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COLLEGE OF BUSINESS AND ECONOMICS

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TECHNICAL EFFICIENCY OF TEFF PRODUCTION IN ETHIOPIA

BY: BERSABET SHEMELIS

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A THESIS SUBMITTED TO ADDIS ABABA UNIVERSITY COLLEGE OF BUSINESS AND ECONOMICS DEPARTMENT OF ECONOMICS IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN ECONOMICS (ECONOMIC POLICY ANALYSIS)

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Declaration

I, Bersabet Shemelis Assefa, confirm that this research paper titled "Technical Efficiency of Teff Production in Ethiopia" represents my work, carried out under the supervision of Dr Hailu Elias at Addis Ababa University's College of Business and Economics, Department of Economics. All data analysis and insights presented in this paper are original. References to existing literature and sources have been appropriately cited and acknowledged.

I declare that this paper has not been submitted or presented for any academic requirement or qualification at any other institution or University

Declared by:	Confirmed by:
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Signature ________________	Signature ________________
Date ___________________	Date ___________________

Approval

This is to certify that Bersabet Shemelis Assefa's thesis paper, “Technical Efficiency of Teff Production in Ethiopia,” fulfills the requirements for the Master of Science (MSc.) degree in Economics (Economic Policy Analysis). This work has been conducted in compliance with the university's regulations and meets the standards regarding originality and quality.

Approved by:

Advisor: ___________________ Signature: ___________________ Date: ____________

Internal Examiner: ___________________ Signature: ___________________ Date: ____________

External Examiner: ___________________ Signature: __________________ Date: ____________

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Abstract

Ethiopia is the largest producer of Teff, a staple grain with significant cultural and economic importance. This study aims to investigate the technical efficiency score of Teff analyzing factors influencing teff yield using stochastic frontier analysis on “Resilience to climate change” data collected in 2023. The study has found labour input and land size negatively impact efficiency, while livestock in tropical units positively influence it. Fertilizer use, crop rotation, and extension service also contribute to reducing inefficiency while literacy and irrigation use show no significant effect. With a technical efficiency score of 0.787, the study highlights the potential for improving resource utilization. Recommendations for enhancing efficiency include adopting better labour and land management practices, promoting integrated farming systems, increasing fertilizer accessibility and proper usage, and strengthening extension services. Further research is suggested to address barriers and evaluate the long-term impacts of these interventions.

Keyword: Technical efficiency, stochastic frontier analysis, RCC data

List of Acronyms

DEA	Data Envelopment Analysis
DMU	Decision-Making Units
DERG	Development Economic Research Group
MLE	Maximum likelihood estimation
PADETES	Participatory Demonstration and Training Extension System
PSI	Policy Studies Institute
RCC	Resilience to climate change
SFA	Stochastic Frontier Analysis
SNNPR	Southern Nations, Nationalities and Peoples
TE	Technical efficiency
TLU	Livestock measured in tropical units

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Chapter One: Introduction

1.1 Background

Ethiopia is the largest producer of teff globally, and it is crucial for the country's agricultural and economic development (Berhanu, 2023). However, despite the large-scale production, many farms experience inefficiency, which hinders optimal productivity. Factors such as poor access to technology, inadequate extension services, insufficient market access, and climate variability can all affect the technical efficiency of teff farming (Tenaye, 2020).

The study of technical efficiency in teff production in Ethiopia is crucial due to the crop's significance as a staple food and its economic importance for smallholder farmers. A study by Wang and Cakir (2021) points out teff provides more than 10% of the total calories consumed in Ethiopia, underscoring its nutritional significance and the increasing demand for this "super grain”. Teff (Eragrostis teff) is not only a primary source of nutrition but also a vital cash crop that contributes significantly to the livelihoods of rural households in Ethiopia. Despite its importance, the productivity of teff remains low compared to its potential, primarily due to inefficiencies in production practices and limited adoption of improved agricultural technologies (Ayele et al., 2020; Jaleta, 2021).

Research indicates that the average technical efficiency of smallholder teff farmers in Ethiopia is approximately 53.23%, suggesting that there is a substantial opportunity for improving productivity by optimizing input use (Fikadu, 2024). One major challenge in technical efficiency is reliance on traditional farming practices, including low fertilizer application rates and outdated land preparation techniques, which limit yield potential can be mentioned (Berhe et al., 2021). Additionally, the adoption of optimal fertilizer use remains low, further constraining productivity (Hailu & Mamo, 2020). Beyond farming techniques, soil health is another critical determinant of efficiency. Soil fertility issues, exacerbated by inadequate nutrient management; significantly impact teff yields, necessitating a more strategic approach to soil health and fertility (Berhanu, 2023; Elemineh et al., 2020).

Smallholder farmers face various challenges in accessing markets, including limited information, inadequate infrastructure, and market volatility (Habtewolde & Challa, 2019). Addressing these challenges through policy interventions and support systems can enhance farmers' participation in the teff market, thereby improving their income and incentivizing the adoption of more efficient production practices (Habtewolde & Challa, 2019; Zerssa et al., 2021).

Furthermore, the adoption of improved agricultural technologies, such as row planting and the use of blended fertilizers, has been shown to significantly enhance teff productivity (Negussie, 2020; Giziew & Mebrate, 2019). Studies have demonstrated that transitioning from traditional broadcasting methods to row planting can lead to better yields and reduced competition among plants, which is critical for maximizing output (Giziew & Mebrate, 2019). Therefore, promoting the adoption of such technologies, alongside providing education and resources to farmers, is essential for improving technical efficiency in teff production.

In general, the technical efficiency of teff production in Ethiopia is influenced by a combination of factors, including agricultural practices, market dynamics, and soil fertility management. By addressing these areas through targeted interventions and support, there is significant potential to enhance the productivity and economic viability of teff farming, ultimately contributing to food security and rural development in Ethiopia.

1.2 Statement of the problem

Teff is one of the most preferred and commercialized cereal crops in Ethiopia. It is well-suited to the country's diverse climatic and soil conditions and is recognized for its nutritional value. Despite its economic and dietary importance, teff production remains inefficient, with significant variation in technical efficiency among smallholder farmers. This inefficiency limits productivity and income potential, making it crucial to assess the factors contributing to these disparities. Despite its significance as a staple crop, there has been limited investment to fully exploit its domestic and international market potential, which may indirectly affect the efficiency of production among small holder farmers (Mihiretu & Abebaw, 2020).

The average technical efficiency score for teff productivity in Ethiopia has been the subject of various studies, revealing a range of efficiency levels among smallholder farmers. The technical efficiency scores are critical for understanding how effectively farmers utilize their resources in teff production.

Existing studies have reported varying levels of technical efficiency in teff production, suggesting inconsistencies across different time periods and regions. For instance, Kassa et al. (2019), using data from the 2013/2014 Ethiopia Socioeconomic Survey (ESS), estimated an average technical efficiency of 73%, with efficiency levels ranging from 13% to 92%, indicating that many farmers were operating about 27% below their potential. Fikadu (2024), analyzing data from 858 teff'growing farm households across the 2014 and 2016 survey rounds at 162 enumeration areas (EAs), found a significantly lower average technical efficiency score of 53.23%, suggesting a possible decline in efficiency over time or regional variations in performance. More recently Ayele et al. (2020), utilizing cross-sectional data from 323 teff-producing farmers during the 2018/19 production season, reported a mean technical efficiency of 69%, highlighting continued inefficiencies.

These varying efficiency scores show the inconsistency in teff productivity across different regions and time periods. The need for updated, empirical data is essential to inform policy-making and to ensure that interventions are relevant and effective. This study aims to address this gap by utilizing data collected by the collaboration of The Policy Studies Institute (PSI) of the Ethiopian government and Copenhagen University's Development Economic Research Group (DERG) in 2023 to provide a contemporary assessment of technical efficiency among smallholder teff producers in Ethiopia. In addition, this study utilizes data from three regions (Amhara, Oromia and SNNPR[1]), providing a broader scope and yielding more recent and comprehensive findings.

The findings of this research provide a recent score of technical efficiency, enabling policymakers to develop and refine agricultural policies that are informed by the latest insights and conditions in the teff production sector. As the agricultural environment undergoes rapid changes influenced by climate variation, economic pressures, and

[1] As of August 18, 2023, the Southern Nations, Nationalities, and Peoples' Region (SNNPR) was dissolved and replaced by two new regions: the South Ethiopia Regional State and the Central Ethiopia Regional State. Any references to SNNPR in this research should be understood within the context of its former administrative boundaries.

technological advancements, there is a pressing need for tailored policy recommendations and interventions that consider current efficiency levels and the factors impacting them. Therefore, this study not only seeks to quantify the technical efficiency of teff production but also identify critical variables affecting efficiency, thus providing a comprehensive foundation upon which to base relevant and effective agricultural policies.

1.3 Objective of the study

1.3.1 General objective

The main objective of the research is to assess the technical efficiency of teff production among farmers in Ethiopia. In this regard, the study particularly aims to achieve the following specific objectives.

1.3.2 Specific objectives

- To measure the level of technical efficiency of farmers' teff production
- To identify the determinants of technical efficiency in teff production

1.4 Research question

In assessing the technical efficiency of farmers' teff production in Ethiopia; the study will answer the following questions;

1. What are the determinants of technical efficiency in teff production in Ethiopia?
2. What is the level of technical efficiency in teff production in Ethiopia?

1.5 Significance of the study

The findings of this research are important to understand that the technical efficiency of teff production is vital in enhancing the livelihood of smallholder farmers. By assessing technical efficiency, the study identifies gaps in resource utilization and recommends strategies that lead to an increment in farmers' yields without requiring additional input, which in turn results in an improvement in food security and reducing poverty as teff is a major source of nutrition for many Ethiopians. The findings provide updated insights for policymakers with evidence-based recommendations to support smallholder farmers to increase their production capacity by designing targeted interventions that align with the specific needs of the farmers.

1.6 Scope of the study

This study mainly concentrates on the technical efficiency of teff production in the case of selected regions in Ethiopia. The study used data collected through a recent household survey conducted in 2023 covering broad geographic areas in Ethiopia. The survey includes households from the Amhara, Oromia, Somali, Gambella and SNNPR regions with a total sample size of 2000 households. However, for this study, only three regions namely Amhara, Oromia, and SNNPR were considered, as teff is predominantly cultivated in these areas. Furthermore, out of the 2,000 surveyed households, a subset of 631 households was selected for analysis, as they were engaged in teff production.

1.7 Organization of the paper

The study is organized as follows: The introduction presents the research background, problem statement, objective, significance and scope. The literature review section summarizes relevant theories and previous studies while identifying gaps that the research aims to address. The methodology section deals with the research design, data collection process, and analytical methods used. The results and discussion section presents the findings including technical efficiency determinants and measurements, and government policy impacts. The conclusion and recommendation section summarizes key findings and recommendations and proposes areas for future research.

Chapter Two: Literature Review

2.1 Literature Review on Teff Production in Ethiopia

This chapter summarizes, both the theoretical and empirical literature review focusing on Technical efficiency in teff production, including factors, methodology, findings and recommendations.

2.1.1 General overview of teff production

Teff (Eragrostis Teff) is an indigenous and most important cereal crop with its origin thought to be Ethiopia, and emerging as a grain crop for consumption between 4000 B.C and 1000 B.C (Getahun, 2018). The crop is well adapted to diverse climatic conditions, blooming in various altitudes and soil types as well as contributing to widespread cultivation across Ethiopia. (Mottaleb & Rahut, 2018; Ayele et al., 2020).

Teff is mainly known for its nutritional value, being rich in fiber, protein and other essential minerals, leading it to be a vital component of the Ethiopian diet being the main ingredient in Injera, traditional Ethiopian flatbread serving as a staple food for the Ethiopian population (Shiferaw et al., 2022; Reda, 2014). Teff is the most preferred cereal crop, fetching a relatively higher price in the market compared to other cereals like maize and wheat, making it both a staple food and a significant cash crop for thousands of smallholder farmers (Berhanu,2023; Fikadu 2023). This has led to an increment in Teff cultivation, both in the context of food security and rural development initiatives (Lee, 2018).

The cultivation of teff has evolved over the centuries, influenced by various socio-economic and environmental factors. In the past, traditional farming practices dominated, characterized by low-input systems and reliance on local seed varieties. However, with the introduction of improved seed varieties and agricultural technologies, there has been a gradual shift towards more intensive production methods (Ayele et al., 2020; Mihiretu & Abebaw, 2020). Despite this progress, challenges remain, including low average yields, limited access to modern inputs, and the impacts of climate variability (Abate et al., 2019; Wato, 2019).

In recent years, the Ethiopian government and various organizations have recognized the potential of teff as a key crop for enhancing food security and economic growth. Efforts have been made to promote the adoption of improved agricultural practices, including the use of fertilizers and better pest management strategies, to boost productivity (Elias et al., 2014). Additionally, the commercialization of teff farming has gained momentum, with farmers increasingly engaging in market-oriented production to meet both local and international demand (Fikadu, 2023; Lee, 2018).

As teff continues to gain recognition on the global stage, particularly as a gluten-free grain, its historical significance in Ethiopian agriculture remains paramount. The crop not only supports the livelihoods of millions of farmers but also embodies the cultural heritage and identity of the Ethiopian people (Mottaleb & Rahut, 2018; Abate et al., 2019).

2.1.2 Geographic distribution

Geographically, teff is predominantly cultivated in several regions of Ethiopia, with the Amhara and Oromia regions being the leading producers. Together, these regions account for approximately 84% of the total cultivated area and production of teff in the country (Mossie et al., 2021; Lee, 2018). Within these regions, specific areas such as East and West Gojam in Amhara and East and West Shoa in Oromia are particularly renowned for their teff production (Mossie et al., 2021; Bikila, 2024).

Teff is well-suited to a variety of agro-climatic conditions, which contributes to its widespread cultivation across Ethiopia. The crop can thrive in diverse environments, from lowland areas to high altitudes, and is adaptable to marginal soils (Gizaw, 2018). This adaptability allows teff to be grown in various regions, including the highlands, where it is often cultivated alongside other crops in mixed cropping systems. The total area under teff cultivation in Ethiopia is estimated to be around 2.8 million hectares, representing approximately 28.5% of the total area dedicated to cereal crops (Nascimento et al., 2018; Anteneh & Asrat, 2020).

The geographic distribution of teff production is influenced by several factors, including climate, soil type, and farming practices. Teff is primarily grown during the main rainy season (Meher), which typically occurs from June to September, although it can also be cultivated during the short rainy season (Belg) in some areas (Agegnehu et al., 2006; Tewolde, 2023). The crop's resilience to drought and its ability to grow in both low and high moisture conditions make it a valuable option for farmers in regions prone to climate variability (Tewolde, 2023; Giday, 2014).

In addition to its nutritional and economic significance, teff plays a crucial role in the cultural identity of Ethiopian society. The grain is a staple food, primarily consumed in the form of injera, a traditional flatbread that is central to Ethiopian cuisine (D'Andrea, 2008; Abate et al 2019). The cultural importance of teff further reinforces its geographical distribution, as it is cultivated not only for subsistence but also for market purposes, contributing to the livelihoods of millions of smallholder farmers across the country (Lee, 2018; Awulachew, 2020). Beyond its nutritional value, teff is also associated with various social and ceremonial practices. Its cultivation and consumption reinforce national identity and heritage, making it an integral part of Ethiopian society (Hager et al., 2012).

2.1.3 Importance in the Ethiopian Economy

Teff is a vital crop in Ethiopia, playing a significant role in the country's economy and food security. As the most important staple grain, teff is integral to the livelihoods of millions of Ethiopians, supporting both subsistence and commercial farming. The crop's importance can be analyzed from various economic perspectives, including its contribution to agricultural GDP, employment, and nutritional security.

Teff has emerged as a key cash crop, generating substantial income for farmers and contributing to rural development. The market for teff has expanded in recent years, driven by rising domestic and international demand for its nutritional benefits and gluten-free properties (Minten et al., 2015). The grain is often sold at premium prices, making it a lucrative option for farmers. Teff is considered the second most important cash crop in Ethiopia, following coffee (Milkias, 2022). This economic value underscores the crop's role in enhancing the livelihoods of rural households and reducing poverty levels. The commercial surplus generated from teff contributes significantly to rural incomes, making it a crucial source of cash for smallholder farmers (Mottaleb & Rahut, 2018).

The cultivation of teff is widespread, covering around 2.8 million hectares, which represents approximately 28.5% of the total area dedicated to cereal crops in Ethiopia (Anteneh & Asrat, 2020). This extensive cultivation not only supports local economies but also plays a critical role in national food security, as teff provides more than 10% of the total calories consumed in the country (Wang & Cakir, 2021). The grain's high nutritional value, including its gluten-free nature and rich mineral content, has led to increased demand both domestically and internationally, further enhancing its economic significance (Ereful et al., 2022).

Teff is not only economically important but also plays a crucial role in addressing nutritional deficiencies in Ethiopia. The grain is rich in protein, fibre, and essential minerals, making it an important dietary component for many Ethiopians (Ereful et al., 2022). As food insecurity remains a pressing issue in the country, promoting the cultivation and consumption of teff can contribute to improved nutritional outcomes and overall health for the population (Wang & Cakir, 2021).

Teff production is a major source of employment in rural areas, where smallholder farmers rely on the crop for their livelihoods. It is estimated that teff supports the dietary needs of approximately 60-75% of the Ethiopian population, making it a staple food for many households (Gizaw, 2018). The crop's cultivation involves a significant labour force, contributing to job creation in both farming and related sectors, such as processing and marketing (Belayneh, 2019).

Furthermore, teff's role in the economy extends beyond mere subsistence; it is increasingly being recognized as a cash crop that can enhance farmers' income through market participation. Studies have shown that smallholder farmers who engage in teff production often experience improved economic outcomes, which can lead to better living standards and reduced poverty levels (Fikadu, 2023).

In General, teff production is of paramount importance to the Ethiopian economy, contributing significantly to agricultural productivity, market dynamics, nutritional security, and cultural identity. As the country continues to face challenges related to food security and economic development, enhancing teff production and commercialization can serve as a strategic approach to improving the livelihoods of millions of smallholder farmers while ensuring food availability for the growing population. The continued focus on teff as a staple crop will be essential for fostering sustainable agricultural practices and promoting economic resilience in Ethiopia.

2.2 Factors influencing Technical efficiency in agricultural productivity

The technical productivity of teff (Eragrostis tef), a staple crop in Ethiopia, is influenced by various factors including labour, land size, livestock measured in tropical unit, fertilizer application, crop rotation, literacy, access to extension services, and irrigation. Understanding these determinants is crucial for enhancing the productivity of teff, which has been historically low despite its agronomic advantages.

Labour availability is a critical factor in the productivity of teff. However, studies have found both negative and positive effects of labour on yield of teff crops. For instance, Ayele et al. (2020) highlight that labour input is a significant determinant of technical efficiency in teff production. Higher labour availability correlates with improved productivity levels. Additionally utilizing labour-saving technologies can enhance productivity by reducing the physical burden on farmers, thereby allowing them to allocate their efforts more effectively across different agricultural tasks (Teshome & Tegegne, 2020). In contrast, a study in Indonesia suggested that more labour leads to a decreased future output, highlighting the importance of labour quality over quantity (Desifitrina et al., 2022). Balaji & Babu, (2022) also found that a significant labour shift from agriculture has corresponded with rising productivity, suggesting that reducing labour can enhance output per hectare by improving efficiency.

While labour availability plays a pivotal role in teff productivity, the size of the land also significantly impacts the efficiency and output of teff farms. Land size also plays a pivotal role in teff productivity. Similar to labour studies have found both positive and negative relationships between land size and teff productivity. Larger landholdings typically allow for more extensive cultivation practices and better resource allocation, which can lead to higher yields. However, due to land scarcity in Ethiopia, many farmers operate on small plots which limit their ability to achieve economies of scale (Orr et al., 2020). This constraint necessitates the optimization of land use through improved agricultural practices, such as crop rotation and intercropping, which can enhance soil fertility and crop yields (Reta et al., 2023). In contrast, a U-shaped relationship between land size and productivity was identified in Kenya where the inverse relationship occurs for farms less than 3 hectares, flattens between 3 and 5 hectares, and becomes positive for farms between 20 and 70 hectares (Muyanga & Jayne, 2019). Another study (Cheng et al., 2019) has found that smaller farms tend to utilize more labour and non-labour inputs per unit area significantly boosting productivity.

Given the setbacks mentioned by limited land size, optimizing resource use becomes very important for teff production. Among the key aspects of resource optimization soil nutrient management can be mentioned. The application of fertilizers is another crucial factor influencing teff productivity. Research indicates that the use of nitrogen and phosphorus fertilizers significantly boost teff yields (Tesfahun, 2018; Abera, 2024). For example, Tesfahun (2018) found that appropriate fertilizer application rates can lead to substantial increases in yield, demonstrating the importance of soil nutrient management in teff cultivation. Moreover, the timing and method of fertilizer application can also affect productivity, as highlighted by Wato (2019), who noted that different nitrogen rates and application timings can lead to variability in yield outcomes.

In addition to fertilizer application crop rotation practices are also essential for maintaining soil health and enhancing productivity. Another study emphasizes that crop rotation can improve soil fertility and reduce pest pressures, leading to better yields of teff (Reta et al., 2023). This practice not only contributes to sustainable farming but also helps in managing the ecological balance within farming systems, which is vital for long-term productivity. A study conducted in the Silte zone of Ethiopia has found that rotating wheat with legumes like field pea and faba bean increased wheat grain yield by 5.45% and 6.6% respectively, compared to those who continuously cropped wheat by reducing inefficiencies in wheat production. (Endrias & Mekonnen, 2023).

Similarly, Admasu et al. (2020) found that rotating wheat with rapeseed and faba bean resulted in 84% and 80% yield increments respectively when compared to farmers that continuously cropping wheat emphasizing the effectiveness of crop rotation in controlling weeds and improving soil fertility, which in turn reduces inefficiencies in production.

While crop rotation is an essential factor in maintaining and controlling pests and soil fertility, effective water management is another crucial factor in agricultural productivity. Irrigation specifically in regions that are prone to drought plays a key role in ensuring crops receives sufficient water throughout their growth cycle. Derib et al. (2011) discuss how small-scale irrigation schemes can improve water productivity and, consequently, crop yields. However, the efficiency of these irrigation systems often varies, and improvements in water management practices are necessary to maximize their effectiveness. Similarly, a study by Sedebo et al., (2021) found that in regions where rainfall is insufficient or erratic, the implementation of irrigation systems can help stabilize yields and improve efficiency. Farmers who adopt efficient irrigation techniques, such as drip or sprinkler systems, can optimize water use and enhance crop performance.

Literacy and education levels among farmers significantly impact their ability to adopt modern agricultural practices and technologies. Higher literacy rates are associated with better understanding and implementation of advanced farming techniques, which can lead to increased productivity (Teshome & Tegegne, 2020). Access to agricultural extension services further supports this by providing farmers with critical information and resources necessary for improving their farming practices. The Ethiopian government's efforts to enhance agricultural extension services have been shown to positively influence the technical efficiency of teff producers (Elias et al., 2014). In contrast, studies have found that literacy might not always significantly affect agricultural productivity. A study in Sri Lanka has found that demographic factors, including literacy, do not significantly affect agricultural productivity. Instead, training programs provided by the In-Service Training Institute (ISTI) play a crucial role in enhancing farmers' productivity (Wilson & Tymon, 2013). Additionally, a study by Aina and Ajayi (2015) found that while literacy can contribute to improved agricultural practice, it does not have a direct and significant effect on productivity. Instead, factors like access to resources, experience, and market conditions play a significant role in determining agricultural output.

The role of agricultural extension services is particularly significant in influencing technical efficiency. Research by Elias et al. demonstrates that the implementation of the Participatory Demonstration and Training Extension System (PADETES) has positively impacted the technical efficiency of teff producers in northern Ethiopia (Elias et al., 2014). The study emphasizes that effective extension services can lead to better agricultural practices, thereby enhancing productivity. Similarly, a study by Kassa et al. (2019) has found that frequent contact with extension services correlates positively with technical efficiency, underscoring the importance of these services in improving smallholder productivity.

Extension services can also provide valuable information on market trends and best practices, further enhancing efficiency (Mihiretu & Abebaw, 2020).

Another study finding has highlighted the significance of using agricultural extension services to increase smallholder productivity indicating that extension services are essential for encouraging better technology, which helps to increase efficiency in farming practices (Berhane & Ragasa, 2018). Additionally, the Ministry of Agriculture (2017) found that farmers participating in extension programs showed improved productivity and efficiency compared to non-participants, suggesting a reduction in overall inefficiency through continuous monitoring

Moreover, the influence of livestock measured in tropical units (TLUs) on technical efficiency has been explored in various contexts. For instance, a study discusses how TLUs serve as a critical indicator of food security and agricultural productivity, suggesting that households with higher livestock densities tend to have better productivity outcomes (Mechlowitz, 2023; Rothman-Ostrow et al., 2020). This correlation is likely due to the multifaceted role that livestock play in providing manure for fertilization, serving as a source of income, and enhancing food security, which collectively contributes to improved agricultural practices and efficiency. Similarly, Bayer and

Waters-Bayer (1998) highlight how integrating livestock with crop production in tropical farming systems can significantly enhance agricultural productivity and sustainability. They emphasize that animal manure improves soil fertility, while crop residues serve as valuable feed for livestock. Furthermore, draught animals provide essential labour for cultivation and transportation, creating a synergistic relationship that benefits both crop and livestock production.

2.3 Theoretical Foundation of Technical Efficiency

The idea of Technical efficiency was first introduced by Farrell (1957), introducing measuring efficiency in production in terms of allocative efficiency, economic efficiency and technical efficiency. Allocative efficiency focuses on resources being most efficient, while technical efficiency focus on maximizing production with the set of inputs or minimizing inputs while keeping output unchanged i.e getting the most out of inputs during production, and lastly, Economic efficiency is the summation of both technical and allocative efficiency (Farrell, 1957).

Technical efficiency is a basic concept in the economics field of study presenting the capacity of a firm or production unit, to optimize output from a given set of inputs or to reduce the number of input needed to generate a given level of output (Farrell, 1957).

Research on Technical efficiency has provided important insights about smallholder farmers' productivity and effects of policy interventions. Bravo-Ureta et al.(2007), studied efficiency conducted in developing nations and found significant resource consumption inefficiencies, emphasizing the need of capacity-building programs. In addition, Sherlund et al. (2022) studied the consequences of risk and uncertainty on productivity, emphasizing how crucial risk management techniques are to the agricultural sector.

2.4 Empirical studies on Technical productivity

The level of technical efficiency in agricultural production varies significantly across different regions and types of agricultural products. Below is a synthesis of findings from various studies that highlight these efficiency levels, the types of agricultural products involved, and the countries where the studies were conducted.

A study made in China by Hsu et al. (2023) has found an average overall agricultural production efficiency of 89.78% across different regions in China from 2012 to 2016, indicating a high level of technical efficiency in the agricultural sector. Additionally, Deng et al. (2016) focused on grape producers in China, emphasizing the importance of farm size and mechanization in achieving technical efficiency, although specific efficiency levels were not quantified.

In Senegal, a study by Telleria and Marco (2022) has found that households produced only 53% of the potential output with the observed input levels, highlighting significant inefficiencies in agricultural production and underscoring the challenges faced by farmers in terms of limited access to fertilizers and mechanization.

Edison and Rosyani (2021) found that the mean technical efficiency score for corn production in Jambi, Indonesia was approximately 74%, indicating that farmers were producing 26% below their potential yield given the existing technical efficiency. This study highlights the potential for improving agricultural practices in the region.

A study has examined the technical efficiency of cocoa farmers in Cameroon, Ghana, Nigeria, and Côte d'Ivoire. The study utilized stochastic frontier models to estimate technical efficiencies, emphasizing the productivity potential of cocoa farmers across these countries, although specific efficiency levels were not detailed (Binam et al., 2008).

Another study focused on wheat production in Punjab, Pakistan, and while specific efficiency levels were not provided, the study aimed to optimize energy efficiency and evaluate greenhouse gas emissions, indirectly addressing technical efficiency in wheat farming (Ilahi et al., 2019).

A study on Czech agriculture reported on the development of technical efficiency and total factor productivity, indicating that farmers were not fully utilizing the opportunities presented by the Common Agricultural Policy (CAP) (Čechura, 2012).

A meta-regression analysis of African agriculture indicated substantial inefficiency in agricultural production, with an average production efficiency of roughly 68% (Ogundari 2014). In addition, Elias et al. (2014) observed a technical efficiency ranging from 33% to 96% , with an average of 72% , among teff producers in Ethiopia's Gozamin district of the East Gojjam zone. Another study focusing on teff producers in the Amhara, Oromia, SNNP, and Tigray regions reported an average technical efficiency of 65% (Abate et al., 2014).

A comprehensive meta-analysis of farm technical efficiency across 169 countries conducted by Bravo-Ureta et al. (2007) revealed average technical efficiencies of 77% for 26 African cases, 75% for 189 Asian cases, 78% for 47 Latin American cases, and 72% for 45 East European cases. Additionally, they found an average technical efficiency of 75% for 158 cases in low-income nations (Bravo-Ureta et al., 2007).

Various studies have reported differing levels of technical efficiency among teff producers. For instance, Kassa et al. (2019) found that the average technical efficiency of smallholder teff farmers ranged from 13 to 92%, with a mean efficiency of 73%. This indicates that there is significant potential for improving productivity through better resource management and the adoption of modern practices.

2.5 Technical Efficiency Measurement

Technical efficiency measurement is essential for understanding and improving agricultural productivity, particularly for crops like Teff. A range of methodologies have been developed to measure efficiency, each providing different insights into technical efficiency. These methodologies will be discussed in the following sections.

2.5.1 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a widely utilized methodology for measuring the technical efficiency of Decision-Making Units (DMUs) that operate with multiple inputs and outputs. This non-parametric approach, developed by Charnes, Cooper, and Rhodes in 1978, allows for the evaluation of relative efficiency without requiring a predefined functional form for the production process (Shu, 2023; Bhat et al., 2001). DEA is particularly valuable in agricultural economics, where it is used to assess the efficiency of farms, cooperatives, and other agricultural entities.

DEA evaluates the efficiency of DMUs by constructing a piecewise linear frontier based on the observed data. Each DMU is compared against this frontier to determine its efficiency score, which reflects how well it converts inputs into outputs relative to the best-performing units (Shu, 2023; Bhat et al., 2001). The efficiency score ranges from 0 to 1, where a score of 1 indicates an efficient DMU and scores less than 1 indicate varying degrees of inefficiency.

DEA has been extensively applied in various fields, including agriculture, healthcare, and education, to assess efficiency and inform policy decisions. In agriculture, DEA has been used to evaluate the performance of mixed crop-livestock systems, measure the eco-efficiency of farming practices, and analyze the technical efficiency of cooperatives (Ahmed et al., 2020; Picazo-Tadeo et al., 2011; Tesema & Gebissa, 2022). These applications demonstrate the versatility of DEA as a tool for improving productivity and resource allocation in agricultural settings.

2.5.2 Stochastic Frontier Analysis (SFA)

Stochastic Frontier Analysis (SFA) is a widely used econometric methodology for measuring technical efficiency in various sectors, including agriculture, banking, and healthcare. Developed independently by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977), SFA allows for the estimation of production functions while accounting for random errors and inefficiencies in production processes (Zheng et al., 2018; Nguyen et al., 2021). This methodology is particularly valuable in contexts where production outputs are influenced by both controllable factors (inputs) and uncontrollable factors (random shocks).

The key feature of SFA is its ability to separate the inefficiency component from the random error component. The inefficiency term reflects the degree to which a firm fails to achieve maximum output given its inputs, while the random error accounts for external shocks or measurement errors that are beyond the control of the firm (Coli et al., 2011; Henningsen & Henning, 2009). This separation allows for a more accurate assessment of technical efficiency.

The parameters of the production function and the inefficiency effects are typically estimated using maximum likelihood estimation (MLE). This approach provides estimates of the production function parameters and the distribution parameters of the inefficiency term, allowing for the calculation of efficiency scores for each firm (Jin et al., 2020; Deelchand & Padgett, 2009).

SFA has been applied in various fields to assess efficiency and productivity. In agriculture, it has been used to evaluate the technical efficiency of farms, analyze the impact of different farming practices, and assess the effects of policy interventions (Daraio et al., 2019; Silva et al., 2019). In the banking sector, SFA has been employed to measure cost efficiency and evaluate the impact of human capital on risk-taking behavior (Zheng et al., 2018; Griffin & Steel, 2007). The flexibility of SFA allows it to be adapted to different contexts and datasets, making it a valuable tool for researchers and policymakers.

Both Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) offer valuable methodologies for measuring technical efficiency, each with its strengths and limitations. DEA's non-parametric nature and ability to handle multiple inputs and outputs make it a flexible tool for efficiency assessment, while SFA's incorporation of random errors and statistical inference capabilities provide a more nuanced understanding of production processes.

Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA) are highly relevant to measuring technical efficiency in teff production in Ethiopia. Each method offers unique strengths that can inform policy decisions, enhance productivity, and support the livelihoods of smallholder farmers. By leveraging these methodologies, stakeholders can identify inefficiencies, promote best practices, and ultimately contribute to the sustainability and growth of the teff sector in Ethiopia.

Chapter Three: Research Methodology

3.1 Research procedure

The study has used a cross-sectional analysis covering one year, 2023. Data is collected in 9 variables which include Teff output per hectare, Labor, Land size, Livestock measured in TLU, fertilizer, crop rotation, literacy, access to extension service, and irrigation are included as explanatory variables.

3.2 Data source and analysis

The study was made based on a household survey conducted in 2023 as part of a large research project titled "Building Resilience to Climate Change in Ethiopia: Policy Options for Actions." conducted by the collaboration of The Policy Studies Institute (PSI) of the Ethiopian government and Copenhagen University's Development Economic Research Group (DERG) serving as a primary source of data for this research.

3.3 Sampling technique

The study was based on cross-sectional data obtained from a household survey using a multistage proportionate sampling. The sampling process consists of three stages: selecting sample woredas (Districts), sample villages, and sample households covering 40 districts drawn from 5 regional states, namely Amhara, Oromia, Somali, Gambella and Southern Nations, Nationalities and Peoples (SNNPR). The sample size includes 120 sample villages and a total of 2000 randomly selected households.

After cleaning the data set the study has found 631 (31.55%) Teff producers among 2000 households and among the 5 regions that the data has been collected, Teff is being produced in the three regions namely Amhara, Oromia and SNNPR while 253 producers are found in Amhara region, 237 producers are found in Oromia region and the rest 141 producers are found in SNNPR. The data has been cleaned and analyzed using the STATA 17 software.

In this study, both descriptive and econometric analysis was used. Descriptive statistics used to analyze the mean, frequency, percentage and standard deviation based on results and tables. On the other hand, econometrics method of stochastic frontier model has been used as method of empirical data analysis.

There are two major widely used approaches to measure technical efficiency. The first one is Data Envelopment Analysis (DEA) a mathematical programming-based technique (Charnes et al., 1978) and Stochastic Frontier Analysis (SFA) which is an econometric technique (Aigner et al., 1977; Meeusen and van den Broeck, 1977). Both approaches estimate best practice frontiers to assess the efficiency of specific decision-making units relative to the frontiers. While Data Envelopment Analysis (DEA) imposes fewer structural constraints on the frontier and is non-stochastic, meaning any deviation from the frontier will be interpreted as inefficiency, the Stochastic Frontier Analysis (SFA) requires the specification of a production functional form (Aigner et al., 1977; Meeusen and van den Broeck, 1977).

The stochastic frontier analysis (SFA) is chosen over data envelopment analysis (DEA) for multiple reasons. SFA shows a reduced sensitivity to outliers (Besstremyannaya, 2011), facilitates the modelling of firm-specific variables, accounts for stochastic variations due to random noise (Aigner, Lovell, and Schmidt, 1977), and supports statistical hypothesis testing.

The Stochastic frontier model (SFA) is a widely used econometric model for assessing the effectiveness of the production process (Aigner, Lovell, & Schmidt (1977)). It is mainly useful in agricultural studies, including technical efficiency in crops like Teff (Meeusen, & Van den Broeck (1977)). SFA divides the measures productivity into two parts using the production function: the efficiency frontier, which represents the maximum possible output, and the inefficiency (random error and deviations from the frontier) (Kumbhakar, & Lovell (2003)).

The frontier model consists of a cobb-Douglas production function of input Labor and capital (Land size and Livestock measured in tropical livestock unit) and for the inefficiency model the study has considered fertilizer, Irrigation, literacy, crop rotation, and extension service.

3.4 Model Specification

3.4.1 Stochastic Frontier Analysis (SFA) Model

The Stochastic Frontier Analysis (SFA) model was employed to estimate the technical efficiency of teff production in Ethiopia. It is the most efficient technique when it comes to studying efficiency for a variable that can be affected by uncontrollable factors in the decision-making unit. The empirical model used in this study is based on the Cobb-Douglas production function specified in the log-linear form. The model is structured to estimate the technical efficiency of teff production in relation to various inputs while accounting for inefficiency variables that affect production outcomes. It allows separating inefficiency effect from random shocks like adverse weather condition affecting output and measurement errors that occurs during data collection and analysis.

The model is expressed as

$$ln\mathrm{Y}_i = \beta_0 + \sum\beta_i\mathrm{X}_{ij} + exp^{ei}$$

Where

ln denotes the natural logarithm

i denotes the ith observation

Y_i denotes Teff yield of the ith observation

β_o denotes the intercept term in the equation

β_i denotes the coefficient for the ith observation

X_{ij} denotes the jth explanatory variable for the ith observation

ei denotes the error term in the observation *i* accounting for the variation in Y_i that is not explained by the independent variables of the model.

In this study, the stochastic frontier model is employed to analyze the technical efficiency of teff farms. A critical component of this model is the specification of the distribution of the inefficiency term. Among the various possible distributions, the truncated normal distribution is chosen because the truncated normal distribution allows for flexibility in modelling the inefficiency effects. Unlike other distributions, it can accommodate a variety of shapes, including those where inefficiency is concentrated near zero but does not follow a strict normal pattern.

In addition, the truncated normal distribution offers greater flexibility in empirical modeling. It enables the capture of heterogeneity among producers by allowing the inefficiency effects to follow a distribution that better fits the data, leading to more accurate efficiency estimates. Comparative studies have shown that the truncated normal distribution often yields more reliable and robust results in stochastic frontier analysis compared to other distributions, such as the half-normal or exponential distributions (Stevenson, 1980; Greene, 2005; Kumbhakar & Lovell, 2000). This reliability enhances the credibility and validity of the efficiency estimates derived from the model. Due to these reasons truncated normal distribution was used while using the stochastic frontier model.

3.4.2 Selection of functional form

Another challenge with parametric borders is the selection of functional forms. In the majority of empirical production analysis research, the translog and Cobb-Douglas functions have been the most often used functional forms among the various algebraic forms. Every functional shape has unique benefits and drawbacks. Because it compares computational feasibility with a sufficient fit of the data, some academics contend that the Cobb-Douglas functional form is preferred over the other functional forms. It is also very efficient with regard to degrees of freedom and useful for interpreting production elasticity. As Hazarika and Subramanian (1999) point out, it is therefore frequently utilized in investigations of the border production function.

The Cobb-Douglas functional form is often used for empirically estimating frontier models because of its simplicity. The simplicity of this approach comes with limitations, as it implies constant elasticity, constant return to scale, and equal elasticity of replacement (Coelli et al., 1998). The Cobb-Douglas functional form is useful for interpreting production elasticity and has a small number of degrees of freedom. Due to these reasons, this study preferred using the Cobb-Douglas functional form.

The Cobb-Douglas production function is a widely used mathematical representation in economics that describes the relationship between two or more inputs (labour and capital) and the output produced. For the stochastic frontier production function the cobb-Douglas production function is stated as follows:

$$lnY_i = \beta o + \sum_{j=1}^{3} \beta j \, X_{ij} + V_i - U_i$$

Where:

Y_i denotes the quantity of teff produced per hectare for the farmer i

β_o denotes the intercept term

β_j denotes the coefficient for the j^{th} input

X_{ij} denotes the quantity of input j used for the production by the i^{th} farmer including Labor and capital i.e. X_{i1} = Labor, X_{i2} (capital 1) = Land size X_{i3} (capital 2) = TLU.

V_i - U_i denotes the error term

In this study, I have used an inefficiency model to analyze the data. The technical inefficiency U_i can be estimated by subtracting the technical efficiency (TE) from one:

$$U_i = 1 - TE$$

This implies that if TE is high i.e. close to 1, the technical inefficiency will be low i.e close to 0, indicating efficient production and vice versa.

The inefficiency model is stated as follows:

$$U_i = \alpha_0 + \sum_{n=1}^{5} \alpha_n \, Z_{ni}$$

Where:

U_i denotes the inefficiency in teff production by the i^{th} farmer

α_o denotes the intercept term

α_n denotes the coefficient that measures the impact of each variable (Z_{ni}) on the output

Z_{ni} denotes the n^{th} input included in the inefficiency model that farmer i has used. The inefficiency variables included in this model are:

Z_{1i} = Fertilizer, Z_{2i} = Irrigation, Z_{3i} = Literacy, Z_{4i} = Crop rotation and Z_{5i} = Extension service

3.5 Variable Description

3.5.1 Dependent variable

Teff productivity

Teff productivity is measured in yield per hectare which is calculated by dividing Teff yield measured in quintals with land size measured in hectare.

$$Agricultural\ productivity = \left(\frac{Teff\ yield}{Land\ size}\right)$$

3.5.2 Independent variables

Labour: Number of manpower that has participated in teff production.

Land size: Represents the area of land allocated for teff production measured in Quintals

Livestock measured in tropical unit: This represents a standardized measure that allows comparing the size and type of livestock across different species and farming systems.

Fertilizer: Refers to any natural or synthetic substances that are added to the soil or plant in order to supply nutrients that are necessary for plant growth and development. Particularly for the crop teff, the study has considered both organic and inorganic fertilizers used by the farmer.

Irrigation: Represent the controlled application of water to soil in order to assist the growth of crop especially to enhance productivity in regions with inadequate or irregular rainfall. The study categorize farmers based on their access to irrigation.

Literacy: refers to the ability to read and write to a stage that enables an individual to function efficiently in order to develop their potential. The study considered farmers who attend formal and informal education enabling them to read and write as a literate and Illiterate otherwise.

Crop rotation: Refers to an agricultural practice that comprises the systematic planting of different crops in a sequential manner across the same field over a series of growing seasons that will help improve soil health, reduce the occurrence of pests and disease and enhance nutrient availability.

Extension service: refers to the availability and utilization of programs and resources that are offered by agricultural extension services, aiming to provide knowledge, support and skill to farmers and rural communities to enhance agricultural productivity and improve the livelihood of the society by providing sustainable practices through outreach.

Table 1: Variables influencing productive efficiency and their expected signs

Variable name	**Measurement type**	**Expected sign of relation**
Teff productivity	Continuous	
Labour	Continuous	+/-
Land size	Continuous	+/-
Livestock in tropical livestock unit	Continuous	+
Fertilizer (0 = no ,1 = yes)	Dummy	+
Irrigation (0 = no access 1= have access)	Dummy	+
Literacy (0 = no, 1 = yes)	Dummy	+
Crop rotation (0= no, 1= yes)	Dummy	+

Extension service (0= no access, 1= have access)-	Dummy	+

Source: Author's own compilation

Chapter Four

This chapter presents the descriptive and econometric analysis for the technical efficiency of Teff production based on the collected data and discusses the determinants of technical efficiency based on the collected data the findings derived from a sample of 631 observations.

4.1 Descriptive analysis

This section of the paper describes the main variables that have been used in the econometrics estimation. The variables being described here include Teff output per hectare, labour, land size, livestock in tropical unit, fertilizer, crop rotation, literacy, access to extension service, and irrigation.

Table 2: Descriptive statistics

Variable	Mean	Std. Dev.
Yield per hectare	4.398	5.644
Labour	3.921	1.584
Land size	1.524	1.641
TLU	4.579	3.528
Fertilizer	0.878	0.328
Crop rotation	0.829	0.377
Literacy	0.537	0.499
Extension service	0.664	0.473
Irrigation	0.011	0.105

Source: Computed by the author based on RCC 2023 data

The data consists of 631 observations of Teff output per hectare, with a mean output of 4.40 quintals per hectare indicating that on average the Teff yield per hectare among the sampled households was around 4.40 quintals per hectare. The standard deviation 5.644 indicates the amount of variation of yield per hectare values around the mean. After comparing the standard deviation with the mean, 5.644 suggests that there is considerable variability in Teff yield per hectare.

Among 631 households, on average households use around 4 man powers while producing Teff. The standard deviation of 1.584 indicates a moderate variability of Labor in reference to the mean.

On average Teff producers have a land size of 1.524 hectares. There exists a high variation among the land size of Teff producers as indicated by the standard deviation of 1.641.

The average Teff producing household owns a 4.58 of a Livestock measured in tropical unit. The standard deviation 3.528 is somehow comparable to the mean suggesting a moderate variability in livestock ownership among observations. This variability could be caused by factors like economic status, cultural practices and access to gazing lands.

Out of the 631 observations, 87.80% (554) observations have used fertilizer, while the rest 12.20% (77) observations did not use fertilizer indicating a high prevalence of fertilizer usage while producing Teff.

Out of 631 observations, 82.88% (523) reported practicing crop rotation, while the remaining 17.12% (108) did not practice crop rotation indicating a high prevalence of crop rotation among farmers while Teff production.

Out of 631 observations, 53.72% (339) household heads were literate while the remaining 46.28% (292) household heads were illiterate indicating over half of the observations have literate household heads.

Out of the 631 observations, 66.40% (419) observations had access to extension services, while the rest 33.60% (212) observations did not have access to extension services indicating the majority of the observations had access to extension workers while producing Teff.

Out of 631 observations, 98.89% (623) reported no availability of Irrigation, while the rest 1.11% (7) reported having access to irrigation indicating a very low prevalence of irrigation access while producing Teff.

4.2 Econometric analysis

Efficiency Analysis

This section of the paper describes the stochastic frontier analysis result as presented in the table below.

Table 3: Result of stochastic frontier analysis

Dependent variable: Ln(Yield per hectare)		
Variable	**Coefficient**	**z-statistics**
Variables for efficiency		
Labor	**-0.039****	**0.050**
Land Size	**-0.083*****	**0.000**
TLU	**0.053*****	**0.000**
Variables for inefficiency		
Fertilizer	**-0.331****	**0.017**
Crop rotation	**-0.551*****	**0.000**
Literacy	**-0.091**	**0.364**
Extension service	**-0.228****	**0.041**
Irrigation	**-6.325**	**0.864**
Number of obs	**631**	
Prob > chi2	**0.0000**	

*Source: computed by the author based on RCC 2023 data   Note: ***, ** and * indicate significance at 1%, 5% and 10%, respectively.*

In the above table, I have run stochastic frontier model to find out the coefficients and the significance of each variable. The table has two parts the first indicating variables explaining efficiency, while the second part indicating variables used to explain inefficiency. The results are presented as follows:

The study has found a negative relationship between labour and Teff productivity. The finding showed that, keeping all other things constant for each labour force that is being added there will be a 3.88% decrease in the efficiency of Teff production. Similarly, a study in Indonesia suggested that more labour leads to decreased future output, highlighting labour quality over quantity (Desifitrina et al., 2022). Another research (Balaji & Babu, 2022) suggested that a significant labour shift from agriculture has corresponded with rising productivity, suggesting that reducing labour can enhance output per hectare by improving efficiency.

The result of the study has identified a negative relationship between land size and Teff productivity. If a farmer expands their land by one hectare keeping all other things constant, increasing Land by one hectare will lead to an 8.32% decrease in Teff output per hectare. Similarly, a U-shaped relationship between land size and productivity was identified in Kenya. This study has found that an increase in land size affects productivity in different ways depending on the farm size i.e for farmers with less than 3 hectares, an increase in land size leads to a decrease in productivity, for those with farm size between 3 and 5 hectares productivity remains unchanged and for farmers with land sizes between 20 and 70 hectares experience an increase in productivity (Muyanga & Jayne, 2019). Another study has found that smaller farms tend to utilize more labour and non-labour inputs per unit area significantly boosting productivity (Cheng et al., 2019).

In contrast, livestock is found to significantly improve Teff's productivity in the study area. As it can be seen from the table above, increasing livestock measured in tropical unit by one is found to increase Teff production efficiency by 5.28%. This is in line with the findings from related studies like Bayer and Waters-Bayer (1998) how integrating livestock with crop production in tropical farming systems can significantly enhance agricultural productivity and sustainability. They emphasize that animal manure improves soil fertility, while crop residues serve as valuable feed for livestock. Furthermore, draught animals provide essential labour for cultivation and transportation, creating a synergistic relationship that benefits both crop and livestock production.

Analysis of Inefficiency

The finding suggests that fertilizer has a negative relationship with the inefficiency of teff production. This indicates that farmers who use fertilizer are approximately 33.1% more efficient in their Teff output per hectare compared to those who do not use fertilizer, holding all other factors constant. Similarly, various studies have shown a significant decrease in inefficiency in agricultural output as a result of fertilizer usage. Fan et al. (2018) have found that farmers who utilize fertilizer can achieve a higher yield compared to those who don't, leading to a positive effect on crop yield and overall productivity in China. In addition, Zou et al. (2024) found that appropriate nitrogen fertilizer has significantly increased maize yield indicating that fertilizer use not only improves crop productivity but also optimizes nutrient use.

Reducing production output inefficiencies is another benefit of crop rotation. The report indicates that a farmer may reduce inefficiencies by 55.1% by rotating their crops compared to those who do not use crop rotation practices keeping other things constant. Several studies have shown that productivity is enhanced by crop rotation practices. A study conducted in the Silte zone of Ethiopia has found that rotating wheat with legumes like field pea and faba bean increased wheat grain yield by 5.45% and 6.6% respectively, compared to those who continuously cropped wheat by reducing inefficiencies in wheat production. (Endrias & Mekonnen, 2023). Similarly, Admasu et al. (2020) found that rotating wheat with rapeseed and faba bean resulted 84% and 80% yield increment respectively, when compared to farmers who continuously crop wheat emphasizing the effectiveness of crop rotation in controlling weeds and improving soil fertility, which in turn reduces inefficiencies in production.

The impact of household head literacy on farmers' productivity is negligible. This implies that a farmer's degree of productivity is not significantly affected by their participation in formal schooling or religious studies. Similarly, a study in Sri Lanka has found that demographic factors, including literacy, do not significantly affect agricultural productivity. Instead, training programs provided by the In-Service Training Institute (ISTI) play a crucial role in enhancing farmers' productivity (Wilson & Tymon, 2013). Additionally, a study by Aina and Ajayi (2015) found that while literacy can contribute to improved agricultural practice, it does not have a direct and significant effect on productivity. Instead, factors like access to resources, experience, and market conditions play a significant role in determining agricultural output.

Extension services have the potential to reduce inefficiency in production. Farmers become 22.85% more efficient when they have access to extension workers compared to those who don’t while keeping other things constant. This finding has highlighted the significance of using agricultural extension services to increase smallholder productivity indicating that extension services are essential for encouraging better technology, which helps to reduce the inefficiency of farming practices (Berhane & Ragasa, 2018). Similarly, a study carried out by the Ministry of Agriculture (2017) found that farmers participating in extension programs showed improved productivity and efficiency compared to non-participants, suggesting a reduction in overall inefficiency through continuous monitoring

Irrigation does not significantly affect Teff’s output per hectare. This is because only 1.11% of the total observation has access to irrigation, which will lead to the minimal impact of efficiency discussed in the finding. Nonetheless, 75% of those who do employ irrigation get results that are above average.

Analysis of Technical efficiency of Teff

This section presents the technical efficiency score derived from summarizing each farmer’s technical efficiency score after conducting a stochastic frontier analysis. The summarized result is presented in the following table.

Table 4: Summary statistics for technical efficiency score

Variable	Mean	Std. Dev.	Min	Max
TE	**.787**	**.126**	**.359**	**.996**

Source: computed by the author based on RCC 2023 data

The table represents the descriptive statistics for the technical efficiency of Teff productivity based on a survey of 631 observations in Ethiopia. The estimates vary widely. The study has found a minimum efficiency score of 0.359, while the maximum score is 0.996. This indicates that producers are operating in the range between 36% and 99.6% efficiency level. The average technical efficiency score is 0.787, indicating that on average, Teff producers are operating at about 78.7% or 21.3% below their potential efficiency highlighting a potential for improvement in resource utilization in producing Teff.

The findings align with a comprehensive meta-analysis of farm technical efficiency across 169 countries conducted by Bravo-Ureta et al. (2007). Their study revealed average technical efficiencies of 77% for 26 African cases, 75% for 189 Asian cases, 78% for 47 Latin American cases, and 72% for 45 East European cases. Additionally, they found an average technical efficiency of 75% for 158 cases in low-income nations (Bravo-Ureta et al., 2007). Further supporting these results, Ogundari's (2014) meta-regression analysis of African agriculture indicated substantial inefficiency in agricultural production, with an average production efficiency of roughly 68% . In addition, Elias et al. (2014) observed a technical efficiency ranging from 33% to 96%, with an average of 72%, among teff producers in Ethiopia's Gozamin district of the East Gojjam zone. Another study focusing on teff producers in the Amhara, Oromia, SNNP, and Tigray regions reported an average technical efficiency of 65% (Abate et al., 2014)

Chapter five

Conclusion and Recommendation

The variables that have been affecting the Technical efficiency of teff productivity in Ethiopia have been examined in the previous chapter. An average teff yield of 4.40 quintals indicates great room for teff productivity growth. The key factors affecting teff productivity significantly determined by the econometric study and include the variables labour input, land size, livestock measured in tropical unit , fertilizer use, crop rotation, irrigation use and extension service accessibility.

The result showed that labour input and land size affect the technical efficiency of teff productivity negatively, and in contrast, livestock measured in tropical unit affects the technical efficiency of teff productivity positively. The inefficiency variables fertilizer, crop rotation, and extension service availability affect inefficiency negatively while literacy of the household head and irrigation use fails to significantly impact technical inefficiency in teff production.

The technical efficiency score of 0.787 indicates teff producers are 78.7% technically efficient suggesting substantial room for improvement in utilization of production resources.

Given that labour impacts the technical efficiency of teff production negatively, it is recommended that teff producers adopt efficient labour management practices including training for seasonal laborers and utilizing task management system which allows farmers to increase quality of workers instead of quantity.

Since land size was found to have a negative impact on technical efficiency, there should be optimizing land use through practices by training farmers on efficient land management techniques to improve yield despite limited land availability.

The positive impact of livestock in tropical unit s on technical efficiency provides a potential synergy between livestock and crop production. Therefore, promoting integrated farming systems encouraging the use of livestock for manure and grazing can enhance soil fertility and productivity.

While fertilizer negatively affects technical inefficiency, I recommend increasing access to fertilizer for teff producers and educating farmers appropriate types, timings and amounts of fertilizer usage to maximize benefits and minimizing waste.

The analysis indicates that crop rotation reduces inefficiency, so the study recommends extension services to promote the benefits of crop rotation to improve soil health and pest management, which will lead to increased teff yield.

The significant role of extension service accessibility on efficiency suggests that strengthening these services is crucial for improving efficiency. The study recommends not only expanding extension workers but also enhancing their training to provide effective support to farmers on resource management, best practices and new technologies.

Additional research is needed to explore specific barriers faced by teff producers and evaluate the long-term impacts of recommended interventions. This will provide a more comprehensive understanding of the dynamics of teff production and inform policy decisions.

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