affects technical efficiency, allocative efficiency, and economic efficiency at the 1% significant level. This means agricultural experience allows farmers to accumulate knowledge, skills, and judgment that enable them to produce crops more efficiently. They can make better decisions, use resources more effectively, and adapt to changing conditions, leading to increased crop production efficiency. This is because agricultural experience is considered agricultural education, which increases agricultural productivity[33].

Participation in irrigation: Irrigation enables farmers to control and optimize water availability for their crops. This leads to improved crop growth, higher yields, reduced risks, and more efficient use of other inputs, all of which contribute to increased crop production efficiency. It's a dummy variable that increases technical and economic effectiveness. Thus, farmers who employ irrigation are more productive both financially and technically than those who do not. This variable affects technical efficiency at a significant level of 5% and economic efficiency at a significant level of 10%. This means those who employ irrigation technology achieve greater efficiency returns than those who don't employ or use irrigation [34].

Cultivated land size: This variable, which is a measured in hectares, had a favorable impact on technical efficiency at the 5% significant level and a negative impact on allocative efficiency at the 10% significant level. That means larger farms may have economies of scale, meaning that they can produce more output with the same inputs as smaller farms. This can lead to higher technical efficiency. On the other hand, larger farms may have more difficulty allocating their resources efficiently due to factors such as managerial challenges and information asymmetries. This can lead to lower allocative efficiency.

Extension service: extension service is measured in the number of days that the farmers are visited and assisted by extension agents per year. This variable was found to be a significant factor for technical and economic efficiency at a 10% significance level. Extension services can help farmers improve their technical efficiency by providing them with information and training on improved agricultural practices, new technologies, and sustainable farming methods. At the same time, extension services can help farmers improve their economic efficiency by providing them with information on market prices, input costs, and efficient resource allocation strategies [35].

Age of household head: it is a continuous variable measured in years. This variable has a positive effect on technical and economic efficiency. Technical efficiency was significantly impacted by it at 10% significant level, while economic efficiency was significantly affected by it by 5% significant level. It's possible that older family heads are more knowledgeable and experienced in agricultural operations, which would increase their technical efficiency. With age, farmers may accumulate knowledge and skills through experience and observation, leading to improved decision-making and resource allocation. Older household heads may have a better understanding of market dynamics and risk management strategies, leading to higher economic efficiency. With age, farmers may develop networks and relationships that provide access to better inputs, information, and market opportunities.

Access to social networks: access to social networks refers to the extent to which farmers are connected to other farmers, agricultural organizations, and sources of information. Due to this, the variable affects technical and economic efficiency positively and significantly at 10% probability level. This means this variable can increase production efficiency by improving access to resources, information, and access to improved technologies, information, extension services, markets, and financial services [36].

Alternative income sources: The term "alternative income sources" describes the sources of income that farmers do besides growing crops. At a 1% probability level, this variable in this study has a negative and statistically significant impact on technical and economic efficiency. Farmers who rely on alternative income sources may have less time to devote to crop production, leading to reduced technical efficiency, and it can lead to farmers missing out on potential income from crop production, reducing their overall economic efficiency [23].

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Using cross-sectional data from nine kebeles chosen from three districts in the Amhara regional state's north Shewa zone, 384 sample households that produced crops used to collect the primary data for this study. Stochastic frontier

production functions were used in the study to examine the factors that influence crop productivity efficiency in Ethiopia's eastern Amhara region. The results show that increased agricultural output is significantly and favorably impacted by better labor, chemical fertilizer, land, and seeds. According to the analysis of the inefficiency component, production inefficiency explains a significant amount (77.78%) of the variation in crop yield, with random noise accounting for the remaining 22.22%. It was established using the likelihood ratio test that there are factors accounting for the variation in agricultural production inefficiency. According to the study, allocative efficiency (86.47%) was higher among farmers in the study area than technical (62.48%) and economic (54.11%) efficiency. This suggests that by improving their technical and economic efficiency, farmers may decrease production costs by 45.89% and increase crop output by 37.52%. The Tobit model's results revealed that some of the factors had a significant impact on TE such as age of the head of the family, access to social networks, cultivated land size, agricultural experience, irrigation participation, and other income sources. Additionally, the number of oxen in the extension service, agricultural experience, access to social networks, alternative sources of income, and age of the household head were significant factors impacting the EE of crop-producing families in the research area. AE was also significantly influenced by agricultural experience and cultivated land size.

Based on these results, it is generally possible to draw the conclusion that a variety of factors influence how efficiently farmers in the research area produce crops. The study offers insightful information on the connections between these variables and the various crop production efficiency categories.

5.2. Recommendation

The researcher would like to offer the following suggestions and policy implications in light of the findings:

- Irrigation provides farmers with a greater degree of control over the growing environment, enabling them to optimize crop growth and maximize yields. In addition, most of the research areas are characterized by a shortage of rainfall. So improving participation in irrigation use can lead to increased crop output. Support farmers in developing and accessing irrigation systems to mitigate the effects of drought and increase crop yields thereby their production efficiency.
- By expanding access to extension services, farmers can gain the knowledge, skills, and resources they need to improve their productivity, increase their incomes, and contribute to agricultural development and food security. So in order to improve production efficiency extension contacts of the formers must increase.
- Access to social networks had a positive and significant effect on crop production efficiencies at different magnitudes. These social networks are improving access to information about the source of inputs, farming practices, and marketing opportunities. So the government should increase partnerships with radio, television, and print media to broadcast agricultural programs and provide farmers with access to expert advice on how to improve their crop productivity.
- By addressing these factors, policymakers and stakeholders can help farmers improve their technical, allocative, and economic efficiency, leading to increased crop productivity and improved livelihoods in Eastern Amhara, Ethiopia.

Data availability:- The datasets analyzed during the current study are not publicly available because the authors intend to use them for other studies, and making them publicly available could jeopardize our ability to conduct other studies, but the data are available from the corresponding author (Tegegn Nigussie Degfachew) on reasonable request..

Declarations

Ethics approval and consent to participate: The study adhered to the ethical guidelines established by Arba Minch University and Woldia University, Ethiopia, which indicated that formal ethical approval was not required for this research. Importantly, all participants were adults who voluntarily chose to participate, ensuring that their involvement was both informed and consensual. The informed consent was obtained from all individual participants included in the study.

Competing interests

The authors involved in writing this article declare that they have no competing interests.

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