UNIVERSITY OF CAPE COAST

# SUSTAINABILITY RESPONSE TO FERTILISER USE IN MAIZE PRODUCTION: IMPLICATION FOR IMPROVING TECHNICAL EFFICIENCY OF SMALLHOLDER FARMERS IN NORTHERN GHANA

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Thesis submitted to the Department of Agricultural Economics and Extension of the School of Agriculture, College of Agriculture and Natural Science, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy Degree in Agricultural Economics

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# DECLARATION

## Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: ……………………. Date: …………………..

Name: Stephen Ekow Mensah

## Supervisor's Declaration

I hereby declare that the preparation and presentation of this thesis was supervised in accordance with the guidelines on the supervision of the thesis laid down by the University of Cape Coast.

Supervisor's Signature: …………................................ Date: ………………………...

Name: Prof. Samuel Kwesi Ndzebah Dadzie

## ABSTRACT

This study aimed to examine the sustainability response to fertiliser use in maize production and further analyse its implication for improving the technical efficiency of smallholder maize farmers in Northern Ghana. A multistage sampling procedure was adopted to sample 189 smallholder farmers and structured interview schedule was used to gather the data. The Marginal Value Product/Marginal Factor Cost, Sustainable Index Score, Stochastic Production Frontier Analysis, Seemingly Unrelated Regression Model, and the Heckit Treatment Effect Model were used in the analysis. The results revealed that row planting, crop rotation, recommended spacing, and pre-emergency weedicides were the commonly used sustainable practices adopted by smallholder maize farmers. The study also revealed that smallholder maize farmers were moderately sustainable in their farming activities. The study result showed that just like other critical inputs such as land, labour, and agrochemicals, smallholder maize farmers overutilised fertiliser while underutilising capital in their production. The technical efficiency level of maize farmers was 52%. The study found that adjusting fertiliser use efficiency level to optimum will increase the sustainability of maize production. Also, the study revealed that sustainable farm practices positively influence the technical efficiency of smallholder maize farmers. The study findings implied that to achieve optimum fertiliser use efficiency and improve technical efficiency, maize farmers would have to adjust fertiliser use levels downwards along with other critical inputs to optimum or increase their sustainable farm practices. The study recommends that the agricultural sector should provide training and other incentive programs to encourage smallholder farmers to engage in sustainable farm practices.

## KEYWORDS

Sustainable Agricultural Practices

Smallholder Farmers

Fertiliser Use Efficiency

Technical Efficiency

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# DEDICATION

To my parents,

Mr. Thomas Mensah and Mrs. Agnes Mensah

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| | |
|---|---|
| DEA | Data Envelopment Analysis |
| FAO | Food and Agricultural Organisation |
| FUE | Fertiliser Use Efficiency |
| HTEM | Heckit Treatment Effect Model |
| IFDC | International Fertiliser Development Community |
| NPK | Nitrogen, Phosphorus and Potassium |
| NUR | Nutrients Use Efficiency |
| OLS | Ordinary Least Squares |
| RFSPG | Regional Fertiliser Subsidy Program Guidance |
| SAPs | Sustainable Agricultural Practices |
| SDA | Sustainable Development Agenda |
| SFA | Stochastic Frontier Analysis |
| SSA | Sub-Saharan Africa |
| SUR | Seemingly Unrelated Regression |
| TE | Technical Efficiency |

# CHAPTER ONE

# INTRODUCTION

## Overview

Sub-Saharan Africa (SSA) has witnessed significant economic and agricultural development in the past two decades, yet it continues to grapple with pressing challenges such as low agricultural production, poverty, and food insecurity, primarily due to the dominance of smallholder farmers who face a multitude of internal and external hurdles. Research indicates that this reliance on smallholder farmers, who often lack education, access to credit, and confront poor climate conditions, may be unsustainable in the face of a growing SSA population. Smallholder farmers, particularly in Ghana, have been significantly affected by soil depletion and nutrient loss, resulting in low crop yields and income. These challenges necessitate the adoption of more sustainable agricultural practices to enhance productivity, reduce soil depletion, and ensure food security in the region.

Efforts have been made to address these issues, with interventions such as the Post-2015 Sustainable Development Agenda (SDA) in Ghana, which aimed to promote Sustainable Agricultural Practices (SAPs) and soil nutrient replenishment. International organizations, including the IFDC have supported the use of fertilizers to combat nutrient loss. However, despite these interventions, there is limited information regarding the adoption of sustainable farming practices among smallholder farmers, and some studies suggest that soil depletion and over-reliance on inorganic fertilizers continue to be a challenge. Therefore, further research is needed to assess the agronomic and sustainability practices of smallholder farmers, as well as their technical efficiency, to develop multifaceted solutions for improving soil quality, crop production, and food security in Ghana and other SSA countries. Therefore, this study focuses on how sustainable farming practice can improve the efficiency of smallholder maize farmers in Ghana and across SSA to create a more resilient and productive agricultural sector.

**Background to the Study**

Sub-Saharan Africa (SSA) has made great strides in economic and agricultural development over the past two decades; however, the region still faces several challenges, including low agricultural production, poverty, and food insecurity (Bjornlund et al., 2020). The challenges are becoming more complex because 80% of the farmers in the region are smallholders and faces many internal and external challenges (Burke et al., 2020). Studies have shown that the smallholder farmers may be unable to feed the growing SSA population, estimated at 1.52 billion in 2050 (Burke et al., 2020; Bjornlund et al., 2020). Therefore, relying on smallholder farmers without robust measures to improve their farming activities will be a dead trap for the people of SSA in the few decades (Ezeh et al., 2020).

According to Fleshman (2014), smallholders in the SSA mine over 8 million tonnes of nutrients from the soil every year without robust practices to regain the nutrients lost. Fleshman's finding is not surprising since most of these farmers are not trained and uneducated (Anang & Awuni, 2018) as well as faces capital constraint, lacks credit availability (Issahaku & Abdulai, 2020; Missiame et al., 2021), and wrestles against poor climate conditions (Quarshie et al., 2023). Additionally, the smallholder farmers had been hardly hit by the loss of nutrients, resulting in low yields and income (Bjornlund et al., 2020; Oyetunde-Usman et al., 2021).

Among the SSA countries, smallholder farmers in Ghana are significantly affected by soil depletion and nutrient loss (Bjornlund et al., 2020; Dubbert et al., 2023; Gondwe & Nkonde, 2017; Nchanji et al., 2017; Quarshie et al., 2023). According to the Food and Agricultural Organisation (FAO) (2015), it was observed that Ghana experienced significant rates of soil depletion compared to other countries in SSA. Specifically, the depletion rates ranged from 40kg to 60kg of potassium, nitrogen, and phosphorus per ha/yr.

Despite the challenges faced by the smallholder farmers in Ghana, their role in agricultural activities in the country cannot be downplayed (Bjornlund et al., 2020). Therefore, a resilient and robust measure is needed to ensure that smallholder farmers are equipped to improve their farming activities, reduce soil depletion, and boost crop yield. In other words, adopting a more sustainable approach to enhance agricultural productivity among smallholder farmers in Sub-Saharan Africa is paramount.

The Post-2015 Sustainable Development Agenda (SDA) was implemented as a targeted intervention for smallholder farmers in Ghana. The primary objective of the SDA was to implement interventions aimed at promoting Sustainable Agricultural Practises (SAPs) within the farming community in Ghana, as outlined by Marfo et al. (2021). The primary objective of the SAP intervention was to effectively rehabilitate and maintain the productive capacity of farmland, thereby enhancing agricultural yields and generating increased income. During this period, the Regional Fertiliser Subsidy Program Guidance (RFSPG) was established to help reform Ghana's fertiliser subsidy programme. The RFSPG support was to promote mass crop production yields, encourage sustainable agricultural practices, improve smallholder farmers' standard of living, and promote food security in the country.

However, despite this intervention, literature on the adoption of sustainable farm practices is limited among the smallholder farmers. According to Bashagaluke et al., (2018) smallholder farmers struggle to implement sustainable agricultural practices due to a lack of access to modern farming techniques, technologies, and adequate training (Dubbert et al., This has resulted in low technical efficiency among the smallholder farmers (Tesfahunegn et al., 2021). These farmers' limited access to resources and knowledge inhibits their ability to adopt environmentally friendly and resource-efficient farming methods. Without the means to reduce soil depletion and improve their crop yield sustainably, smallholder farmers resort to less eco-friendly practices, such as over-relying on inorganic fertilizers, which exacerbates soil degradation and negatively impacts the environment.

Emphasis on agriculture in Ghana cannot be done without focusing on the Northern part of Ghana where agriculture is their main occupation. This region faces specific challenges that contribute to the low technical efficiency levels among smallholder farmers and their struggles with sustainability. The Northern Region experiences a heightened vulnerability to climate change, with erratic rainfall patterns and droughts being more pronounced. These climatic challenges often force farmers into practices that are less sustainable due to immediate survival needs. Furthermore, limited access to agricultural resources and services in this region can lead smallholder farmers to opt for less sustainable practices, as they may not have the means or knowledge to implement eco-friendly alternatives. By focusing on the Northern Region, the study aims to understand the intersection of technical efficiency and sustainable farming practices in the face of unique environmental and resource constraints.

The study's location in the Northern Region of Ghana also aligns with the government's broader efforts to promote sustainable agriculture throughout the country. Targeting this region allows for a more specific examination of the challenges smallholder farmers face in adopting sustainable practices and the potential interventions needed to address these challenges. It is crucial to understand the distinct dynamics at play in the Northern Region, where climate change and resource limitations may be driving the adoption of unsustainable practices. By addressing these issues in the Northern Region, the study seeks to provide insights and recommendations that can help these smallholder farmers transition towards more sustainable farming methods, ultimately contributing to the long-term environmental health and food security of the region and the nation. Based on the background, the study therefore sought to examine how sustainable farming practice can improve the fertiliser and technical efficiency of smallholder maize farmers in the Northern Regions of Ghana.

**Statement of the Problem**

The soil quality in SSA has long been worsening, and the soil in Ghana is no exception (Gondwe & Nkonde, 2017). Nchanji et al. (2017) reported that soil nutrient deficiencies have been found throughout farmlands in Ghana and can be attributed to poor cultivation and low sustainable practices. Nitrogen and phosphorus are the most inadequate nutrients in Ghana, with nutrient depletion prevalent throughout all agroecological zones (Nchanji et al., 2017). Hill and Kirwan (2015) claimed that the nutrients lost during crop harvest are not replenished, leading to low crop yield and food insecurity.

A multifaceted solution is needed, and recent studies have shown that improved fertiliser use efficiency and sustainable farm practices can improve soil deficiency and boost crop production (Adzawla et al., 2021; Bua et al., 2020). However, fertiliser use efficiency and sustainability practices have rarely been studied among smallholder farmers in the country. Bua et al. (2020) recommended that there is a need for more studies to ascertain the agronomic and sustainability practice of smallholder maize farmers in the Northern part of Ghana.

Also, according to the policy briefing from the IFDC on fertiliser use and maize yields in Ghana, using fertilisers alone to increase maize yields is unsustainable due to low agronomic efficiency (Adzawla et al., 2021). The low agronomic efficiency was seen as a significant threat to maize production in the region, especially as climatic conditions become more unfavourable for cropping (Adzawla et al., 2021). Therefore, the policy paper recommended investigating the importance of fertiliser use efficiency, sustainable agriculture practices, and economic efficiencies.

Several studies have been carried out on fertilizer use in Ghana. Some of these studies include; Yield responses of maize to fertilisers in Ghana (Bua et al., 2020); Fertiliser and genotype effects on maize production on two soils in the Northern region of Ghana (Tahiru et al., 2015); Fertiliser recommendation for maize and maize within the breadbasket zone of Ghana (Tetteh et al., 2018); The response of maize growth and development to mineral fertilisers and soil characteristics (Atakora et al., 2014); "Evaluation of low phosphorus tolerance of rice varieties in northern Ghana (Atakora et al., 2014); and Influence of phosphorus fertiliser blends on grain yield, nutrient concentration, and profitability of soybeans in the southern Guinea Savannah of Ghana (Adjei-Nsiah et al., 2021).

However, to the best of my knowledge, there are limited studies on fertiliser use and maize production in Ghana as well as it is hard to find a study that focused on the sustainability response to the use of fertiliser in Ghana. The study fills the gap and responds to the concerns and recommendation of Adzawla et al. (2021) by focusing on the sustainability implication of fertiliser use in maize production and how that subsequently impact the technical efficiency of the smallholder farmers.

**Purpose of the Study**

The study seeks to achieve its general objective of examining the sustainability responses to fertiliser use in maize production and how that impacts the technical efficiency among smallholder maize farmers in the Northern Regions of Ghana.

## Objectives of the Study

a. To examine the extent of fertiliser use efficiency in maize production.

b. To analyse the extent of sustainability in maize production.

c. To assess how fertiliser use efficiency influences the sustainability of smallholder maize production.

d. To analyse the technical efficiency in maize production.

e. To examine the effect of sustainable farm practices on the technical efficiency of smallholder maize farmers.

## Research Questions

a. What is the extent of fertiliser use efficiency in maize production?

b. What is the extent of sustainability in maize production by smallholder farmers in Northern Ghana?

c. What is the technical efficiency level of maize production by smallholder farmers in Northern Ghana?

## Research Hypothesis

$H_1$: There is a statistically significant relationship between fertiliser use efficiency and sustainable farm practices among smallholder maize farmers.

$H_2$: There is a statistically significant effect of sustainable farm practices on the technical efficiency of smallholder maize farmers.

## Significance of the Study

This study will provide valuable insights for agricultural policymakers and management in enhancing their involvement with smallholder maize farmers to promote sustainable maize production. The study will provide a foundation for policy development to strengthen sustainable farming practice within Northern part of Ghana. The research findings will have substantial implications for the Ministry of Agriculture to investment in sustainable farming practises within the country. This study will provide a significant reference point for future research in the academic institutions.

**Delimitation of the Study**

The study primarily examined smallholder farmers engaged in maize cultivation within the five regions of Northern Ghana, namely Upper West, Upper East, North East, Northern, and Savannah. Furthermore, the investigation centred on three primary domains and established their relationship. The three focal domains were fertiliser use efficiency, sustainable farming practises, and technical efficiency. The research was grounded in the positivist research philosophy, and its analysis was solely focused on quantitative methods.

**Limitations of the Study**

The primary limitation of this study pertained to the constrained imposed by time and finances. Due to these limitations, the research could not extend its focus to a more extensive and diverse population in the country. Also because of these limitations, the study was unable to incorporate other pertinent study areas such as the middle belt regions in the country. Additionally, the exclusive use of a quantitative research method restricted the depth and contextual richness of the study findings, potentially overlooking important qualitative nuances and insights that could have enriched the overall analysis.

**Definition of Key Terms**

1. **Smallholder farmers**: Smallholder farmers cultivate relatively small portions of land and produce relatively small volumes of agricultural products. Smallholder farmers are generally less well-equipped than large commercial farmers, and they are typically considered part of the informal economy due to factors such as lack of registration, limited access to labour legislation and social protection, and minimal record-keeping. Smallholder farmers rely on family labour, and few hire workers to help them on the farms.
2. **Sustainability farm practices**: It is the agronomic practices used by maize farmers. It includes row planning, appropriate planting distance, planting with recommended spacing, crop rotation, improved seed varieties, keeping weed-free farm, crop-livestock integration, organic fertiliser, bunding, mulching, minimum tillage, contour farming, and pre-emergence weedicides application.
3. **Fertiliser Use Efficiency**: Fertiliser use efficiency measures how effectively farmers apply or utiliser fertiliser on the farm. It is calculated by measuring the marginal value product over the marginal factor cost of fertiliser. A higher fertiliser use efficiency indicates that more value is attained at less cost.
4. **Technical Efficiency**: Technical efficiency refers to the ability of a farm to use its inputs, such as land, labor, capital, fertiliser and agrochemicals in an optimal manner to produce the maximum possible level of crop output or yield. A technically efficient farm is one that produces the highest attainable level of agricultural products given its available resources and the technology it employs, without any wastage or inefficiencies in the production process. In other words, it

represents the farm's ability to get the most out of its inputs and available technology to produce crops.

**Organisation of the Study**

The thesis was organised into five chapters. Chapter one covered the introduction, which was made up of the background of the study, statement of the problem, research objectives, research questions, significance of the study, the delimitation of the study, limitation, definition of key terms, and organisation of the study. Chapter Two constituted a review of relevant theoretical and empirical literature related to the study as well as the conceptual framework of the study. Chapter Three covered the methodology used for the study. Chapter Four covered the results and discussion of the study. Chapter Five presented the summary, conclusions, recommendations, and suggestions for future research.

# CHAPTER TWO

# LITERATURE REVIEW

## Introduction

Chapter two comprises the study's theories, concepts, key models and empirical literature. First, the chapter explained the two theories, namely, the theory of production and Schultz's theory. The study also reviewed the core concept of the research, that is, sustainability, sustainable farm practices, the production efficiencies (resource efficiency, fertiliser use efficiency, and technical efficiency). The study reviewed the literature on the two main theoretical models: Heckit Treatment Effect Model and the Seemingly Unrelated Regression Model. Also, the chapter presented empirical literature on resource efficiency, fertiliser use efficiency, technical efficiency, the influence of fertiliser use efficiency on the sustainability of crop production, and the effects of sustainable farm practices on the technical efficiency of smallholder farmers. The chapter also presented the conceptual framework of the study.

## Theoretical Literature

### Theory of Production

The theory of production in economics is a fundamental concept that deals with the processes and relationships involved in transforming inputs into outputs (Cobb & Douglas, 1928). It examines how an entity or an economy uses a variety of inputs, including labour, capital, and raw resources, to produce goods and services (Inkoom & Micah, 2017). The theory of production is primarily focused on the relationship between inputs and outputs, as well as devising strategies to optimise output within the constraints of limited resources. The theory is explained through a mathematical exposition of the combination between inputs and outputs (Inkoom & Micah, 2017).

The theory of production considers the concepts of productivity and efficiency and examines short-run and long-run production decisions (Cobb & Douglas, 1928). The theory of production provides insights into resource allocation, cost analysis, technological advancements, and the factors influencing output levels in both microeconomics (individual firms) and macroeconomics (the entire economy). It forms the basis for understanding production decisions, economic growth, and productivity (Inkoom & Micah, 2017).

The production theory is based on three (3) primary inputs: land, labour, and capital (Inkoom, 2014). This theory is highly applicable to farmers' operations in the agricultural sector, particularly those engaged in crop production (Inkoom, 2014). Farmers utilize a range of inputs, including land, labour, capital, fertilisers, and agrochemicals, to cultivate their crops. The theory provides valuable insights into the practices and principles underlying the work of smallholder maize farmers (Inkoom, 2014). By employing the theory of production, this research project adopted more accurate empirical concepts and measurement techniques to achieve the study objectives.

**Schultz Theory**

The theory was propounded by Theodore William Schultz (Schultz, 1965) and aimed to improve traditional farming (Lundahl, 2021). Farming practices that have been passed down through generations rely on the same production factors. According to Schultz, this type of farming often resulted in low yields and income (Lundahl, 2021; Schultz, 1965). Therefore, the goal of Schultz was to address the issue by transforming traditional agriculture into a highly productive form of farming. Schultz argued that solving the low yields among smallholder farmers requires more than simply injecting capital into their farmers' activities (Schultz, 1965).

Schultz argued that smallholder farming cannot achieve significant growth solely by relying on the same traditional production factor (Lundahl, 2021). Following Schultz's assertion, smallholder farmers in Ghana continues in conventional agricultural practices, which have endured across generations, leading to low crop yields and income levels for these farmers. Hence, new and different production factors are necessary to achieve higher productivity. Thus, Schultz's theory focused on adopting a more robust farming approach among smallholder farmers.

This theory has a significant implication for the study as it seeks to address the same issue Schulz raised and its approach to solving the problems. This study also emphasised improving smallholder farmers' practices by adopting a more sustainable approach to achieve resource and overall technical efficiency. Schultz's seminal contributions underscored the importance of education, agricultural extension services, and research and development as catalysts for augmenting agricultural productivity. This study also makes the case that smallholder farmers need to be trained in sustainable agricultural farming. The researcher argued that implementing sustainable farm practises would increase farmers' productivity and efficiency, which would increase agricultural output and economic growth.

## Concept of Sustainability

Sustainability, as a concept, has deep historical roots but has gained prominence and evolved over time. Its history can be traced back to the early 20th century, when visionaries like Gifford Pinchot and Theodore Roosevelt in the United States recognized the importance of conserving natural resources for future generations (Bacon, 2023). They laid the groundwork for modern environmental conservation efforts. However, the concept of sustainability gained further traction in the mid-20th century with the publication of Rachel Carson's groundbreaking book, "Silent Spring," which raised awareness about the environmental impacts of pesticides (Heitkamp, 2017). This led to the establishment of the Environmental Protection Agency (EPA) in 1970, signaling a growing commitment to protecting the environment.

The 1980s and 1990s saw a significant shift towards a more comprehensive understanding of sustainability. The Brundtland Report, published by the United Nations in 1987, defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development (WCED) & Brundtland, 1987). This definition highlighted the interdependence of economic, social, and environmental factors in achieving sustainability. In recent decades, the concept of sustainability has broadened to include a wide range of issues, such as climate change, biodiversity conservation, social equity, and economic stability (Caradonna, 2022; Spindler, 2013). The United Nations' Sustainable Development Goals (SDGs), adopted in 2015, represent a global framework for addressing these challenges. Sustainability is no longer just an environmental concern; it's about finding holistic solutions to global problems (Caradonna, 2022).

Today, sustainability is a guiding principle for governments, businesses, and individuals around the world. It informs policies, corporate practices, and consumer choices. Efforts to achieve sustainability involve renewable energy, waste reduction, sustainable agriculture, and green infrastructure (Caradonna, 2022). The urgency of addressing global challenges like climate change and resource depletion makes sustainability an ever more pressing and central concept in our modern world.

In summary, Sustainability encompasses satisfying current needs while safeguarding the capacity of future generations to fulfill their own requirements. Sustainable practices ensure the responsible use of natural resources, promote social equity, and strive for economic viability, aiming to create a balance that preserves the well-being of current and future generations while safeguarding the health of the planet. Sustainability encompasses environmental conservation, social responsibility, and economic stability, emphasizing the interconnectedness of ecological, social, and economic factors in decision-making processes and actions. In the context of this study sustainability is geared towards addressing farm practices.

**Sustainable farm practice**

Sustainable farm practice also known as sustainable agriculture originated from the concept of sustainability and has its roots in ancient agricultural practices. However, with the advent of industrialization in the 20th century, agriculture underwent significant changes (Caradonna, 2022). Intensive farming methods, widespread pesticide and fertilizer use, and monoculture cropping became prevalent, leading to environmental degradation, loss of biodiversity, and soil erosion (Adnan et al., 2017). In response to these challenges, the concept of sustainable agriculture emerged as a holistic approach to farming, emphasizing the importance of balancing environmental stewardship, economic viability, and social equity.

In the pursuit of sustainable agriculture, farmers and agricultural scientists began to integrate ancient farming techniques with modern scientific knowledge. Crop rotation, cover cropping, and organic farming methods gained prominence, aiming to enhance soil fertility, reduce reliance on chemical inputs, and promote natural pest control (Khwidzhili & Worth, 2016). Conservation tillage techniques were introduced to minimize soil erosion, and agroforestry practices integrated trees into farmland, enhancing biodiversity and providing valuable ecosystem services (Donkoh, 2019). These efforts were complemented by the development of integrated pest management strategies, emphasizing the use of natural predators and organic solutions to control pests, reducing the need for harmful chemicals. Additionally, sustainable agriculture placed a strong emphasis on community engagement, encouraging farmers to work closely with local communities, adopt fair labor practices, and support regional economies (Adnan et al., 2017).

Today, sustainable agriculture stands as a beacon of hope for the future of food production. By embracing these practices, farmers can mitigate the adverse environmental effects of traditional farming, conserve vital natural resources, and create a more resilient and equitable agricultural system for generations to come.

Through ongoing research, education, and global collaboration, sustainable agriculture continues to evolve, offering innovative solutions to the complex challenges faced by the agricultural sector.

In this study, sustainable agricultural practices are defined as the specific agronomic methods employed by farmers to enhance the productivity of their farms while simultaneously minimizing environmental impact. These practices encompass a range of techniques, such as strategic row planning, appropriate planting distances, and adhering to recommended spacing between crops. Farmers also employ methods like crop rotation, integrating livestock with crops, using organic fertilizers, and adopting weed management strategies to maintain weed-free fields. Additionally, techniques such as bunding, mulching, minimum tillage, and contour farming are implemented to preserve soil structure and fertility. Furthermore, pre-emergence weedicides are applied to control weed growth. These practices are meticulously chosen and implemented to ensure that farmers can not only increase their crop yields but also enhance the quality of their soil. Moreover, these methods are designed to counteract soil depletion and minimize the adverse impact on the environment, promoting a sustainable and harmonious relationship between agriculture and nature.

## Concept of Production Efficiency

### Production Efficiency

Production efficiency refers to the state in which a firm or economy is producing goods and services at the maximum possible output level for a given set of inputs and technology (Inkoom & Micah, 2017). It is often associated with minimizing waste and optimizing resource utilization in the production process. Production efficiency focuses on using resources and inputs as effectively as possible to produce the highest possible level of output. The dimension of efficiency has garnered significant attention from policymakers and scholars in the 21st century. It is the bedrock of economics and agricultural production (Inkoom & Micah, 2017). First, the theoretical framework of Adam Smith began the concepts of productivity and efficiency measurement. He argued that dividing the production process into specialized tasks would significantly increase efficiency and productivity. Apart from Adam Smith, Koopmans (1951), Debreu (1951), and Farrell (1957) also became instrumental in establishing a robust analytical framework for the measurement of production efficiency (Inkoom, 2014). Many studies on efficiency measurement, especially in agricultural production, was built on the work of Farrell (1957).

Farrell's essential contribution in 1957 expanded the theoretical framework of production efficiency by further developing the foundations laid by Koopmans and Debreu. Koopmans (1951) expounded upon the concept of efficiency by employing the input-output vector as a fundamental framework. As per Koopmans, the concept of efficiency posits that it is unfeasible to augment the production of any given output or curtail the utilisation of any input without concomitantly diminishing the production of another output or intensifying the utilisation of another input. With Debreu's (1951), most of his work focused on the valuation of production efficiency and measuring the coefficient of resource utilisation.

In conjunction with Koopmans and Debreu's seminal contributions, Farrell acknowledged the necessity for producers to choose the optimal input-output combination by considering the prevailing market prices of both inputs and outputs. According to Farrell's proposition, obtaining productive efficiency on a macro level is dependent upon the harmonious integration of both allocative and technical efficiency, which is usually referred to as economic efficiency. In other words, economic efficiency is the key to creating productive efficiency. According to Farrell, the attainment of economic efficiency occurs when a producer can optimise resource use to maximise output while simultaneously minimising the cost associated with achieving maximum revenue. Farrell concluded in his earlier works that production economists should factor out technical and allocative efficiency when measuring any form of production efficiency.

Daraio and Simar (2005) later also built upon the works of Farrell and other production economists. Daraio and Simar define efficiency as the ability of a production body to maximise output by using a certain mix of inputs, considering different production units and technological factors. This definition takes into consideration the idea that the best-performing factors may not necessarily use the same inputs or have the same technologies. The efficiency definition, as articulated by Daraio and Simar, is widely employed in the context of data envelopment analysis (DEA), a non-parametric technique employed to assess the relative efficiency of multiple decision-making units.

According to Kavi (2015), farmers need to be efficient, technically, allocatively and resourcefully. Given the primary objective, which is to determine the technical and resource efficiency of smallholder maize farmers, it is imperative to grasp the fundamental concept of production efficiency. It is also important to understand production efficiency because the smallholder farmers used limited resources such as land, capital, labour, fertiliser and agrochemical.

**Resource Use Efficiency**

Resource use efficiency refers to the optimal utilization of resources to achieve a desired level of economic output or well-being while minimizing waste and inefficiency (Hodapp et al., 2019). It involves using resources in a manner that maximizes the benefits derived from them and minimizes their negative impacts on the environment, as well as considering factors like cost-effectiveness and sustainability. RUE is the ability to use limited resources sustainably while minimising environmental negative impacts (Moreno & García-Álvarez, 2018). Through the implementation of resource use efficiency, farmers can increase their output while using fewer resources, resulting in the generation of higher value with reduced input (Moreno & García-Álvarez, 2018). The definition shows how important it is to use resources in agriculture in a way that is sustainable and how farmers could benefit from using good methods for managing resources.

According to Hodapp *et al.* (2019), the concept of resource use efficiency (RUE) in the agricultural sector can be attributed to the law of the minimum postulated by Sprengel and Liebscher. The definition offered by these authors concentrated on the proportion of mineral nutrients required to stimulate plant growth, as well as the appropriate supply of nutrients. Liebscher scholarly work explained that to achieve the highest crop yields, the agricultural sector must rely on resource use efficiency (Hodapp et al., 2019). Currently, the concept of RUE has its roots in the works of De-Wit (1992). According to De-Wit, efficient crop production in the era of agricultural industrialization requires the most effective use of available resources. RUE is now increasingly employed in agricultural economics together with allocative and technical efficiency.

Recent research has also shown how important it is for the farming sector to make efficient use of its resources (Osei Danquah et al., 2020; Tasila Konja et al., 2019). Tasila Konja et al. (2019) defined resource efficiency as the ability to make the best use of natural resources and get the most out of them. When there is a better level of resource efficiency, agricultural production uses less resources to produce more benefits. This shows how important it is for agriculture to use sustainable practises for managing resources and how helpful it could be to improve resource efficiency in the field.

Awunyo-Vitor et al. (2016) described how land, labor, capital, fertilizers, and agrochemicals play a crucial role in crop production as essential agricultural resources. However, the authors also highlighted that smallholder farmers tend to excessively exploit these finite resources, posing a significant concern that undermines the pursuit of sustainable development goals. Sienso et al. (2014) asserted that ensuring the efficiency of these resources is the gateway to achieving economic efficiency, improving output, and achieving the SDGs.

Therefore, based on the discussion, RUE can be said to be the strategic and sustainable utilization of limited resources, such as land, labor, capital, fertilizers, and agrochemicals, in agricultural production to maximize output while minimizing environmental negative impacts. It involves implementing practices that allow farmers to generate higher value with reduced inputs, in line with the principles of cost-effectiveness, sustainability, and minimizing waste, contributing to the pursuit of sustainable development goals and improved agricultural productivity (Hodapp et al., 2019; Moreno & García-Álvarez, 2018; Osei Danquah et al., 2020; Tasila Konja et al., 2019; Awunyo-Vitor et al., 2016; Sienso et al., 2014).

**Technical Efficiency**

Farrell (1957) is credited with introducing the concept of technical efficiency. According to Farrell technical efficiency can be explained as a firm’s ability to achieve the highest level of output, given an established quantity of input and technology available at the time. Ellis (1993) also defined technical efficiency as the maximum amount of output that can be achieved with a certain level of input, taking into account the limitations of the firm's available technologies (Kavi, 2015).

The evaluation of technical efficiency can be conducted using two major orientations, specifically the output-oriented approach and the input-oriented approach. The input-oriented approach aims to allocate resources efficiently to attain a specific output level, whereas the output-oriented approach aims to maximise output by efficiently utilising resources. Technical efficiency is attained when the production process operates effectively along the production possibility frontier. This implies that the optimal production level is achieved when a specific combination of inputs is utilised, or alternatively, the minimal amount of inputs required to generate an optimum output level. Technical efficiency is a pivotal concept within the realm of production economics, as it serves to gauge the productivity and efficiency of a given production process.

Narrowing down this concept to agricultural production, Inkoom (2014) asserted that farmers are deemed technically efficient if they operate at the production frontier level. When farmers perform below the production frontier level, they are deemed technically inefficient. Inkoom (2014) added that farmers may not consistently operate at the production frontier owing to unpredictable variables, such as adverse climatic conditions, animal-related losses, and idiosyncratic factors specific to individual farms.

**Fertiliser Use Efficiency**

The term "Fertiliser Use Efficiency" (FUE) has been in use for several decades, and it has gained more popularity in recent times as FUE indexes are used to evaluate the global productivity of NPK fertilisers (Fixen et al., 2015). FUE is a pivotal concept that holds significant prominence in the existing body of food production literature (Grzebisz & Łukowiak, 2021). FUE is the method of applying fertilisers strategically to increase crop yield and overall agricultural output (Fixen et al., 2015). The fundamental aim of FUE is to optimise the productivity of agricultural systems by ensuring that crops receive the necessary nutrients to maximise output, while simultaneously minimising nutrient wastage from the field.

According to Barlóg et al. (2022) FUE can improve the efficiency of nitrogen uptake and utilisation within the soil/plant ecosystem. The efficacy of fertiliser is determined by the availability of critical nutrients required for absorption and utilisation during a clearly defined phase of crop yield development. FUE can be optimised through deliberate adjustment of fertiliser application based on the plant's unique requirements. FUE also removes soil obstacles that prevent plant nutrients from reaching the root surface.

According to Jin's (2012) findings, the attainment of FUE can yield cost reductions in food production and safeguard natural resources. Allison's (2019) observed that a significant proportion, precisely 40%, of NPK fertiliser applied to crops goes waste due to non-utilization. Through the improvement of FUE agricultural producers have the potential to mitigate losses and augment their profit margins. The fertiliser industry has strategically advocated for the concept of FUE by offering a range of fertiliser management strategies, including the 4R Nutrient Stewardship and the Fertiliser Product Stewardship Programme. These initiatives emphasise the importance of employing the appropriate nutrient source, timing, rate, and placement to optimise fertiliser utilisation.

Grzebisz and Łukowiak (2021) stated that although FUE may appear to be a straightforward term, it is, in fact, a complex concept that requires a comprehensive and operational definition due to a variety of possible nutrient sources, such as manure, soil, and aerial deposition, and numerous factors that affect crop nutrient demand, including crop management, genetics, and weather. The fundamental objective of FUE remains unchanged: to optimise the efficiency of agricultural systems by providing economically optimal nutrients to crops while minimising nutrient losses from the field. Furthermore, the implementation of FUE serves to bolster the sustainability of the crop system through the growth of soil fertility and other pertinent facets of soil quality (Drechsel et al., 2015).

This section provided an overview of the main concepts employed throughout the research. These concepts of production efficiency, resource use efficiency, technical efficiency, fertiliser use efficiency, sustainability and sustainable agriculture are essential for addressing the objectives of the study. The next section provides the analytical framework of the study. It is crucial to review literature on the primary analytical models of the study. This will provide a better picture of how these models were used to analyse the key study objectives.

**Empirical Review of Theoretical Models**

**Heckit Treatment Effect Model**

Rejeb and Boughrara (2013) explained that the Heckit Treatment Effect Model (HTEM) can be traced back to Heckman's seminal contributions 1976 concerning wages and labour supply. In subsequent years, a collection of scholarly articles published in the late 1970s by Heckman and Lee, and other esteemed economists served to enhance, elaborate, and demonstrate the existing model. The model's conceptual foundation is selection bias, a term that is frequently used in econometrics.

The Heckit model postulates that the sample selection process is contingent upon a latent variable that correlates with the outcome variable under scrutiny. The model comprises a dual-stage process: the initial stage involves estimating the selection equation, which represents the likelihood of being chosen for inclusion in the sample, based on the observed and unobserved variables that influence the selection mechanism. The second phase entails the estimation of the outcome equation, which encapsulates the economic nexus between the outcome variable and the observed, as well as unobserved factors that influence the outcome.

Heckman (1976) introduced the "treatment effect model" to resolve omitted variables bias during a regression-adjusted comparison (Guo & Fraser, 2014; Spieker et al., 2015). The model can be used to estimate regression models, instrumental variables and matching estimators using the two-step process (Basu, 2011; Guo & Fraser, 2014). Greene (2003) proposed that the potential-outcomes framework offers a clear understanding of the connection between omitted variables causality, bias and treatment effects.

The concept of sample selection bias is commonly revealed by scholars as a sequential procedure, as expounded upon by Certo et al. (2016). In the initial phase, it is imperative to ascertain whether an observation within the broader population is encompassed within the ultimate representative sample. The subsequent phase involves doing an in-depth simulation of the association that exists between the endogenous and exogenous variables that have been identified inside the final model (Scott, 2019). Nevertheless, conventional approaches such as OLS regression have the potential to generate coefficient estimates that are susceptible to bias in situations in which an unexplained factor enhances the correlation between the error components in both stages (Guo & Fraser, 2014; Scott, 2019). The Heckit model is frequently used to address the problem of sample selection bias (Scott, 2019).

Rabbi et al. (2019) used Heckit's treatment model to examine the process of commercialization and how it affects the lives of smallholder rice farmers. They study hypothesised that selection bias might be present if latent variables have an impact on the welfare equation's error term as well as the market's participation. Therefore, the study ignored the use of ordinary least squares (OLS) as it will lead to a biased estimate. Rabbi et al. (2019) addressed this issue by implementing the two-step approach of the Heckit model. Moreover, Rabbi et al. (2019) concluded that the model was suitable for correcting the issue of simultaneity bias.

The benefits of using the Heckit treatment effect model include addressing endogeneity issues between variables and assessing the influence of the intermediary variable (treated variable) (Rejeb & Boughrara, 2013). This study adopted the Heckit treatment effect model due to the researcher's assumption that there might be some endogeneity issue arising when investigating the impacts of sustainability practices on technical efficiency of smallholder maize farmers in northern Ghana.

**Empirical Review of Heckit Treatment Effect Model**

Danso-Abbeam et al. (2018) examined the economic implications of agricultural extension services on farm productivity and income levels in the Northern Region of Ghana. The researchers employed the Heckit treatment effect model to address the issue of selectivity bias in the third stage. The researchers found that the Heckit model emerged as the most appropriate approach for analysing extension officers' impact on farm productivity and income. Danso-Abbeam successfully addressed the selection bias and found out that Heckit treatment effect model, outperformed other models used.

Ehiakpor et al. (2016) examined the impact of climatic variability on farmers' perceptions of adaptation techniques in the Suaman region of the Western Region. Ehiakpor et al. adopted the Heckit treatment effect model as a means to address the issue of selection bias within the sample. They employed a two-stage approach within the framework of the Heckit model. This approach involved the use of a binary probit model to address the selection equation, followed by implementing a linear or average response model to tackle the substantive equation. The authors asserted that employing the Heckit model produced a better result in achieving the study's objective compared to using the ordinary least squares.

Lambongang et al. (2019) assessed the influence of Planting for Food and Jobs project on maize yields in the Yunyoo District of the Northern Region was carried out. Due to potential endogeneity concerns with the participation variable, the study employed the Heckit effect model. The authors recognized that unobserved factors, including the quality of fertilizers and certified seeds, farmers' reluctance to participate, and the limitation of surveying only one group, might influence the actual impact of the program on maize yields. Therefore, the Heckit Model was considered the most suitable approach to address endogeneity and account for these unobserved factors.

The study conducted by Azumah and Zakaria (2019) delved into the intricate dynamics between fertiliser subsidies and rice productivity within the context of Ghana. The researchers employed treatment effect models to examine the determinants of farmers' engagement in fertiliser subsidy programmes and the subsequent effects on rice productivity. The study utilised Heckit's sample selection model to implement a two-stage method. The initial phase involved estimating a probit equation to determine the endogenous dummy dependent variable. Subsequently, a regression model of a non-linear least squares factor was estimated in the second stage. According to Azumah and Zakaria, the Heckit model emerges as the optimal and suitable model for the study.

Abdul-Rahman and Abdulai (2022) studied the use of mobile money technology and its impact on smallholder rice farmers in the Northern Region. In the first stage, a two-stage Heckit treatment effects was used to study the factors that affect farmers' use of mobile money technology. In the second stage, the effects of this technology on continuous outcome variables like input use and output were studied. The authors highlighted the model's intrinsic benefits as justification for selecting it over alternative impact assessment techniques like PSM and IPWRA.

The literature reviewed suggests that the Heckit Treatment Effect Model addresses selectivity bias in data analysis. It also helps to solve problems such as endogeneity and unobserved factors. Heckit treatment effect model was the best fit to achieve the study objectives of examining the effects of sustainable practises on the technical efficiency of smallholder maize farmers. Despite the advantages of the Heckit treatment effect model, some key concerns or irregularities need to be noted when using the model.

**Seemingly Unrelated Regression Model**

Seemingly Unrelated Regressions (SUR) is a group of regression equations with interrelated error terms (Olamide, 2018). These equations can be separately estimated using various methods, such as iterative ordinary least squares, generalized least squares, and ordinary least squares. Numerous researchers have investigated the SUR model in various forms, and Zellner (1962) comprehensively explained the model. According to Zellner's analysis, the SUR model involves estimating a set of linear regression equations with correlated errors, leading to more efficient estimations in comparison to the alternative method of estimating each equation separately.

Binkley and Nelson (1988) provided further insight into the efficiency of the SUR model, stating that the covariance matrix is equivalent to that of the ordinary least squares model. This means the SUR model can be more appropriate than OLS in multi-equation regression models where disturbances may be correlated, leading to incorrect assumptions of independent errors. Consequently, many researchers prefer to use SUR over OLS to avoid the issue related to OLS (Afolayan & Adeleke, 2018; Grover et al., 2022; Olamide, 2018).

The SUR method considers the correlations and associations between error variables, resulting in more accurate estimates (Afolayan & Adeleke, 2018; Olamide, 2018). In this study, the SUR model was employed to examine the effect of fertilizer use efficiency on the sustainability of maize production. Furthermore, the SUR model was chosen as the preferred regression model over other alternatives due to its ability to produce lower standard errors.

**Empirical Review of Seemingly Unrelated Regression Model**

Mensah-Bonsu and Appiah (2008) employed the SUR model to derive estimates for cost function in their study. This function was characterised by the coefficients obtained from the cost share equations about different inputs, including fertiliser, fuel, agrochemicals, and labour. The investigation focused on vegetable farms in the Volta Region. The researchers utilised cross-sectional study design was used for the analysis. The empirical study analysis showed the SUR model was the best model fit and statistically showed a significant substitution effect between agrochemicals and fertiliser.

In a scholarly inquiry by Acharya (2018), an examination was conducted to scrutinise the implications of climate change and prevailing market conditions on the production output of crops and the distribution of land resources in Nepal. In the study, Acharya utilised the SUR model to estimate the acreage and the crop yield. The study discovered that the distribution of land resources is influenced by the costs of agricultural inputs and products. Moreover, the findings unveiled that a 10% decline in the number of precipitation days throughout the agricultural period would yield a 4.8% decrease in rice yields, a 1.7% decrease in maize yields, and a 0.8% decrease in wheat yields.

Awiti et al. (2022) undertook a comprehensive investigation to assess the influence of crop diversification on the variable cost structure among smallholder farmers in Western Kenya. The researchers utilized both a translog function model and a SUR model to study the effects of adopting a crop diversification approach on production variable costs. By applying the SUR model, the study successfully analyzed the influence of crop diversification on the overall cost framework of farm production among smallholder farmers in the Western part of Kenya.

Maniriho et al. (2020) assessed the economic efficiency of input combinations utilised by small-scale onion farmers in of Rwanda. The data collection process involved using a survey, which was distributed to a randomly selected group of 94 individuals involved in onion production. To ascertain the origins of allocative, technical and economic efficiencies, the researchers delineated and computed a simultaneous-equations model employing the SUR method. The authors posited that the SUR model was deemed suitable due to its ability to explain the relationship between seeds and organic fertilisers in onion production.

Edriss and Matchaya (2013) evaluated the efficiency of smallholder potato farmers in Dedza district, Malawi. This evaluation employed a translog cost frontier, input elasticities and the inefficiency effect model derived from the SUR Model equations related to fertiliser, seed, labour and land. The study revealed that the mean level of technical efficiency in Irish potato cultivation within Dedza District is estimated to be 0.61, displaying a range of variability spanning from 0.12 to 0.94. The observed disparities in economic efficiency were attributed to various factors such as educational attainment, non-farm employment, access to credit, degree of specialisation, level of farm experience and household size. The study further revealed that labour and fertilisers exhibit the most pronounced degree of input substitution, with seed and fertilisers following suit regarding their substitutability.

Hung-Anh and Bokelmann (2019) examined the market preferences of farmers in Vietnam. The SUR model was used in the study to ascertain the socioeconomic factors, transaction cost attributes, sales volume in various markets, and behavioural aspects of sustainable coffee farmers. The researchers indicated that the SUR model was deemed suitable for the study objective, which entails assessing the impact of farmers' market preferences on various factors, including price uncertainty, market competition, speed of payment, transportation cost, and the socioeconomic characteristics of the farmers.

Danso-Abbeam and Baiyegunhi (2020) analysed the influence of technical efficiency on welfare. This investigation employed two methodologies: DEA and CMP. The construction of CMP was predicated upon utilising the SUR model. The researchers recommended that the SUR model was able to estimate better than the other regression models. The researchers found that the overall technical efficiency level of the farmers was 56%.

The study conducted by Quansah et al. (2020) delved into the agricultural practises employed by urban vegetable farmers in Greater Accra to explore the correlation between farm practises and the safety of microbial in vegetables. The researchers utilised the SUR model to ascertain the correlation between agricultural practises, and microbial safety. Quansah and colleagues asserted that the SUR model, in comparison to alternative models like the OLS, demonstrated superior efficacy in estimating the correlation of their study objective.

Moreover, Martey et al. (2021) studied the influence of cropland distribution amidst the COVID-19 pandemic. The empirical investigation encompassed a sample of 309 agricultural households, wherein the data was subjected to analysis employing the probit and SUR models. The results revealed that the decision-making process regarding the allocation of cropland was influenced by socio-economic, production, institutional, and political considerations. These factors were been found to significantly impact the selection of legumes and cereals and the magnitude of cropland allocated to these crops.

Based on the review of the literatures, it can be asserted that the SUR model has been widely employed in the agricultural economics field to establish regression relationships or correlations between variables. Studies reviewed showed that the SUR model is useful in addressing limitations observed in other regression models. The present investigation, thus, employed this framework to examine the effect of fertiliser use efficiency on the sustainability of smallholder maize farmers.

## Empirical Review

### Resource efficiency of maize farming

The study conducted by Awunyo-Vitor et al. (2016) assessed the resource use efficiency within the context of maize cultivation in Ghana. A cross-sectional design involved 576 maize farmers across various regions of Ghana was used. The researchers used different analytical techniques, including descriptive statistics, the ratio of marginal value product to marginal factor cost and stochastic frontier analysis to examine and interpret the data. The study revealed that the maize farmers in Ghana underutilised resource resources. Regarding resource use efficiency, land, fertilisers, pesticides, herbicides, manure, seeds were underutilised and capital and labour were overutilised. The empirical analysis further revealed that the agricultural producers demonstrated a relationship between the scale of production and output, indicating the potential for enhanced productivity by augmenting critical resources.

Osei Danquah et al. (2020) evaluated the efficacy of smallholder maize farmers in optimising input resources, including labour, capital, land, fertilisers, herbicides, pesticides, and improved seed. The study findings showed that smallholder farmers did not achieve optimal use of resources such as fertiliser, herbicides, pesticides, improved seed, and land. The farmers were found to either overutilised or underutilised the farm resources. The study also found that labour and capital were extensively overutilised which resulted in high cost of inputs over revenue generated on the farm.

Tasila Konja et al. (2019) examined the resource-use and technical efficiency levels of rice farming in the Northern Region. The findings indicated a positive correlation between farm size, weedicide quantity, and fertiliser usage with rice output. On the other hand, it was observed that weedicide, fertiliser, and seed are being excessively employed, suggesting an overutilization of these inputs. The empirical analysis also indicated that implementing a farm-level policy that emphasises incentivizing and providing training to rural farm households in farm management has the possibility to enhance the farmers productivity and resource use efficiency.

Sienso et al. (2013) measured resource utilization efficiency among farmers in Nkoranza, Brong Ahafo Region, during the 2008 cropping season. The researchers employed the stochastic frontier to estimate the parameters of a Translog production function. The findings showed that maize farmers Nkoranza overused labour and underused fertiliser and seeds. The study concluded most farmers in Ghana are unable to achieve resource use efficiency due to low resilient and robust sustainable farm practices.

The existing body of literature on resource efficiency showed that smallholder farmers in Ghana are not resource use efficient and they are either overusing or underusing farm resources (Awunyo-Vitor et al., 2016; Osei Danquah et al., 2020; Sienso et al., 2013; Tasila Konja et al., 2019). Even though the current study focused on only fertiliser use efficiency, it also analysed all other resource input used by farmers such as land, labour, capital and agrochemical. The study assumed that analysing other farm resources in addition to fertiliser will provide a better picture for empirical discussions.

**Fertiliser Use Efficiency**

Hill's (2014) empirical inquiry delved into the intricate dynamics surrounding the utilisation of fertilisers and its consequential impact on maize yields within the agricultural landscape of Ghana. The empirical analysis revealed a significant correlation between the application of fertilisers and the enhancement of maize yields. Likewise, Kintché and colleagues (2015) conducted a study that revealed a notable reduction in maize yields among farmers who refrained from using fertilizers.

Kamanga et al. (2014) studied the efficiency of fertiliser use among smallholder maize farmers in Malawi. Their research findings indicated that maize farmers showed a lack of efficiency in their use of fertilisers. Therefore, Kamanga et al. (2014) investigated a dozen small-scale agricultural establishments in Chisepo, a region in the heart of Malawi. The primary objective was to scrutinise the repercussions of employing diminished levels of nitrogen (15 or 30 kg per hectare) and phosphorus (9 kg per hectare) fertilisers, alongside enhanced weed control measures, on the overall output of maize crops. The empirical analysis revealed that the utilisation of NP fertiliser exhibited a statistically significant impact ($p < 0.001$) on the increase of maize grain yield. Furthermore, it is worth noting that the application of double-weeding techniques on fertilised maize demonstrated a statistically significant increase in maize yields (p 0.001) compared to the practise of single weeding, which resulted in gains of 0.9 t ha1.

Sheahan et al. (2016) undertook research in Kenya to examine the implication of fertiliser use on maize output. The researchers have unveiled that during the period spanning from 1997 to 2010, there was a notable decline of approximately 27% in the actual prices of fertilisers. This decline led to the implementation of market reforms to reduce marketing margins. The study observed that reduction in price led to a notable surge of 36% in fertiliser use on maize fields, accompanied by a corresponding 9% upturn in maize production. The study therefore suggest that the more fertiliser was used by maize farmers, maize production increased marginally.

Kanton et al. (2016) examined the reduction in maize yields in the Northern Region of Ghana. The study found that inefficient utilisation of fertiliser resulted in low productivity. The study also revealed that organic and inorganic fertilizer use among the few maize farmer showed an outstanding improvement in stem girth, plant height, straw yields and harvest outcomes. Kanton et al. (2016) concluded that effectively using fertiliser among smallholder farmers in Ghana will improve maize production substantially.

There is some form of gap in existing body of literature when it comes to fertiliser use efficiency. It is quite noting that, only few studies have been done in Ghana that focused on fertiliser use among smallholder farmers. Nevertheless, upon careful examination of these studies, it is evident that utilising fertiliser efficiently has the propensity to enhance crop yields and bolster agricultural output. Hence, this study aims to ascertain the fertilizer use efficiency level among smallholder maize farmers and how it influences the sustainable maize production.

**Technical efficiency in smallholder maize farmers**

Bempomaa and Acquah (2014) employed a stochastic frontier approach to examine maize farmers' productivity levels within the Ejura District of Ghana. The used the maximum likelihood estimation, and revealed that farmers exhibited an mean technical efficiency level of 67%. This observation implied that approximately one-third of the maize yield was unrealized. The researchers recommended that there maize farmers can improve upon their production by relying on other innovative farm practises and government interventions.

Oppong (2013) investigated the factors influencing technical efficiency and measured its effect among small-scale maize farmers residing in the Akyem North District. The study utilised the Cobb-Douglas stochastic model and SUR model. The findings indicated that the average technical efficiency of maize farmers within the municipality stood at 73%, implying that maize production fell short by 27% compared to their maximum attainable yield. The study also measured the significance of socio-economic factors to technical efficiency. The study found that some socio-economic factors positively influenced the technical efficiency of small-scale maize farmers.

Abdulai et al. (2018) conducted a study to examine the technical efficiency of maize production in the northern region of Ghana. The study finding showed that fertiliser application, seed quality, farm size and herbicide usage significantly influence overall maize production. Also, extension services, agricultural mechanisation, gender, and experience greatly impacted the technical efficiency of smallholder maize farmers.

Wongnaa and Awunyo-Vitor (2018) assessed the technical efficiency of maize farmers in Ghana. The objective of this study was to identify potential avenues for enhancing the technical efficiencies of smallholder farmers, with the ultimate aim of mitigating poverty and alleviating hunger within the region. The study revealed that the average technical efficiency estimated for maize farmers in Ghana stood at 58.1%. Additionally, the study indicated a positive correlation exists between the farming experience, educational attainment, the use of fertilisers, extension contact, and improved seeds, and technical efficiency among maize farmers in Ghana. The studies also revealed that male farmers exhibited higher technical efficiency than their female counterparts. Furthermore, the study found that being part of the farmer association membership positively enhanced technical efficiencies of maize farmers. Finally, the dimensions of land destruction and farm size adversely influenced the technical efficiency of maize farmers.

A recent study by Tweneboah-Kodua et al. (2022) assessed the comparative technical efficiency levels of farms in Ghana utilising improved and local maize seed varieties. The study adopted cross-sectional data of 214 maize farmers. Also, the study employed the Stochastic frontier model technique to arrive at the study findings. It was revealed that smallholder maize farmers were not technically efficient in their produce of maize. However comparable to improved and local maize seed, farmers who used improved seed improved their technical efficiency from 44% to 50% and when combined, they were efficient at 72%.

Kwawu et al. (2021) examined maize farmers operating within the Techiman Municipality of Ghana. The researcher's primary objective was to ascertain the extent to which these farmers have embraced enhanced maize technology. Also, whether they are technical efficiency and lastly identify the various obstacles the maize farmers encountered in their agricultural farming activities. The cross-sectional data analysis was conducted using a sample size of 407 maize farmers. The data was analysed using descriptive statistics, the Poisson, and the stochastic frontier models. The empirical results indicated that on average, maize farmers within the Techiman Municipality exhibited a technical efficiency level of 70% while also experiencing increasing returns to scale of 1.26. The study additionally revealed that the degree of adoption of enhanced maize technology, the age of farmers, land and livestock ownership, and the farmers' perception of soil fertility showed statistical significance to the technical efficiency of maize farmers.

Anang et al. (2022) evaluated the level of technical efficiency and the factors influencing it among smallholder maize farmers residing in rural areas of Ghana. A bootstrap data envelopment analysis (DEA) method was utilised to assess the technical efficiency level. The study uncovered that smallholder maize farmers were technical efficient at 68%. Based on the findings, the researchers explained that the maize farmers have the prospective to boost their technical efficiency by improving the use of their existing input levels and technology. Anang et al. added that the maize farmers can improve the technical efficiency by adopting the seed varieties, increasing weeding frequency, and expand farm size. The study further explained that household size, age, and group membership and educational status has a corresponding impact of smallholder maize farmers technical efficiency.

Sienso et al. (2013) studied smallholder maize farmers in Nkoranza, Brong Ahafo Region. The study revealed that the smallholder farmers were technical efficiency at 91%. The study identified several components that influenced the technical efficiency of these farmers. The factors included the specific maize cultivar used by the farmers, the gender of the farmers, their level of expertise, the proximity of the farms to their residences, and the frequency of visits from extension agents. Based on the study, the researchers recommended increasing the training of extension agents to reach a larger number of farmers with their services.

Additionally, Addai and Owusu (2014) examined the level of technical efficiency exhibited by maize farmers operating within different agroecological zones in Ghana. The research used a translog stochastic production frontier function to gather cross-sectional data from 453 maize farmers in the Forest, Transitional, and Savannah Zones. The estimates were derived from the maximum likelihood method. From the findings, it was observed that the average technical efficiency of maize farmers in the selected regions stood at 64.1%. Notably, farmers operating within the forest zone exhibited the top level of technical efficiency at 79.9%. This was followed by farmers in the transitional area, who achieved a technical efficiency of 60.5%. Lastly, farmers in the savannah zone recorded the lowest technical efficiency, 52.3%. The empirical analysis further revealed that variables such as extension services, land ownership, mono-cropping, access to credit, age and gender positively impact technical efficiency.

Siaw et al. (2021) studied the impact of credit accessibility on the technical efficiency of smallholder maize farmers in Ghana. The researchers employed the stochastic frontier analysis (SFA) method to derive outcome estimations. According to the study's findings, it was opined that the mean technical efficiency among maize farmers stood at 74%. Also, the study revealed that enhanced credit accessibility resulted in an 8% increase in the technical efficiency of smallholder maize farmers.

In the Eastern Region of Ghana, a study was conducted by John and Seini (2013) to ascertain the technical efficiency of maize farmers and identify the factors that influence it. The study employed a multi-stage random sampling method to demonstrate a representative sample of 226 maize farmers from the four primary geographical regions within the country. The findings revealed an average level of technical efficiency at 51% among the farmers. The researchers posited that implementing optimal agricultural techniques such as technological advancements and input use efficiency by small-scale maize farmers can enhance their technical efficiency by 49%.

In summary, technical efficiency within the context of smallholder maize farmers in Ghana has garnered considerable attention. Stochastic frontier analysis has emerged as the predominant method employed for assessing farmers' technical efficiency. The reviewed literature revealed there are presence of an inefficiency gap among smallholder maize farmers. Therefore, there is the need for a resilient and robust approach that can bridge the gap of smallholder maize farmers inefficiency and improve maize yields. The present study holds significant importance and prominence to improving the smallholder maize farmers efficiency by examining the impact of sustainable farm practices on the technical efficiency of smallholder maize farmers.

**Sustainable Farm Practices**

Sustainable farm practices has revolved around the philosophical approach that human actions must safeguard the environment and also protect existing resources for future generations (Adnan et al., 2017; Khwidzhili & Worth, 2016). The Food and Agriculture Organisation (FAO) (1989) presented an enhanced clarification of SAP during their council assembly. According to the FAO, SAPs encompass the effective administration and preservation of water, land, plant, and animal genetic resources, to ensure the sustained contentment of human requirements for the current and forthcoming generations. According to FAO (1989), it is imperative to emphasise that adopting sustainable practises in agriculture is not only ecologically sound but also represents an economically viable strategy and a socially responsible practise.

Sustainable farm practise is an indispensable component of agricultural systems, augmenting soil quality, optimizing water utilization, regulating crop management, and ameliorating the ecological milieu (Donkoh, 2019; Khwidzhili & Worth, 2016). Some sustainable agricultural practices, according to literature, include row planning, appropriate planting distance, planting with recommended spacing, crop rotation, improved seed varieties, keeping weed-free farms, crop-livestock integration, organic fertilisers, bunding, mulching, minimum tillage, contour farming, and pre-emergence weedicides application (Adnan et al., 2017; Sustainable Agriculture Research & Education Program [SAREP], 2021).

The successful cultivation of crops relies not only on the use of high-quality seeds but also on a multitude of factors. These factors encompass the soil's condition, the accessibility of adequate and high-quality irrigation water, a clean atmosphere with appropriate levels of nitrogen, carbon dioxide, and oxygen, the presence of farm animals, a diverse array of microorganisms, birds, and earthworms, as well as the existence of pollinating insects and other non-domesticated plant and animal species. (Kesavan & Swaminathan, 2008). Thus, with sustainable farm practises, the factors listed by Kesavan and colleague can be conserved and protected, thereby, enabling farmers to steward the environment and improving crop yields (Adnan et al., 2017; Donkoh, 2019; Khwidzhili & Worth, 2016). Practises such as the implementation of reduced tillage techniques, strategic management of plant population, and judicious regulation of water utilisation constitute a prominent subset of Sustainable Agricultural Practises (SAPs) that have been widely experimented with by a vast majority of farmers (Khwidzhili & Worth, 2016). From an economic perspective, it is worth noting that while these sustainable practices have been proved to substantially improved crop yields.

From the current study, sustainability crop production or farm practices was observed to have a reciprocal relationship, acting as a dependent and independent variable in this study. For this reason, the researcher adopted the SUR model as a method to fulfill the study's objective of investigating the effect of fertilizer use efficiency on the sustainability of crop production. Furthermore, the researcher employed the Heckit model to examine the influence of sustainable practices on the technical efficiency of smallholder maize farmers.

**The effect of Fertiliser use efficiency on the sustainability of crop production**

Only a few studies can be related to the effect of FUE on the sustainable crop production. The study conducted by Bai et al. (2020) assessed the economic consequences of enhancing FUE on the sustainability of crops and the environment. The study analysed FUE by employing panel data from 31 provinces in China from 2007 to 2017. The research utilised a stochastic frontier method, incorporating a heteroscedastic inefficiency term, to examine the spatial characteristics of the data. The study revealed that China's FUE on average stood at 0.722. Also, the study found that the is FUE had a significant implication for the long-term viability of the natural environment and crop yield.

Singh et al. (2018) also studied fertiliser and nutrient use efficiency (NUE) and its corresponding impacts on sustainable agriculture practices. The study argued that FUE or NUE is an essential concept in evaluating crop production systems. Singh et al. (2018) posited that the predominant share of fertilisers, exceeding 90%, is allocated toward the cultivation of cereals, with a primary focus on wheat, maize, and rice. The study revealed that there is a significant relationship between fertiliser use efficiency and crop yield. Singh et al. (2018) further explained that adopting sustainable practices will help increase nutrient use efficiency and yield. Singh et al. (2018) concluded that the optimisation of nutrient use efficiency can be achieved by implementing best management practises for fertilisers. These practises involve the application of nutrients at appropriate rates, timing, and locations, while also being accompanied by suitable sustainable practises.

Randhawa et al. (2021) additionally discovered that the efficiency of fertiliser utilisation serves as a robust indicator for the accumulation of soil nutrient levels, which in turn affects the nutritional security of crops within a rice-wheat system. The study indicated that the implementation of sustainable farm practices such as the integration of manures and fertilisers, resulted in high levels of organic carbon. Furthermore, adopting sustainable practises resulted in an observable growth of the overall macro- and micronutrient composition within the soil. The findings of this study indicate that implementing sustainable agricultural practises in a rice-wheat system can lead to improved efficiency in fertiliser usage and, consequently, enhance nutritional rice and wheat crops.

According to the findings of Awada and Phillips (2021), it was observed that the efficiency of nutrient use by crops was relatively low, with a range of 25% to 50%. The nutrient efficiency was influenced by various factors such as crop type, prevailing environmental conditions, and the specific management practises employed. According to the analysis provided by Awada and Phillips, it is evident that the excessive and ineffective utilisation of fertilisers leads to a substantial portion of the nitrogen misplaced through nitrification, denitrification, leakage, and volatilization. The researchers further posited that, from an economic vantage point, enhancing FUE would bolster farm profitability. Awada and Phillips (2021) concluded that attaining fertiliser and nutrient use efficiency represents the ultimate objective of achieving sustainable crop production.

Srinivasarao (2021) studied FUE and its impact on food productivity, profitability, and environmental sustainability. The study revealed that public responsiveness to the need for improved fertiliser use efficiency is growing, but there is still low fertiliser use efficiency. Srinivasarao found that a decline in partial productivity can be attributed to fertiliser use inefficiency and that this has incurred environmental and agricultural sustainability problems. Srinivasarao included that enhancing fertiliser use efficiency is important in the current agriculture system to bring sustainability to the ecosystem.

Furthermore, Hu et al. (2019) have expounded that the underutilisation of fertilisers has engendered significant ecological challenges and hindered the sustainable progress of the agricultural sector in China. Consequently, to tackle this issue, Hu et al. (2019) embark on a study aimed at assessing the efficiency of fertiliser use efficiency and its consequential effects on technical efficiency, as well as the sustainability of crop production. The research revealed that the mean fertiliser use efficiency for the sample was 60%. The study also showed that on average, approximately half of the fertiliser employed in China was surplus. The study additionally found a significant correlation between the fertiliser use efficiency and the sustainability of crop production and the environment.

Wehmeyer et al. (2020) also observed that China's agricultural sector has been grappling with the issue of excessive fertiliser utilisation, resulting in a concerning situation where crop yields have reached a plateau while concurrently witnessing an escalation in environmental pollution levels. The study argued that a sustainable agricultural research study in China should include social and environmental impact analysis. Wehmeyer and colleagues revealed that increasing fertiliser use efficiency will improve sustainable crop production and vice versa.

Panhwar et al. (2019) posited that using chemical fertilisers in contemporary agricultural practises exerts detrimental effects on soil health and the environment. The researchers proposed that by implementing the principles of optimal fertilisation, namely utilising the appropriate fertiliser type, quantity, timing, and location will enhance fertiliser use efficiency while concurrently mitigating environmental degradation. The researchers also recommended that sustainability practices, such as applying organic matter and biofertilisers, can reduce the need for chemical fertilisers. The researchers stated that sustainability practices such as crop recycling, legume green manuring, and farmyard manure should be used to improve soil nutrient status and replace 10-50% of crop nutrient requirements in wheat cultivation. Panhwar et al. conclude that achieving fertiliser use efficiency will help sustain soil fertility, enhance crop productivity, and it is the most effective approach for promoting sustainable wheat production.

Yadav et al. (2017) posited that under utilisation of fertiliser leads diminished agricultural output, whereas excessive application engenders adverse consequences for both soil quality and the environment. Hence, it is imperative to closely monitor fertiliser use efficiency levels to achieve optimal crop potential and ensure the long-term viability of crop yields. Yadav et al. (2017) explained that a comprehensive implementation of fertiliser and nitrogen use efficiency will result in improved crop yield, reduced cultivation expenses, and the preservation of environmental integrity. These outcomes, in turn, align with the overarching objective of establishing a durable and sustainable production system. Yadav et al. (2017) concluded that enhancing fertilizer use efficiency, specifically concerning applied nitrogen, is crucial for attaining sustainable agricultural production and optimising crop yield.

The available research on the effect of fertilizer use efficiency on sustainable crop production is limited, and there is a notable absence of studies focusing on smallholder maize farmers in Ghana. This gap in the literature highlights the need for further investigation into the relationship between fertilizer use efficiency and sustainable crop yields.

**The Effect of Sustainability of Farm Practices on Technical Efficiency**

Darkwa et al. (2010) revealed that sustainable farm practises have a considerable effect on the technical efficiency of crop yields. Akowuah et al. (2012) observed that maize farmers who practised unsustainable farm practices had low grain yields in Ghana. Also, a reviewed paper was published by Akinnifesi et al. (2010) on sustainable practice in East and Southern Africa. Results showed that adopting sustainable agricultural practices will substantially increase crop yield.

Furthermore, an empirical investigation carried out by Karavidas et al. (2022) about the impact of sustainable agriculture practises on bean yield showed that sustainable agriculture practises such as rhizobia application, irrigation, and sowing density potentially enhanced the fertilisation, quality of common beans and yield. Karavidas et al. (2022) concluded that sustainable bean production has yielded a substantial enhanced both crop yield and crop quality.

Danquah et al. (2018) conducted similar research to enhance sustainable agricultural practises for cultivating yams. The study employed two treatment packages encompassing improved sustainable agriculture practises. The farmers practises were organised in a complete block design across a collective of 8 farmers' fields, with an equal distribution of 4 areas from both Ejura and Atebubu. The empirical analysis indicated that there was a substantial increase in yam tuber yields, specifically 196% and 205% due to improved sustainable agriculture farm practices. The study's findings indicate that the expansion of enhanced sustainable farm practises has the potential to effectively maintain yam production while tackling the deforestation issue linked to yam production.

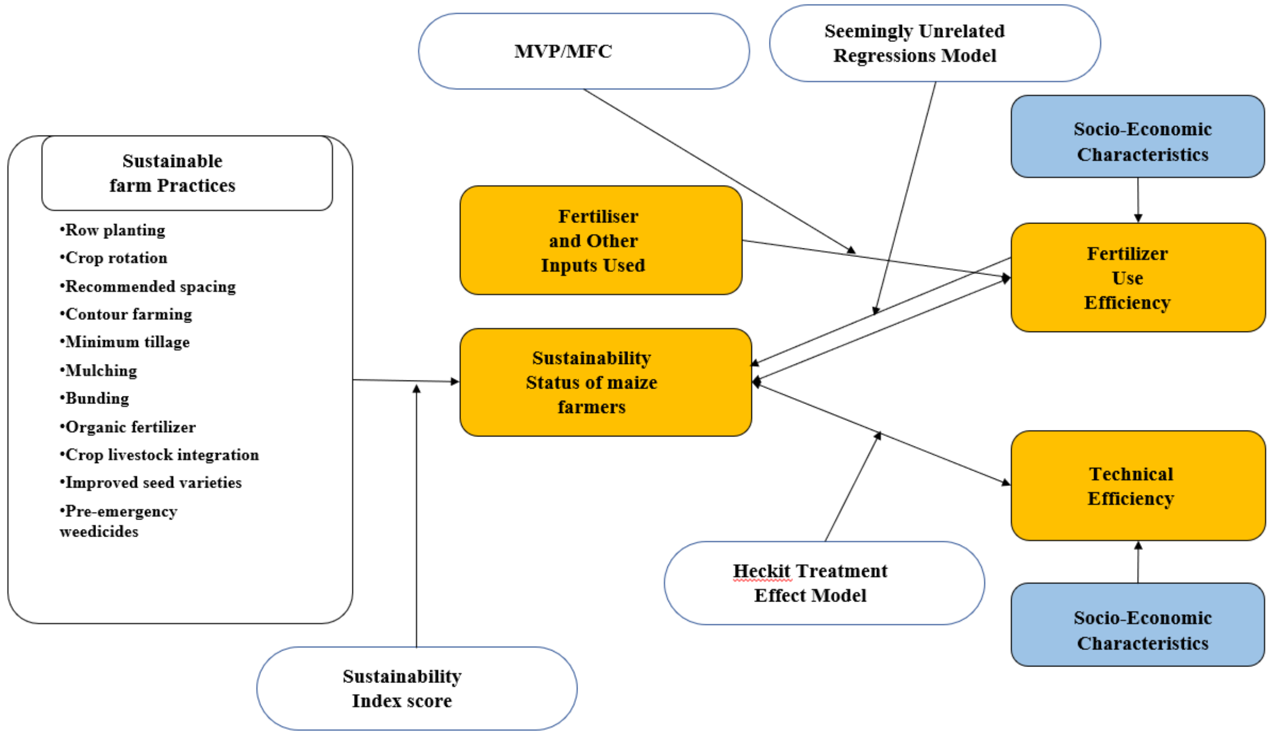
Issahaku and Abdulai (2020) conducted a study to investigate the impact of sustainable land management practices on the technical efficiency and environmental efficiency of farm households in Ghana. The researchers employed a selectivity-biased-corrected stochastic production frontier methodology using household-level data to mitigate potential bias from observed and unobserved factors. The study revealed that farm households that embraced sustainable land management practises exhibited superior technical efficiency and output levels compared to their counterparts who did not adopt such practises.

The existing body of research concerning the effect of sustainability practices on the technical efficiency smallholder farmers is currently limited. Consequently, this study primary objective is to investigate how sustainable farm practices influence the technical efficiency of smallholder maize farmers in Ghana. The literature reviewed in this chapter indicates the presence of an efficiency gap among smallholder farmers in Ghana, which could potentially be reduced through the adoption of appropriate sustainable farm practices. Thus, the main focus of this study is to determine the validity of this assumption.

**Conceptual Framework**

The goal of the study was to determine the extent of sustainable practices engaged by smallholder maize farmers, as well as to examine the effects of fertiliser use efficiency on sustainable crop production as well as the impact of the sustainable approach on the technical efficiency of smallholder maize farmers. The study analysed a list of sustainable practices, and based on the level of sustainable practices adopted, the study measured the sustainability index score. The sustainability index score was used to determine whether or not the farmers were practising sustainably or not. The fertiliser input was measured along with other resource inputs to determine the fertiliser and other input efficiencies. The farmers' sustainability status was then examined with the fertiliser use efficiency results using a SUR model to attain the relationship between them.

Additionally, the study examined the effect of sustainable farm practises on the smallholder maize farmers technical efficiency level. To achieve this, the study employed stochastic frontier analysis to determine the technical efficiency level, and then the Heckit treatment effect model was used to examine the relationship between the two variables: sustainable of farm practices and technical efficiency. Both fertilisers use efficiency and technical efficiency were measured alongside other socio-economic variables. Figure 1 below shows the graphical representation of the study.




Source: Author's Construct, 2023

Figure 1: Conceptual framework showing the relationship between sustainable farm practices, fertiliser use efficiency and technical efficiency in maize farms.

## Chapter Summary

This chapter reviewed the relevant theories and concepts, theoretical models, empirical literatures, and the conceptual framework of the study. It was observed from the chapter that the theory of production and Schultz theory were relevant to the study. Also, the concept reviewed explained why production efficiency, technical efficiency, resource use efficiency and fertiliser use efficiency is very important and form part of the basis for the research. Again, based on the nature of the study, two key theoretical models were used extensively reviewed to key a better picture of why study adopted it to measure its main objectives. Additionally, the chapter reviewed empirical studies on the resource efficiency of maize farming, the technical efficiency of maize farming, fertiliser use, fertiliser efficiency in Ghana, and sustainable practices related to maize yield in Ghana. Finally, the chapter explained the conceptual framework of the study.

# CHAPTER THREE

# METHODOLOGY

## Introduction

This section discusses the methods employed in the study. The section includes research design, the target population, selection of a representative sample utilising appropriate sampling techniques, the establishment of reliable and valid research instruments, verification of instrument reliability, implementation of a systematic data collection procedure, adherence to ethical considerations, and adoption of a rigorous method for data analysis.

## Research Design

A quantitative research approach was adopted since the researcher intended to to obtain numerical data and statistical analysis for objective and structured assessment of relationships and patterns within the research topic. According to Creswell & Creswell (2017), the quantitative method enables researchers to describe the most important aspects of a study by making use of quantitative tools such as descriptive and inferential statistical tools. Due to its proficiency in translating the application of statistical analysis to establish a link between existing knowledge and potential insights derived from research, utilizing quantitative methods for data analysis necessitates a comprehension of the associations among variables. This understanding can be acquired through descriptive or inferential statistical approaches.

Also, the research utilized a cross-sectional survey design, which was considered suitable for achieving the study's objectives. Although a longitudinal research design could have been beneficial in some respects, the focus of the study necessitated the use of a cross-sectional survey design, as it provided the researcher with the necessary means to gather data effectively. By employing this design, the researcher can draw conclusions about population characteristics by generalizing findings from the sample to a larger population (Babbie, 2007).

**Study Area**

The study was conducted in Northern Ghana, which consisted of five Regions: Upper East, Upper West, Northern, North East, and Savannah Regions. Geographically, the five regions are located in the Guinea and Sudan Savannah agro-ecological zones. The population of all five Regions is approximately 5.83 million, with 55 administrative districts and a total land area of about 97.7 $km^2$, representing approximately 40.97% of the nation's land area (GSS, 2021). The regions are relatively homogeneous on almost all social, political, ecological, cultural, and educational indices. The livelihoods of the majority of the populace in the study area are rooted in agriculture, and the majority of farmers are smallholders with plots of land under two hectares. The smallholder farmers mostly grow maize, millet, sorghum, cassava, groundnuts, rice, cowpea, and soybeans. Livestock reared in the regions includes cattle, goats, sheep, poultry, etc. Irrigation farming is almost absent, and land rights are customary (Kumah, 2015).

The farmers are partiality low-income earners and are susceptible to the adverse repercussions of climate change. The regions undergo a period of condensed rain from January to March, commonly called the dry season, followed by increased rain from

May to October, known as the wet season. On an annual basis, the average amount of rainfall ranges between 750-1050 mm (30-40 inches). The temperature fluctuations in the region exhibit a diurnal pattern, with a nocturnal low of 14 °C (59 °F) and a daily high of 40 °C (104 °F). With regard to climatic patterns, it is commonly observed that the peak of scorching temperatures is customarily encountered towards the dry season.

In contrast, the lowest point of temperature readings manifests during December and January. The rainfall levels in the northernmost part of the region do not exceed 1100 mm per year. The chosen area was designated for the study owing to its recognition as a prominent hub for agricultural endeavours in Ghana, including the cultivation of maize (Amanor-Boadu et al., 2015).

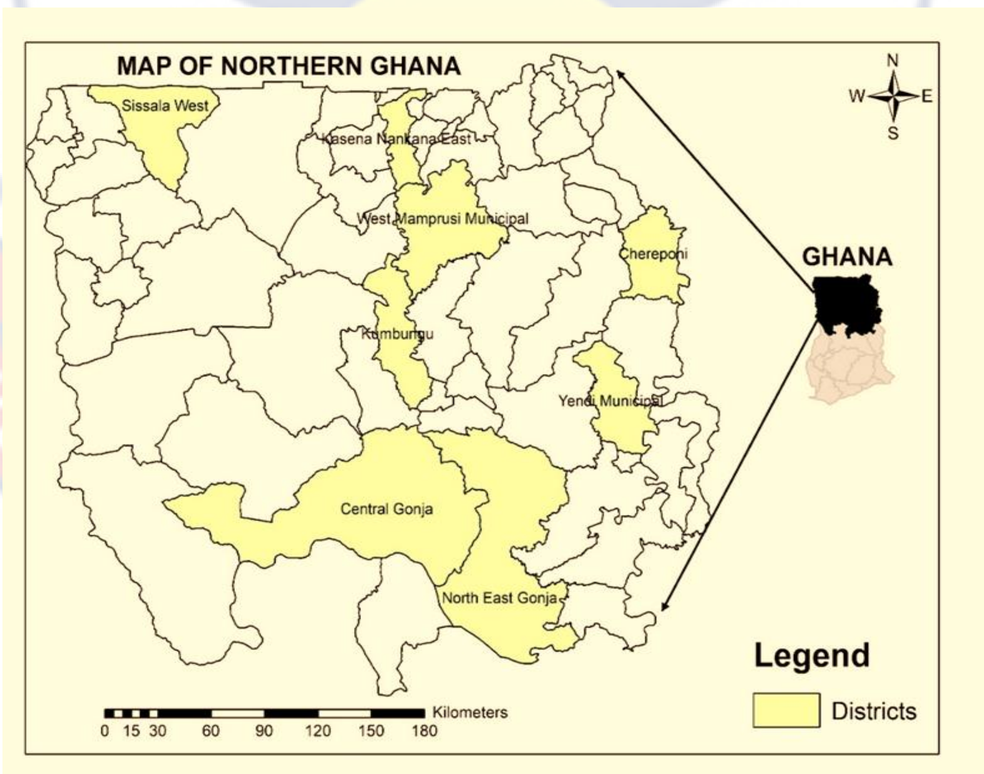



Figure 2: Map of the Study Area

**Population**

The target population for the study was maize farmers in the five regions of northern Ghana. The farmers utilize various farm inputs such as land, labour, capital, agrochemicals and fertiliser to cultivate maize and other crops. Nonetheless, maize crop stands as their primary focus, and the smallholder farmers cultivate it in significantly larger quantities compared to other crops.

**Sample Procedure and Sample Size**

Sampling is selecting a subset of a population to participate in a study. It involves choosing individuals to ensure they are representative of the larger sample they were selected from (Chircir & Simiyu, 2017). For this study, a multistage sampling technique was employed. Eight districts were purposively selected from the five regions in the first stage. In the second stage, 21 maize-producing communities were purposively sampled within the eight selected districts where maize production is predominant. In the third stage, nine maize farmers were randomly selected through a simple random sampling from a sample frame obtained with the help of local Agricultural Extension agents who worked in the selected communities under the district department of Agriculture. In total, 189 (i.e., 21 x 9) maize farmers were sampled for the study. Table 1 summarises the study sample obtained from the survey.

Table 1: Sample Size of Farmers

| Region | District | No. of communities | Number of farmers |
|---|---|---|---|
| North East | Chereponi | 3 | 27 |
| | West Mamprusi | 3 | 27 |
| Northern | Kumbugu | 3 | 27 |
| | Yendi | 3 | 27 |
| Savannah | Central Gonja | 3 | 27 |
| | North East Gonja | 3 | 27 |
| Upper East | Kasena Nankana East | 1 | 9 |
| Upper West | Sisala West | 2 | 18 |
| **Total** | **8** | **21** | **189** |

**Data Collection Instrument**

Primary data was used for this study and the datas was collected using a structured interview schedule. The data was digitally solicited with the help of a computer tablet and a Computer-Assisted Personal Interview (CAPI). The maize farmers were interviewed individually for information using a computer tablet. The expected detailed information for the respondents was explained for better understanding and to facilitate their response to the questions. The structured interview schedule consisted of three sections. In Section A, basic demographic information was collected, including the respondent's sex, age, marital status, highest level of education, engagement in other economic activities, household size, farm size for maize crop, and access to financial resources for maize production. Section B focused on the sustainability practices employed by farmers in maize production, presenting a list of sustainable/integrated agricultural practices. In Section C, questions pertained to crop production, inputs, and outputs, including the types of crops cultivated, major crop choice, cultivated area for other crops, farm ownership, accessible land for farming, input quantities and costs, and details regarding output quantities, utilization, and post-harvest losses. The section also included a comprehensive list of fertilizers used and their unit prices.

**Data Collection Procedure**

Before the pre-test of the instrument, enumerators (interviewers) were selected based on their experience and proficiency in English and local dialects. The interviewers received training on the objectives of the study, the use of the Computer-Assisted Personal Interviewing (CAPI) software, and went through each question in the data collection instrument. Before starting any interview, consent was obtained through a statement, and respondents were allowed to decline participation voluntarily. The survey questions were translated into local dialects for the respondents to facilitate comprehension. The data was collected from May 2021 to June 2021.

**Pre-Test of the Instrument**

The supervisor conducted a comprehensive check of the interview questions. Pre-testing of the research instruments was conducted prior to the commencement of the data collection process to assess their reliability and content validity. The assessment of instrument quality includes criteria such as legibility, comprehensibility, relevance, and representativeness of the questionnaire items, as evaluated by both the interviewer and the interviewees. Pre-testing of the instruments was undertaken approximately fourteen days before the commencement of actual data collection in the Tolon district, in the northern region of Ghana. The pre-testing involved a sample of fifty maize farmers. The preliminary examination effectively facilitated the detection of prospective flaws in the research instruments, prompting subsequent rectifications to enhance the accuracy, consistency, and relevance of the interview schedule.

**Data Processing and Analysis**

The study employed statistical software tools such as Excel, Stata, and R programming to perform data processing and model estimation. The socioeconomic parameters of the participants, including both the farmers and the characteristics of the farms were measured and interpreted using descriptive statistics. The sustainability index score was calculated using Excel. Fertiliser input use efficiency was estimated with the ratio of marginal value product to marginal factor cost using R programming software. Further, Stata was used to run the technical efficiency of the smallholder maize farmers. Additionally, the SUR model was analysed using Stata, and finally, the Heckit treatment effect model was analysed using the Sample Selection package in R.

**Econometric Specifications of the Estimated Models in the Study**

**Fertiliser Use Efficiency Estimation**

As per the findings of Awunyo et al. (2016), to achieve optimal resource use efficiency, maize farmers must ensure that the marginal value product (MVP) is equivalent to the marginal factor cost (MFC). The parameter of fertiliser use efficiency was been derived by evaluating the ratio between the marginal value product of inputs and the marginal factor cost. The efficiency of resource utilisation is measured as

$$r = \frac{MVP}{MFC} \tag{1}$$

Therefore, in this study, the empirical model for calculating the fertiliser use efficiency was estimated as:

$$\text{Fertiliser use Efficiency} = \frac{\text{Marginal Value Product of Fertiliser}}{\textit{Marginal Factor Cost of Fertiliser}} \quad (2)$$

**Modelling Sustainability Practices of Maize Farmers**

To evaluate the extent to which sustainable practices were adopted in maize farming, the researcher used the sustainability index score adopted by Dadzie et al. (2021). A list of 12 items suitable for measuring the sustainability of farming practices was used. They were row planting, planting with a recommended spacing, crop rotation, improved seed varieties, keeping weed-free farms, crop-livestock integration, organic fertiliser, bunding, mulching, minimum tillage, contour farming, and pre-emergence weedicides application. Farmers were asked to identify which sustainable practices they used at their farms, and these practices were scored either 1 or 0. A score of 1 indicated that the farmer used a sustainable approach, while a score of 0 indicated that they did not.

The total scores assigned to farming practices were added up for each farmer. The calculation of the sustainability index for the *i*th farmer involved the division of the aggregate score of farm-level practises by the count of sustainable practises provided to the farmers. The computation as mentioned earlier is depicted in the subsequent equation:

$$SI = \frac{\sum(n^{+} + n^{0})}{N} \quad (3)$$

The sustainability index (SI) represents the measure of sustainability for the *i*th farmer.

Let *n* denote the total number of sustainable practises implemented by the *i*th farmer.

*N* represents the comprehensive compilation of sustainable practises proffered to the agricultural community.

The sustainability index can be defined as the quotient obtained by dividing the cumulative score of farm-level practises by the total set of sustainable practises provided to farmers. This index is bounded between 0 and 1, representing the range of possible values. After computing the result of the dataset, it was observed that the mean sustainability index was approximately 0.4, and with the minimum value of 0 and maximum value of 0.8. By the principle of binomial distribution, the researcher analysed the sustainability index scores as potential outcomes of a binomial experiment. The mean value was the benchmark for adopting sustainable farm practises within the study region. Farmers whose scores were above the threshold of 0.4 were categorised as having high sustainability, while those whose scores were below the threshold were categorised as having low sustainability.

**Modelling the Relationship Between Fertiliser Use Efficiency and Sustainability Index Using the Seemingly Unrelated Regression Model**

The SUR model can be characterised as a framework of linear equations in which the errors exhibit correlation within equations for a specific individual while remaining uncorrelated across individuals. The economic model encompasses a set of *j*=1…m linear regression equation representing *i*=1…N individuals. The equation denoted by the *j*th index for individual *i* can be expressed as follows:

$$y_{ij} = x'_{ij}\beta_j + u_{ij} \tag{4}$$

when all observations are aggregated, the mathematical representation for the *j*th equation can be formulated as follows.

$$y_j = x_j' \beta_j + u_j \tag{5}$$

The *m* equations are stacked into a SUR model:

$$\begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_m \end{bmatrix} = \begin{bmatrix} X_1 & 0 \dots & 0 \\ . & \ddots & \vdots \\ 0 & \dots & X_M \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ . \\ . \\ . \\ \beta_m \end{bmatrix} + \begin{bmatrix} u_1 \\ u_2 \\ . \\ . \\ . \\ u_m \end{bmatrix} \tag{6}$$

Upon aggregating all observations, we can express the mathematical representation for the *j*th equation in the following manner.

$$E\left(u_{ij} u_{ij}' \middle| X\right) = \sigma_{jj}, and\ \sigma_{jj'} \neq 0\ where\ j \neq j'$$

**SUR Estimation**

- In the initial stage, each equation is estimated using the OLS method, wherein the residuals obtained from the m equations are subsequently utilised for estimation purposes.

$$\sum;\ \text{using}\ \hat{u}_j = y_j - X_j \hat{\beta}_j, and\ \hat{\sigma}_{jj'} = \frac{\hat{u}_j \hat{u}_j}{N}$$

The subsequent stage involves replacing the $\sum$ with the estimated summation $\sum$ in the Generalised Least Squares estimator.

$$\hat{\beta}_{GLS} = \left\{X'\left(\hat{\Sigma}^{-1} \otimes I_N\right)X\right\}^{-1} \left\{X'\left(\hat{\Sigma}^{-1} \otimes I_N\right)y\right\}$$

As per the findings of Cadavez and Henningsen (2012) the SUR is employed to enhance efficiency in cases where the equations are solely interconnected through the error term. Singh et al. (2018) established a significant and structural relationship between fertiliser use efficiency and sustainability in farm practises. This relationship is attributed to the jointness of the error terms and the non-diagonal covariance matrix. This suggests that a correlated random error component makes the SUR model particularly suitable for conducting this analysis. Hence, the present study employed the SUR model to ascertain the reciprocal association between the fertiliser use efficiency and the level of sustainability among maize farmers. The empirical model for establishing bidirectional causality within the SUR model for fertiliser use efficiency (FUE) and the extent of sustainable farm practises (SI) can be expressed as follows:

$$\textit{Fertiliser Use Efficiency} = \beta_0 + \beta_1 \textit{Sustainable Practice} + \beta_2 \textit{Land Ownership} + \beta_3 \textit{Sex} + \beta_4 \textit{Age} + \beta_5 \textit{Level of Education} + \beta_6 \textit{Household size} + \beta_7 \textit{Extension services} + \beta_8 \textit{Credit availability} + \beta_9 \textit{Training} + \varepsilon_1 \quad (7)$$

$$\textit{Sustainability Practice} = \gamma_0 + \gamma_1 \textit{Fertiliser Use Efficiency} + \gamma_2 \textit{Land Ownership} + \gamma_3 \textit{Sex} + \gamma_4 \textit{Age} + \gamma_5 \textit{Level of Education} + \gamma_6 \textit{Household size} + \gamma_7 \textit{Extension services} + \gamma_8 \textit{Credit availability} + \gamma_9 \textit{Training} + \varepsilon_2 \quad (8)$$

**Estimation of Maize Farmers' Technical Efficiency Levels Using Stochastic Frontier Analysis model**

***Theoretical Specification of the Stochastic Frontier Model***

Assessing the performance of production units in the agricultural sector is vital for identifying factors that hinder growth and development. The measurement of farm-level productivity has relied on technical efficiency, which was first introduced by Koopmans and Debreu and later refined by Farrell (1957). Inkoom and Micah (2017) and Osun, Ogundijo, and Bolariwa (2014) identified two distinct methodologies scholars adopted to measure the technical efficiency of farmers. These methodologies include the mathematical programming approach, specifically DEA, and the econometric approach, SFA.

The non-parametric nature of the DEA framework allows for the attribution of all deviations from the efficient frontier solely to technical inefficiency. Nevertheless, the deterministic characteristics of DEA frequently result in outcomes deemed inscrutable and unviable. Hence, it can be observed that most researchers have employed the econometric approach, specifically the SFA technique. SFA is preferred because it can determine the impact of technical inefficiency and stochastic effects (Guo & Fraser, 2014; Inkoom & Micah, 2017).

Researchers have found the SFA technique more favorable than DEA because it can produce farmers-specific output estimates and distinguish between technical inefficiency and stochastic effects. Van den Broek et al. (1980) and Aigner et al. (1977) developed the stochastic frontier model. Given the inherent benefits of SFA and the unpredictable characteristics of agricultural production, the present investigation employed the standard stochastic production frontier as the suitable SFA methodology for assessing technical efficiency. The researcher specified the standard stochastic production frontier according to the formulation provided by Meeusen et al. (1980) and Aigner et al. (1977).

$$Y= f(X_i; \beta) \exp (V_i - U_i) \qquad (9)$$

The production level of the *ith* farmer denoted as $Y_i$, is contingent upon the vector of agricultural inputs $X_i$ and a vector of estimated parameters, $\beta$. The exogenous fluctuations in production resulting from exogenous factors beyond the farm's jurisdiction are denoted as $V_i$, whereas the endogenous factors within the farm's purview that give rise to inefficiency are denoted as $U_i$. The distribution of $V_i$ is assumed to be independent and identically distributed as $N(0, \sigma_v^2)$, with no correlation to $U_i$. $U_i$, on the other hand, follows a non-negative half-normal distribution. The error term, denoted as ε, is defined as

$$\varepsilon_i = V_i - U_i \qquad (10)$$

Jondrow and colleagues (1982) assumed that the variable u conforms to a normal distribution, while the variable $v$ adheres to a half-normal distribution. The farm-specific conditional inefficiency ($^{u}/_{\varepsilon}$ for each observation can be derived from the conditional distribution of u, where $u = \varepsilon + v$. Therefore, the expected value of $u$ is determined by:

$$E(^{u}/_{\varepsilon}) = \sigma^2 \left[\frac{f\left(^{\varepsilon\lambda}/_{\sigma}\right)}{1-F\left(^{\varepsilon}/_{\varepsilon\lambda}\right)} - \frac{\varepsilon\lambda}{\sigma}\right] \tag{11}$$

The variables "f" and "$F$" denote the standard average density and cumulative distribution functions, respectively, following economic terminology.

$$\lambda = \frac{\sigma_u}{\sigma_v} \tag{12}$$

Equation (4) denotes the quotient of the two standard errors employed by Jondrow et al. (1982), serving as a measure for the overall extent of output deviation from the frontier that can be ascribed to technical efficiency. $\sigma_u^2$ represents the variance of the stochastic model, which pertains to the systematic component, and $\sigma_v^2$ represents the variance of the inefficiency model.

The TE can be computed by calculating the proportion of actual output to potential output, as established by Aigner et al. (1977) and Van den Broek et al. (1980). Mathematically, this can be represented as:

$$TE = \frac{Y_i^*}{Y_i} = \frac{f(X_i;\beta)\exp(V_i - U_i)}{f(X_i;\beta)\exp(V_i)} = \exp(-U_i) \tag{13}$$

TE of a firm is defined as, $TE = \exp(-U_i)$.

Additionally, the researcher incorporates the model that Battese and Coelli (1995) suggested, where the equation explains the technical inefficiency.

$$U_i = Z_i\delta + w_i \tag{14}$$

$Z_i$ represent a vector of explanatory variables associated with the TI effects, with dimensions $(1 \times m)$. $\delta$ is a vector of unknown parameters to be estimated, with dimensions $(1 \times m)$. Additionally, $w_i$ is an unobservable random variable. The parameters indicate the effects that variables in Z have on TE. A negative value implies a positive impact on total efficiency (TE), while conversely, a positive value implies an unfavourable impact.

***Empirical Specification of the Stochastic Frontier Model***

The use of SFA models in the literature predominantly hinges upon two functional form specifications: the Cobb-Douglas and the Translog function (Inkoom & Micah, 2017). However, there isn't complete agreement in the literature yet on the dominant condition. The selection of the functional form is primarily contingent upon its appropriateness to the datasets and its alignment with the theoretical underpinnings of the research goals (Kumbhakar & Wang, 2005). Therefore, it is important to weigh the advantages and disadvantages of both models in terms of how well they capture the available data in order to choose the ideal functional form.

The Cobb-Douglas functional form demonstrates strong algebraic tractability and can clarify the input substitution phenomena. However, the framework's intrinsic limitations do not diminish the analysis's empirical potency. It is important to note, though, that the Translog functional forms have become well-known for their strong and adaptability. The Translog model facilitates evaluating the interdependent relationships between inputs and their influence on the output level. Nevertheless, it is imperative to acknowledge that the Translog model exhibits a notable drawback in its intricate specification and the inherent possibility of encountering multicollinearity.

Therefore, subjecting the dataset to both modeling estimation approaches is appropriate to determine which fits the dataset more efficiently. Considering the strengths and weaknesses of the two models, we decided to estimate both functional models and test them to determine which best fits the dataset in line with the theoretical basis for choosing a model. The researcher sampled maize farmers and used the maximum likelihood estimate method of the stochastic production frontier model to calculate the technical efficiency. Below are the empirical model specifications for the estimated functional forms for Cobb-Douglas (Equation 8) and Translog (Equation 9):

***Cobb-Douglas function***

$$\log y = \beta_0 + \beta_1 \log(x_1) + \beta_2 \log(x_2) + \beta_3 \log(x_3) + \beta_4 \log(x_4) + \beta_5 \log x_5 + V_i - U_i \tag{15}$$

***Translog function***

$$\begin{aligned} log(y_i) = {} & I_0 + I(log(x_1)) + I(log(x_2)) + I(log(x_3)) + I(log(x_4)) + I(\log(x_5)) \\ & + I(0.5 * (\log(x_1))^2) + I(0.5 * (\log(x_2))^2) + I(0.5 * (\log(x_3))^2) + I(0.5 * (\log(x_4))^2) \\ & + I(0.5 * (\log(x_5))^2) + I(\log(x_1) * \log(x_2)) + I(\log(x_1) * \log(x_3)) + I(\log(x_1) * \log(x_4)) \\ & + I(\log(x_1) * \log(x_5)) + I(\log(x_2) * \log(x_3)) + I(\log(x_2) * \log(x_4)) + I(\log(x_2) * \log(x_5)) \end{aligned}$$

$+I\big(log(x_3) * log(x_4)\big) + I\big(log(x_3) * log(x_5)\big) + \ I\big(log(x_4) * log(x_5)\big) + v_i - u_i$

(16)

**Definition of variables in the model:**

$log(\,y_i) = \log\ of\ \ output\,; log(x_1) =\ \log of\ land; log(x_2) =\ \log of\ labour;\ log(x_3) =\ \log of\ fertiliser;\ log(x_4) =\ \log of\ Agrochemical;\ \log(x_5)\ = \log of\ Capital\,; I(0.5 * log(x_1)^2) =\ square\ of\ land; I(0.5 * log(x_2)^2) = square\ of\ labour;\ I(0.5 * log(x_3)^2) =\ square\ of\ fertiliser;\ I(0.5 * log(x_4)^2) =\ square\ of\ agrochemical;\ I(0.5 * log(x_5)^2) = square\ of\ capital; I\big(log(x_1) * log(x_2)\big) = land - labour\ interaction;\ I\big(log(x_1) * log(x_3)\big) = land - fertilizer\ interaction;\ I\big(log(x_1) * log(x_4)\big) = land - agrochemical\ interaction;\ I\big(log(x_1) * log(x_5)\big) = land - capital\ interaction;\ I\big(log(x_2) * log(x_3)\big) = labour - fertiliser\ interaction\ ;\ I\big(log(x_2) * log(x_4)\big) = labour - agrochemical\ interaction;\ I\big(log(x_2) * log(x_5)\big) = labour - capital\ interaction;\ I\big(log(x_3) * log(x_4)\big) = fertilizer - agrochemical\ interaction;\ I\big(log(x_3) * log(x_5)\big) = fertilizer - capital\ interaction\ I\big(log(x_4) * log(x_5)\big) = agrochemical - capital\ interaction;\ v_i - u_i = composed\ error\ terms\ of\ noise\ and\ technical\ ineffeciency\ effect$

**Modelling the Effect of Sustainable Farm Practices on the Technical Efficiency of Maize Farmers**

The Heckit Treatment Effect Model was employed to assess the impact of sustainable agricultural practices on the technical efficiency of maize production in the northern region of Ghana. The technical efficiency of maize farmers is contingent upon the sustainability of their agricultural practises. Assessing the impact of this phenomenon poses significant difficulties due to numerous unobservable variables. Therefore, it would be deemed inappropriate to regress the impact of sustainable agricultural practises directly on technical efficiency, as it would be susceptible to self-selection bias, as noted by Agula et al. (2018) and cited in Dadzie et al. (2021).

To mitigate the potential issues of selection and endogeneity bias, the adoption of the Heckit treatment effect model was deemed suitable, as suggested by previous studies conducted by Agula et al. (2018); Dadzie et al. (2021). Therefore, the Heckit treatment effect model is estimated using the maximum likelihood approach to assess the impact of an endogenously selected binary treatment (sustainability of farm practises) on a continuous endogenous variable (technical efficiency). The estimation of the model according to Agula et al. (2018) and Dadzie et al. (2021) is as follows:

$$y_i = \alpha_0 + \beta x_i + \delta z_i + \varepsilon_i \tag{17}$$

where $z_i$ is a dichotomous endogenous variable denoting the level of sustainability in the agricultural practises employed by the $i$th maize farmer. The explanatory variables are denoted as $x_i$, with $\delta$ and $\beta$ being the parameters to be estimated, and $\varepsilon_i$ representing the stochastic error term. Moreover, the binary endogenous variable, denoted as $z_i$ in equation (1), is conceptualised as the result of an unobservable latent variable, $z_j^*$. This latent variable is assumed to be influenced by exogenous covariates $w_i$ in a linear manner, along with a random term, $u_i$. Consequently, the formulation of $z_j^*$ is as follows:

$$z_j^* = w_j \gamma + u_j \tag{18}$$

where observed binary treatment variable, it is given as

$$z_j = \begin{cases} 1 \text{ if } z_j^* > 0 \\ 0, \text{if otherwise} \end{cases} \quad (19)$$

Equations (1) and (2) have two error terms (ε and u) which are assumed to be bivariate normal with a mean of zero and a covariance matrix.

$$\begin{bmatrix} \sigma^2 & \rho\sigma \\ \rho\sigma & 1 \end{bmatrix} \quad (20)$$

The estimation of rho holds significant importance in assessing the suitability and efficacy of the Heckit treatment effect model for the given dataset. The objective is to ascertain the presence of a treatment-effect association between the selection model and the outcome model. To mitigate potential bias in estimation, it is customary for the Heckit treatment effect model to posit a nonzero correlation (ρ) between the error terms ($\varepsilon$ and $u$). Hence, a hypothesis test is conducted to assess the plausibility of the combined probability of the selection equation (probit model) and the outcome equation (regression model) on the given data compared to the treatment effect model. The null hypothesis posits that ρ(H_0: ρ = 0). Suppose the estimated ρ is found to be non-zero. In that case, it leads to rejecting the null hypothesis, suggesting that the Heckit treatment effect model is suitable and effectively represents the data. Based on the model, the empirical calculation was estimated as:

$$TE = \beta_0 + \beta_1 Sex_i + \beta_2 Age_i + \beta_3 Edu_i + \beta_4 Extc_i + \beta_5 Hhs_i + \beta_6 Own_i + \beta_7 Acrdt_i + \beta_8 Train_i + \beta_9 SScat_i + \varepsilon_i \quad (21)$$

$$SScat = \theta_0 + \theta_1 Sex_i + \theta_2 Age_i + \theta_3 Edu_i + \theta_4 Extc_i + \theta_5 Hhs_i + \theta_6 Own_i + \theta_7 Acrdt_i + \theta_8 Train_i + u_i \quad (22)$$

The aforementioned empirical specifications indicate that the Technical Efficiency (TE$i$) is contingent upon implementing sustainable farm practises, as represented by the zero-one binary probit selection model, *SScat*. It is of utmost significance to acknowledge that within the equations, as mentioned earlier, the observation of TE$i$ solely occurs when SS*cat* attains a value of 1; otherwise, it is excluded from the sample. The variables $\varepsilon_i$ and $u_i$ exhibit a normal distribution, specifically $\varepsilon_i$ follows a normal distribution with a mean of 0 and a variance of $\sigma^2$. Additionally, these variables are correlated and conform to a bivariate normal distribution. The covariance between the error term $\varepsilon_i$ and the unobserved heterogeneity term $u_i$ is denoted as $\rho\sigma$, where $\rho\sigma$ is a non-zero value (specifically, $\rho \neq 0$). This assumption is crucial in assessing the suitability of the Heckit model for the given dataset. As part of the empirical estimation, the null hypothesis of $\rho = 0$ was tested to determine the suitability of the model for the data. To fulfil the goal of estimating equation (6), the sustainability index score (ranging from 0 to 1) for maize farm households was divided into two primary categories. This allowed for binary coding of the variable, which was then incorporated into the model.

**Ethical Consideration**

Ethical considerations play a crucial role in distinguishing between acceptable and unacceptable behaviors in research, as noted by Creswell (2014). According to Creswell (2014) key ethical issues that researchers must address include voluntary participation, the right to privacy, maintaining anonymity, and safeguarding the confidentiality of information. Consequently, this study made concerted efforts to address these ethical concerns. For instance, voluntary participation was upheld by allowing all respondents to willingly take part in the data collection process. To respect the right to privacy, respondents answered the interview schedule independently, and were informed that they could leave unclear questions unanswered.

The issue of anonymity was meticulously managed by instructing respondents not to provide their names or contact information, assuring that their identities would remain confidential and not be disclosed or used for any purpose beyond this study. Additionally, the study ensured the confidentiality of the provided information, assuring participant that their data would be kept private and not used against them or shared with the public.

Considering these efforts, all major ethical considerations were met in the study. Participation was entirely voluntary, with no coercion involved. Participant interview schedule responses were kept confidential, and their names were omitted to guarantee anonymity throughout the study. Furthermore, the research team maintained professional competence during data collection and analysis, ensuring independent objectivity in the interpretation of survey findings.

## Chapter Summary

The chapter focused on the methodological procedure of the study. It described the research design, the study area, population, sample procedure and sample size, the data collection instrument, data collection procedure, data processing, analytical framework, model specifications, estimations of the study and ethical consideration.

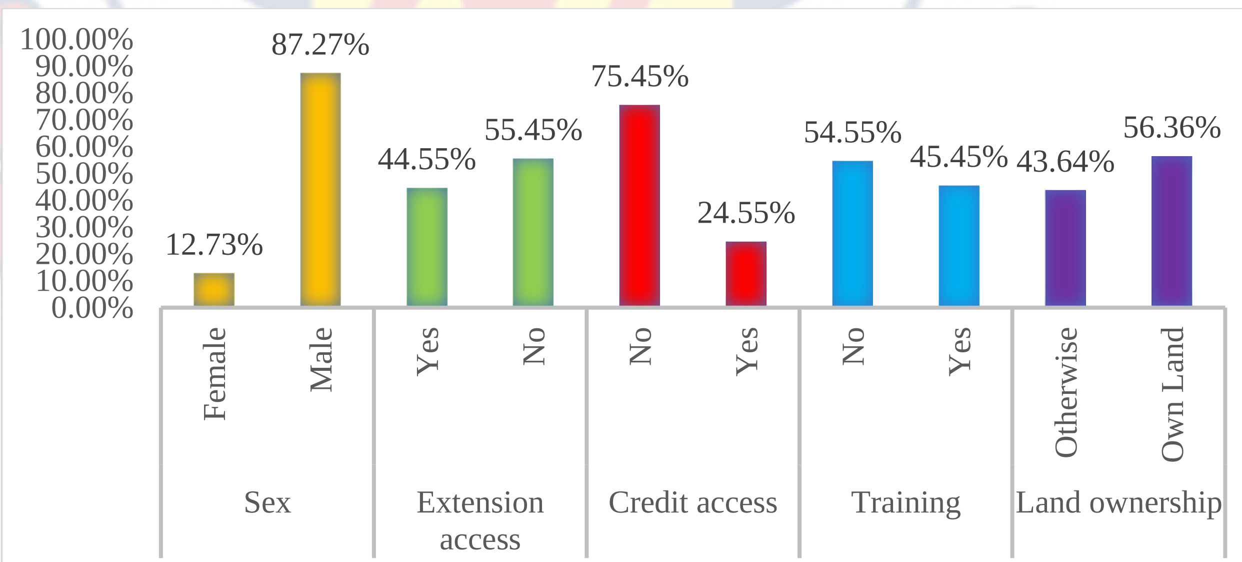
# CHAPTER FOUR

# RESULTS AND DISCUSSION

## Introduction

This chapter discussed the results and discussion section of the study. The chapter explained the socio-economic characteristics of the respondents. The rest of the results and discussions were presented based on the study objectives, which are to examine the extent of fertiliser use and fertiliser use efficiency in maize production, assess how fertiliser use efficiency influences the sustainability of smallholder maize production, analyse the extent of sustainability in maize production, analyse the technical efficiency in maize production, and examine the effect of the sustainability of farm practices on the technical efficiency of smallholder maize farmers.

## Socio-Economic Characteristics of Maize Farmers




Source: Fieldwork 2023

Figure 3: Socio-Economic Characteristics of Maize Farmers

An analysis of the socio-economic characteristics of the respondents was done using descriptive statistics. Figure 3 shows the categorical variables for the socio-economic characteristics of maize farmers. It was revealed that the majority, 87.27% of the farmers who participated in the study, were males, and 12.73% were female farmers. This suggests that men dominate maize farming. It can also imply that women in the region are not particularly engaged in maize farming or lack the prerequisite resources and skills to start their farming businesses.

The results resonate with Ayaaba (2022) wherein it was observed that males accounted for approximately 61% of total labour hours, while females contributed about 39% to the overall maize production process. Based on the findings of the Food and Agriculture Organisation (FAO) (2012), it is observed that men possess a significantly higher proportion of the overall farms compared to women, with a ratio of 3.2 to 1. Furthermore, when considering medium and large-sized farms spanning an area of 5 acres or more, men exhibit a substantially greater dominance, with a ratio of 8.1 to 1. According to Dembélé's (2021) findings, West African rural farming communities show pronounced gender disparities regarding the accessibility of opportunities and resources. According to Wahabu's (2020) findings, it was observed that traditional norms constrain women's ability to engage in independent farming activities. This restriction led to various obstacles, including restricted access to labour and capital resources. Several factors may have constrained the ability of women to engage in agricultural activities in this study autonomously. This trend may account for the disproportionate weight of poverty experienced by women.

Figure 3 also showed that 44.55% of farmers had access to extension services. This leaves the majority, 55.45%, unable to receive support from extension officers. This implies that extension officers did not engage a significant proportion of farmers on up-to-date proper farming practices. Danso-Abbeam et al. (2018) found that positive economic gains come from participating in agricultural extension programs and interacting with extension agents. Issahaku and Abdulai (2020) revealed a positive and significant correlation between extension services and the technical efficiency of smallholder farmers.

Danso-Abbeam et al. (2018) reiterated the pivotal significance of extension programmes in augmenting agricultural productivity and household income for farmers residing in the Northern region of Ghana. According to Anang et al. (2020), a statistically significant correlation exists between agricultural extension and the outcomes of adoption and farm income. The empirical research conducted by Setsoafia et al. (2022) reveals that adopting sustainable agricultural practises among Ghanaian farmers is significantly influenced by socio-economic factors, specifically the availability of extension services and geographical location.

In their comprehensive study, Piñeiro et al. (2020) meticulously examined a vast corpus of 18,000 papers, revealing that technical assistance and extension services are the paramount determinants for fostering sustainable practises among farmers. Hence, the insufficiency of extension programmes and services identified in the present study may impact the limited uptake of sustainability practises among maize farmers in Northern Ghana (Figure 5).

Furthermore, as depicted in Figure 3, the research noted that the majority of maize farmers, 75.45%, did not seek credit access. This observation suggests that the maize farmers may not have required external funding, lacked awareness of available credit sources, or potentially stemmed from their limited involvement in farmer-based organizations, which typically facilitate access to finance and external loans. It is also important to consider that the application process for loans could play a significant role in shaping their decision to pursue credit options. According to Sarfo (2018), loan usage significantly increases smallholder maize farmers' gross margins, net income, and returns on investment.

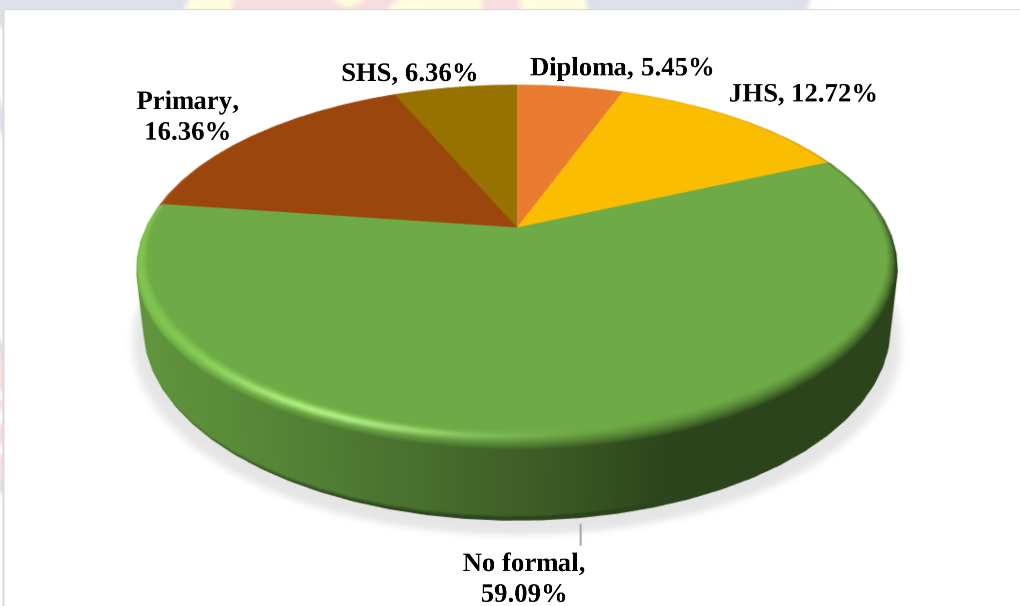
The research results of Issahaku and Abdulai (2020) demonstrated that there is a positive and statistically significant relationship between credit accessibility and the technical efficiency of smallholder farmers. The study conducted by Missiame et al. (2021) revealed that providing credit facilities to smallholder farmers notably enhances farmers' technical efficiencies. In this study, it is evident that smallholder maize farmers were disadvantaged, given that a significant proportion lacked access to credit facilities or any agricultural loan.

Moreso, figure 3 shows that about 45.45% received training concerning their farming activities. This means that 54.55% of the maize farmers, representing the majority, did not receive any training on their farming practices. Therefore, it can be argued that most maize farmers did not receive training on sustainability responses to fertiliser use and other agronomic farming practices. According to Anang and Awuni's (2018) findings, training improved the number of extension visits, group memberships, credit opportunities, and the level of specialisation in farm output. Anang and Awuni

(2018) also found that participation in training increases output and labour productivity. Figure 3 also showed the maize farmers' ownership of the farmlands, revealing that the majority (56.36%) of the farmers owned their farmland.

**Educational level of Respondents**

The study revealed that most of the respondents, specifically 59.09%, lacked formal education. Conversely, the remaining 40.91% possessed varying degrees of formal education, distributed as follows: 11.3% with primary education, 12.72% with junior high school education, 6.36% with senior high school education, and 5.45% with a diploma, as depicted in figure 4. The data presented indicates that a considerable proportion of maize farmers hold a limited formal education, which may have implications for their comprehension of sustainable farming practices and crop production efficiency.




Source: Fieldwork 2023

Figure 4: Educational Level of Maize farmers

Again, the farmers were assessed on their age, household size, and farm size in Table 6. It was revealed that most farmers were within 40 years old on average. This means that generally, the farmers were in adulthood and are energetic to manage their farm activities and production. Additionally, most farmers had a family size of 4 members. This suggests that the families of these farmers are relatively large, which increases the family burden and dependency. The study also showed that on average, most farmers had about 1.38 hectares of fields.

**Table 2: Descriptive Statistics of Farmer and Farm Specific Variables**

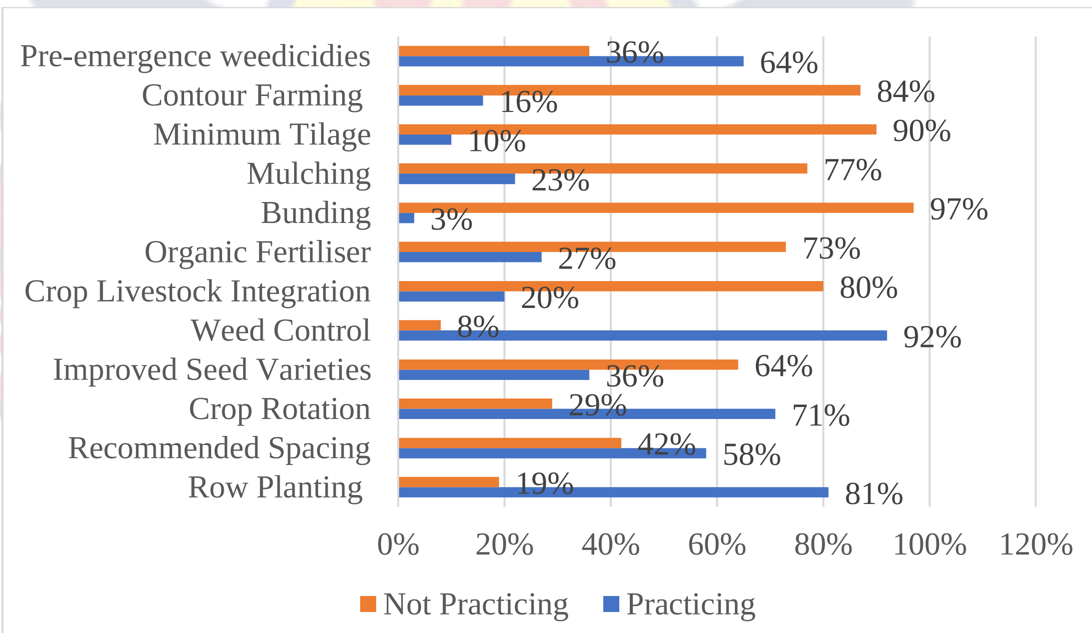
| Continuous Variables | Mean | SD |
|---|---|---|
| Age | 43.17 | 11.29 |
| Household Size | 14.08 | 6.69 |
| Farm Size (Hectares) | 1.38 | 0.86 |
| Labour | 94.18 | 89.64 |
| Capital | 222.19 | 124.62 |
| Fertiliser Use | 57.10 | 29.77 |
| Agrochemicals | 47.94 | 35.19 |

Source: Fieldwork 2023

**Sustainable Farm Practices by Maize Farmers**

The study revealed that most of the maize farmers adequately practised five (5) out of twelve (12) sustainability practices outlined in the study. Row planting, crop rotation, recommended spacing, weed control, and pre-emergence weedicide application were highly practised among maize farmers. On the other hand, the adoption of contour farming, minimum tillage, mulching, bunding, organic fertiliser and improved seed varieties were low among maize farmers, as shown in Figure 5.

Ehiakpor et al. (2021) reported low adoption rates of sustainable practices among smallholder farmers. The proposition has been made to allocate significant consideration towards SAP due to its capacity to safeguard the environment, enhance soil, mitigate the exhaustion of vital ecosystem resources, and bolster farm productivity. Akowuah et al. (2012) observed more unsustainable practices among smallholder farmers, which resulted in low grain production. Danquah et al. (2018) also found that yam farmers barely adopted sustainable practices. However, on an improved sustainable agriculture field, yam yields increased by more than 100% in Ejura and Atebubu farming communities.

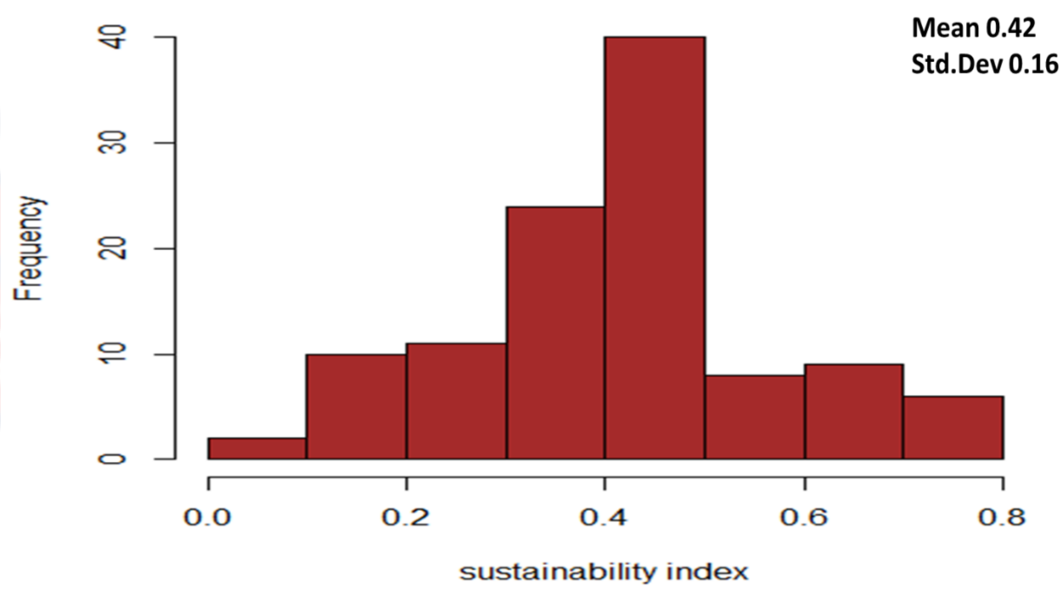



Source: Fieldwork 2023

Figure 5: Sustainable Practices of Maize Farmers

**Sustainability of the Maize Farm Practices**

The sustainability index score was used to determine the level of sustainability based on the agronomic practices engaged by the maize farmers. It was revealed in Figure 6 that the maize farmers' mean sustainability index score stood at 0.42, ranging from 0 to 0.8. This shows a moderate extent of smallholder farmers' sustainability of maize production practices in Northern Ghana. The study's results conform to the finding of Mutyasira et al. (2018) who reported that adopting sustainable practices is lagging among smallholder farmers. According to Oyetunde-Usman et al. (2021), SAP adoption rates have traditionally been poor, particularly in developing nations. Therefore, it is unsurprising to see a moderate level of sustainability practised among maize farmers in Northern Ghana.




Source: Fieldwork 2023

Figure 6: Distribution of Sustainability Index

**Levels of Fertiliser Use and Fertiliser Use Efficiency in Maize Production**

**Levels of Fertiliser Use in Maize Production**

Descriptive statistics were performed on the levels of fertiliser use among smallholder farmers in maize production. However, all the other resources (land, labour, agrochemicals, and capital) were included because the sustainability concept relies not solely on fertiliser but also the other farm resources. Table 3 shows the mean, standard deviation, minimum, and maximum use of land, labour, fertiliser, agrochemicals, and capital. The average use of land, labour, fertiliser, agrochemicals, and capital were 1.5, 120.6, 186.4, 58.7 and 291.6 respectively.

**Table 3: Level of Fertiliser and Other Input Use**

| Measurement | Land (ha.) | Labour (ha.) | Fertiliser (ha.) | Agrochemical (ha.) | Capital (ha.) |
|---|---|---|---|---|---|
| Mean | 1.5 | 120.6 | 186.4 | 58.7 | 291.6 |
| Min | 0.4 | 8.09 | 0.04 | 4.07 | 9.39 |
| Max | 12.1 | 864.0 | 954.18 | 71.70 | 2780.25 |

Source: Fieldwork 2023

**The Fertiliser Use Efficiency in Maize Production**

The efficiency of fertiliser use refers to applying appropriate and acceptable quantity of fertilisers to increase yields, improve soil fertility, and provide measures that reduce emissions and nitrate leaching or leaking into the environment (Moreno & García-Álvarez, 2018). To determine the efficiency of fertiliser use, it is also imperative to determine the efficiency of other resources used for maize production. Table 4 shows that among the inputs used, land, labour, fertiliser, and agrochemicals were below the threshold of 1.0 of optimised resource efficiency level, indicating overutilisation of these inputs. The study also showed that capital was above the threshold of 1.0 optimised resource efficiency level, meaning that capital input is underutilised. It can be inferred that the maize farmers were not fully efficient in using their capital resource. Awunyo-Vitor et al. (2016) revealed that maize farmers in Ghana were inefficient in using resources available to them. The current study found overutilisation of land and fertiliser, while Awunyo-Vitor et al. (2016) found underutilisation of these inputs. This study also found underutilisation of capital, which contradicts Awunyo-Vitor et al. (2016) who found overutilisation of labour and capital among maize farmers. Osei-Danquah et al. (2020) also found that inputs like fertiliser and land were underutilised, while land and capital were overutilised.

Osei-Danquah et al. (2020) reported that farmers are not using the resources efficiently, either overusing or underusing them. As farmers aim to increase their yields, they stretch some resources beyond their limits whiles other resources are used within its limit. There is no balance of efficiency, and these actions are projected to affect agricultural production in the long term adversely. Therefore, Danquah et al. (2020) suggested that more effort should be made to attain resource use efficiency in agricultural production.

Sienso et al. (2014) found that Nkoranza, Brong Ahafo Region maize farmers were overutilising labour but underutilising fertiliser and seeds. Tasila Konja et al. (2019) found that, apart from land, all other factors used in farm production by smallholder farmers in Northern Ghana were overutilised. This shows that the current study's findings were not new. Also, given that most farmers were not practising sustainable farming, it is not surprising to see that fertiliser use efficiency did not meet the optimisation threshold.

**Table 4: Resource Use Efficiency in Maize Production**

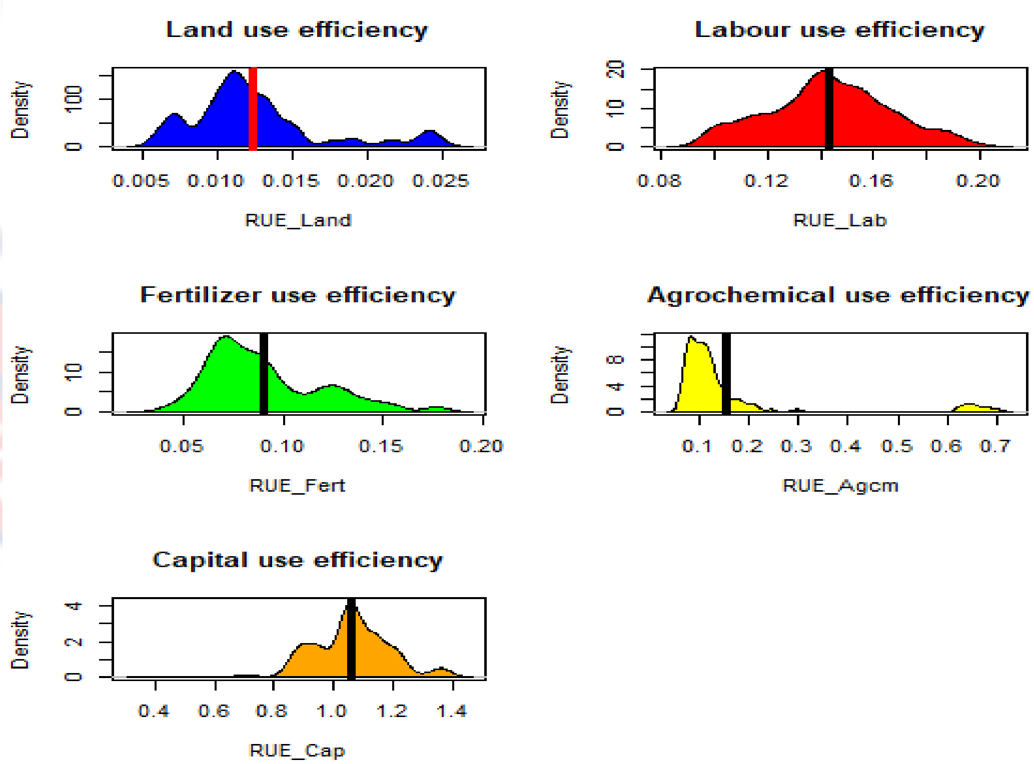
| Input variable | Resource Use Efficiency (RUE) | Decision Rule |
|---|---|---|
| land | 0.01 | Overutilised |
| Labour | 0.14 | Overutilised |
| Fertiliser | 0.09 | Overutilised |
| Agrochemicals | 0.16 | Overutilised |
| Capital | 1.06 | Underutilised |

Source: Fieldwork 2023

*NB: RUE = 1 (Full RUE Efficiency Level); RUE < 1 (Overutilisation of Resources); RUE > 1 (Underutilisation of Resources)*

It is clear from the above discussion that maize farmers were overusing fertiliser. Ignoring optimisation does not paint a good picture of achieving sustainable development goals. Figure 7 provides a better view of the distribution of individual farmers' resource use efficiencies. In the case of land use efficiency, labour use efficiency, fertiliser use efficiency, and agrochemical use efficiency, as shown with blue, red, green, and yellow colours, respectively, it can be seen that the individual farmers' responses were skewed too far left and were less than 1.0, which implies overutilisation of land, labour, fertiliser, and agrochemicals. This emphasises the excessive utilisation of these resources. Capital use efficiency, on the other hand, with the orange colour, was skewed to the right, indicating underutilisation of capital.

Awunyo-Vitor et al. (2016) argued that to increase productivity among smallholder farmers, the focus should be maximising their available resources. Osei-Danquah et al.'s (2020) findings also revealed that smallholder maize farmers in Ghana were not resource efficient. The current study affirmed the results from Awunyo-Vitor et al. (2018) and Osei-Danquah et al. (2020) where smallholder maize farmers were observed to be resource inefficient.




Source: Fieldwork 2023

Figure 7: Resource Use Efficiency

**The Relationship Between Fertiliser Use Efficiency and Sustainable Agricultural Practices of Maize Production**

Using the SUR Model, the study assessed at the correlation between fertiliser use efficiency and the sustainability of maize production. Table 5 present models from two equations. Equation 1 showed the dependent variable as sustainability practices against fertiliser use efficiency, land ownership, sex, age, educational level, household size, extension services, credit availability, and training. Equation 2 showed fertiliser use efficiency as the dependent variable against sustainability practice, land ownership, sex, age, educational level, household size, extension services, credit availability, and training.

The analysis showed a positive relationship between the efficiency of fertiliser use and the adoption of sustainable farm practices. The more maize farmers use sustainable agricultural practices, the more efficient they become in using fertiliser towards achieving the optimum output level. In essence, increasing or adjusting the optimal fertiliser use towards the optimal level can be attributed to the adoption of improved and sustainable agricultural practices.

Hill's (2014) found similar results, demonstrating a positive and statistically significant relationship between the efficiency of fertilisers use and maize crop yields. The findings of Panhwar et al. (2019) posited that the implementation of integrated nutrient management, which involves the utilisation of both bio-organic fertilisers and chemical fertilisers, contributes to achieving sustainable wheat production. According to Kintché et al. (2015) maize yields experienced a decline from 2 ha following the clearance of woodland areas to 0.5 ha after a decade of cultivation in the absence of fertilisers. On the other hand, cotton yields decreased from 1.5 to 0.5 ha, but this decline was observed after a shorter period of 5 years. In a similar vein, the study conducted by Naher et al. (2019) revealed that incorporating sustainable practises, such as utilizing organic nutrient sources, played a significant role in enhancing rice grain yield and soil carbon storage.

**Table 5: SUR Model Results Showing the Relationship Between Sustainability of Farm Practices and Fertiliser Use Efficiency.**

| Explanatory Variable | Equation 1 (Sustainable Practices) | | Equation 2 (FUE) | |
|---|---|---|---|---|
| | Estimate | Std. Error | Estimate | Std. Error |
| Intercept | 0.2089*** | 0.0733 | 0.2089*** | 0.0733 |
| FUE | 0.0476*** | 0.0118 | - | - |
| Sustainable Practice | - | - | 0.0010*** | 0.0001 |
| Land Ownership | -0.0809 | 0.1592 | 0.0030 | 0.0023 |
| Sex | 0.0190 | 0.0156 | -0.0044 | 0.0030 |
| Age | 0.0334** | 0.0161 | -0.0129*** | 0.0030 |
| Level of Education | 0.0039 | 0.0035 | -0.0022*** | 0.0007 |
| Household Size | 0.0018** | 0.0008 | 0.0029 ** | 0.0058 |
| Extension Services | 0.0054 | 0.0100 | -0.0015 | 0.0019 |
| Credit Availability | 0.0234** | 0.0112 | 0.0044 ** | 0.0021 |
| Training | 0.0760*** | 0.0099 | 0.0076*** | 0.0019 |

***Significant codes: '***' 0.01, '**' 0.05, '*' 0.1***

Source: Fieldwork 2023

Pedercini et al. (2015) submitted that using NPK fertiliser alone depletes soil organic matter in the long run. However, in addition to sustainable practices, soil organic matter will remain in the soil and improve the production of crop yields. FAO (2019) revealed that fertiliser use efficiency coupled with sustainable practices tends to shift the course of farming. According to FAO (2019), several studies have demonstrated that using inorganic fertiliser alone reduces the organic quality of the soil, but adding organic fertiliser or other sustainable practices can significantly improve crop yields. Akinnifesi (2018) reported that fertiliser use efficiency is rare among smallholder farmers, and achieving optimum efficiency will take many years. Therefore, supporting fertiliser use efficiency with sustainable practices can maximize crop production among smallholder farmers. Based on the literature and the study findings, it is clear that fertiliser use efficiency with sustainable agricultural practices tends to improve maize production among smallholder farmers.

**Table 6: SUR-Covariance Matrix and Correlation of the Residuals**

| Covariance matrix | Sustainability Index | Fertiliser Efficiency |
|---|---|---|
| FUE | 2.1268e-02 | 9.3364e-05 |
| SI | 9.3365e-05 | 7.699e-04 |
| Correlations of the residuals | Sustainability Index | Fertiliser Efficiency |
| FUE | 0.0231 | 1.0000 |
| SI | 1.0000 | 0.0231 |

Source: Fieldwork 2023

**Technical Efficiency of maize production in Northern Ghana**

**The Maximum Likelihood estimate of the stochastic frontier model.**

The Maximum Likelihood estimate of the stochastic frontier model was used to estimate the technical efficiency of maize farmers in Northern Ghana. The Cobb-Douglas and the Translog functions model were used to determine the log-likelihood ratio test and model fitness. The log-likelihood ratio test empirically aids in determining which of the two models is best fit given the data assumption of the stochastic Translog models. The larger log-likelihood value shows stronger evidence for empirical support for one model over the other. The log-likelihood ratio test result of the Translog model had a larger value of -894.5 compared with the log-likelihood value of -1059.727 for the Cobb-Douglas model as shown in table 10. This means that there is some form of tolerance in the Translog model estimation for the data set compared to that of the Cobb-Douglas model.

Additionally, a generalized likelihood ratio test was performed using the Cobb-Douglas and Translog models with a formulated hypothesis, with the Cobb-Douglas model serving as the null hypothesis and the Translog model serving as the alternative. The Translog model had a chi-square value of 330.45 and a significance level of 1% (p-value = 2.2e-16 ***) as shown in table 9. On the other hand, the Cobb-Douglas model did not appear to be significant, hence, it was rejected. The Translog model provided the best fit for the data.

Since the Translog model is the best fit for the data, its estimates have been presented to discuss the efficiency results. The estimated sigma square value of 1.4437e+00 was significant at a 1% alpha level, which shows a good fit for the model. Apart from the interaction effects of all the variables in the model, the coefficients of most of the inputs in the model were highly significant at less than 1%. Only two inputs were recorded to be significant at 5%, and one input was significant at 10%.

**Table 7: Maximum Likelihood Estimates of Stochastic Translog technical frontier model of maize farmers**

| Variable | Coefficient | Standard Error |
|---|---|---|
| **Intercept** | 2.4681e+01*** | 9.2507e-01 |
| Land | 1.3849e+00** | 5.4245e-01 |
| Labour | -7.8790e-01*** | 1.6823e-01 |
| Fertiliser | 4.1862e+00*** | 3.6282e-01 |
| Agrochemical | -2.2918e+00*** | 9.5892e-02 |
| Capital | 1.0185e+01*** | 2.2978e-01 |
| Square of land | -3.1140e-01*** | 2.4230e-02 |
| Square of labour | -5.5019e-01*** | 6.7997e-02 |
| Square of fertilizer | -6.0742e-02*** | 1.0006e-02 |
| Square of agrochemical | -2.0109e+00*** | 4.7635e-02 |

| | | |
|---|---|---|
| Square of capital | 2.7029e-01*** | 4.3365e-02 |
| Land-Labour | -4.1366e-01*** | 9.0583e-02 |
| Land-Fertiliser | 7.7967e-02* | 4.1052e-02 |
| Land-Agrochemical | -2.3403e-01** | 9.4289e-02 |
| Labour-Fertiliser | 1.5292e-01*** | 2.5235e-02 |
| Labour-agrochemical | -1.7442e-01*** | 1.2392e-02 |
| Labour-Capital | 3.6888e-01*** | 3.0319e-02 |
| Fertiliser-Agrochemical | 1.0823e-01*** | 2.0768e-02 |
| Fertiliser Agrochemical | -5.1224e-01*** | 3.6800e-02 |
| Agrochemical-capital | 4.9733e-01*** | 1.6143e-02 |
| **Diagnostic statistics** | | |
| **Sigma square** | 1.444*** | |
| **Gamma** | 1.000*** | |
| **Log-likelihood** | -894.5 | |
| **Mean Efficiency** | 0.5145 (52.0%) | |

Source: Fieldwork 2023

NB: *, **, and *** denotes significant levels of 10%, 5%, and 1% respectively

The Cobb Douglas production function was also analytically processed to compare the efficiency of the two model. The Cobb Douglas model showed some inefficiency and therefore decreased the endogenous variables in the production function. The dependent variable is logged. Iterative ML estimation was terminated after 13 iterations and the log likelihood values and parameters of two successive iterations were within the tolerance limit. Table 9 revealed the results of the Cobb Douglas frontier values and estimates.

**Table 8: Maximum Likelihood Estimates of Stochastic Cobb Douglas frontier model of maize farmers**

| Variable | Coefficient | Standard Error |
|---|---|---|
| **Intercept** | 2.590776 *** | 0.223462 |
| Land | -0.163815 ** | 0.059683 |
| Labour | -0.022262 | 0.017519 |
| Fertiliser | 0.250848 *** | 0.031463 |
| Agrochemical | -0.043552 ** | 0.019922 |
| Capital | 0.622593 *** | 0.041854 |

Source: Fieldwork 2023

NB: *, **, and *** denotes significant levels of 10%, 5%, and 1% respectively

**Table 9: The appropriateness and significance of the Model**

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| Sigma | 0.53494 | 0.02694 | 19.86 | <2e-16 *** |

| | | | | |
|---|---|---|---|---|
| Rho | 0.99527 | 0.36564 | 2.722 | 0.00654 ** |

Source: Fieldwork 2023

Signif. codes: ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1

**Table 10: Result of hypothesis tests**

| Models | Df | LogLik | Chisq | Pr(>Chisq) | Decision |
|---|---|---|---|---|---|
| **1** | 8 | -1059.7 | - | - | Reject Cobb Douglas |
| **2** | 22 | -894.5 | 330.45 | 2.2e-16 *** | Translog Appropriate |

Source: Fieldwork 2023

NB: *, **, and *** denotes significant levels of 10%, 5%, and 1% respectively

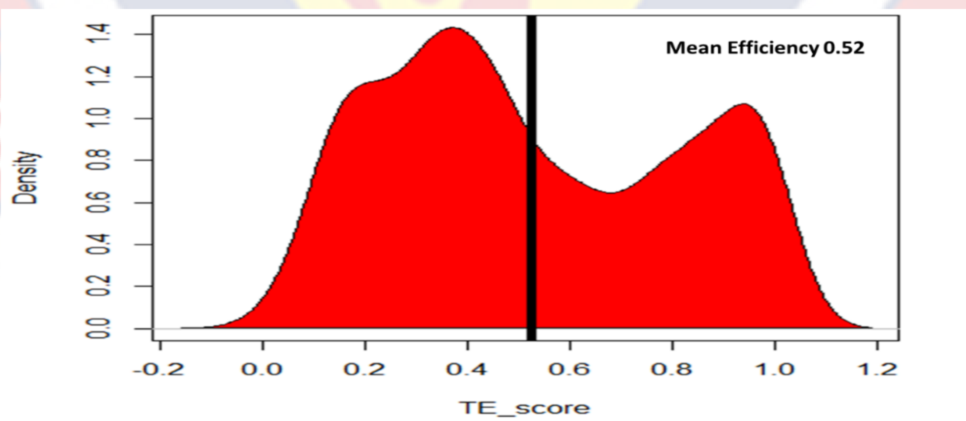
The estimation of the Translog best fits the data set and gives the most efficient estimates.

**The Implication of the Technical Efficiency Results**

The technical efficiency results were derived from the translog model, which showed that the maize farmers did not maximise their output levels, indicating they were not fully technically efficient. The mean efficiency was 51.45%, leaving an efficiency gap of about 48.55%. This result is not surprising because, looking at the essential resources used in maize production, the farmers could not fully utilise resources at the optimal efficiency level (see Table 4 and Figure 7). The resources were either underutilised or overutilised. Therefore, the decision-making pattern of the smallholder maize farmers not being technically efficient is apparent.

Anang et al. (2022) conducted similar study to evaluate the technical efficiency of smallholder maize farmers. They found that these farmers were 68% efficient, leaving an inefficiency gap of about 32%. Abdulai et al. (2018) and Bempomaa and Acquah (2014) found that maize farmers were not technically efficient and reported an efficiency gap of about 33%. Kodua et al. (2022) also revealed about 56% technical inefficiency among local maize seed farmers. Siaw et al. (2020) found 26% inefficiency among maize farmers in Ghana. Kwawu et al. (2021) observed an average maize farmers' technical efficiency of 70%.

Sienso et al. (2014) found a relatively high 91% technical efficiency among the Brong Ahafo Region maize farmers. Wongnaa and Awunyo-Vitor (2018) found 41.8% technical inefficiency among smallholder maize farmers. Wongnaa and Awunyo-Vitor (2018) findings are close to what the current study revealed. Therefore, it can be concluded that smallholder maize farmers in Ghana, to some extent, are not technically efficient, and this study did not prove otherwise.




Source: Fieldwork 2023

Figure 8: Distribution of technical efficiency scores of maize productions

### The Effect of Sustainability of Agricultural Practices on Technical Efficiency Using the HeckitTreatment Effect Model

The Heckit treatment effect model was employed to examine the impact of sustainable agricultural practises on the technical efficiency of maize farmers. The outcomes of the model are displayed in Table 10. Table 10 presents two model outcomes derived from the selection equation related to sustainable agricultural practises and the outcome equation concerning technical efficiency. The selection equation also discussed the impact of socioeconomic factors on adopting sustainable agricultural practises in maize production. While the outcome equation examined the treatment effect of sustainable agricultural practises and other factors on the technical efficiency of maize farm households.

In the Heckit Treatment effect model, sustainable practices were categorised into binary data indicating high and low sustainable practices. The study used the sustainable index score to calculate the average score, which was found to be 0.42. This value was used as the threshold to categorise highly or lowly sustainable agricultural practices. Agricultural practices with a sustainability index score of 0.42 and above were considered highly sustainable. In contrast, those below the threshold 0.42 were considered lowly sustainable in using agricultural practices for maize production.

The Probit Selection Equation was used to estimate the selection process, which included the socio-economic characteristics of the maize farmers. The results of this equation were used to construct the variable that captures the selection effect in the outcome equation, which was the sustainability category. The study found a positive relationship between sustainable practices and technical efficiency among maize farmers. This shows that more sustainable farmers were more technically efficient, while less sustainable farmers were less technically efficient, as indicated in Table 10.

**Table 11: Probit Selection and Outcome Equation of the Heckit Treatment Effect Model**

| Variable | Probit Selection Equation (Sustainability Index) | | Outcome Equation (Technical Efficiency) | |
|---|---|---|---|---|
| | Estimate | Std. Error | Estimate | Std. Error |
| Intercept | 3.0479 | 2.7116 | 1.9549*** | 0.2752 |
| Sustainability | - | - | 0.9639*** | 0.0587 |
| Sex | -0.5673 | 2.477 | -0.0347 | 0.0578 |
| Age | -0.5604** | 0.2017 | -0.2099*** | 0.0599 |
| Education | -0.0572 | 0.0441 | 0.0247** | 0.0132 |
| Household size | -0.0097 | 0.0161 | -0.0059*** | 0.0028 |
| Extension cont. | -0.1263 | 0.1320 | -0.1768*** | 0.0369 |
| Access to credit | 0.1127 | 0.1240 | 0.0638 | 0.0418 |
| Own | 0.4671*** | 0.1137 | 0.1308*** | 0.0437 |
| Training | -0.5875*** | 0.1875 | -0.0621* | 0.0368 |

| | Estimate | Standard Error |
|---|---|---|
| Sigma | 0.5349*** | 0.0269 |
| Rho | 0.9953*** | 0.3656 |

Source: Fieldwork 2023

*NB: Significant codes: '***' 0.01 '**' 0.05 '*' 0.1*

Issahaku and Abdulai's (2020) research showed that farmers who implemented sustainable land management practises displayed more significant technical efficiency and output than non-adopters. This means that smallholder farmers become more technically proficient when adopting more sustainable agricultural techniques. FAO (2011) found that adopting sustainable land management significantly impacts smallholder farmers' production and efficiency.

Similarly, Khanal et al. (2018) observed that implementing sustainable agricultural practises yields a significant boost in productivity and efficiency among smallholder farmers in Nepal. According to Nkonya et al. (2016), implementing sustainable farming practises can enhance food production amidst climate uncertainty. In other words, all of this literature confirms the study findings that technical efficiency can be improved with increased sustainable agricultural practices among smallholder farmers.

**Chapter Summary**

The chapter discussed reported and discussed the findings revealed in this study. The study revealed that men dominated maize farming and that more than half of the farmers did not receive assistance from extension officers. Additionally, most maize farmers did not receive credit accessibility or training during their farming activities. The chapter reported that farmers moderately utilised sustainable farming techniques with a mean sustainability index score of 0.42. Furthermore, the study revealed that resources such as land, labour, fertilisers, and agrochemicals were overutilised, while capital was underutilised. The maize farmers were also unable to maximize their output, with a 48.55% efficiency gap in achieving technical efficiency. The chapter concludes with a report on the findings of the SUR and Heckit treatment effect models, which discovered a positive relationship between fertiliser use efficiency and farm practise sustainability. The study also found a significant effect of sustainable farming practices and smallholder farmers technical efficiency.

# CHAPTER FIVE

# SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The study examined the sustainability responses to fertiliser use in maize production. The study achieved this goal by first addressing the fertiliser use efficiency of maize production, analysed other key resources such as land, labour, capital, and agrochemicals. The study also analysed the extent of sustainability practices by maize farmers, the technical efficiency of maize production, and the relationship between fertiliser use efficiency and the sustainability of maize production. Finally, the study determined the relationship between sustainable practices and the technical efficiency of maize production.

## Summary

The study discovered that men cultivated more maize than women in northern part of Ghana. It also implied that women in Northern Ghana lack the initiative to engage in maize farming or perhaps lack the necessary resources and skills to launch their farming enterprise. There is a need for more studies to probe into some of the reasons why this is so. Also, the disparities could be yet another factor contributing to more women than men experiencing poverty in the farming communities of Northern Ghana.

According to the study, more than half of the farmers did not receive assistance from extension officers, which may impact farmers' ability to stay current with sustainable practices, fertiliser use efficiency, and achieve optimum production.

The study found that most maize farmers did not request credit accessibility. This could mean that the farmers did not require external loans or were unaware of where to apply for loans. It is also possible that most farmers are not members of farmer-based organisations, which frequently offer easy access to financing. There is a need for more inquiry into the low credit accessibility to smallholder maize farmers in Northern Ghana. The study also showed that most maize farmers did not receive training on sustainable farming and other agronomic farming practices.

According to the study, maize farmers in Northern Ghana only used a few agronomic techniques. Row planting, crop rotation, recommended spacing, pre-emergency weedicide application, and weed control were the sustainable practices actively engaged by most maize farmers. The majority of sustainable farming practices, such as contour farming, minimal tillage, mulching, bundling, organic fertiliser, crop-livestock integration, and improved seed varieties, were lowly practised.

Based on the farmers' agronomic practices, the level of sustainability was assessed using sustainability index scores. The study found that the farmers moderately utilised sustainable farming techniques to produce maize. Most maize farmers did not use improved seed varieties, contour farming, minimum tillage, mulching, bundling, organic fertiliser, or crop-livestock integration to their total capacity. Therefore, it is unsurprising to see that the mean sustainability index score is as low as 0.42 on average and is skewed to the left.

The study revealed that all the input resources used did not meet the optimized resource efficiency level threshold. Land, labour, fertiliser, and agrochemicals were overutilised, and capital was underutilised. Therefore, it is possible to conclude that the maize farmers were not using their resources efficiently. With regards to fertiliser use efficiency, it is not surprising that it did not meet the optimisation threshold because most farmers were not farming sustainably.

It was revealed that the maize farmers did not maximize their output. The mean technical efficiency was 51.45%, leaving an efficiency gap of about 48.55%. This is not surprising given that the farmers could not achieve optimum resource efficiency when it came to the primary resources used in production. The resources were either underutilised or overutilised. Therefore, it is possible to suggest that the decision-making pattern of the farmers is not technically efficient.

The study revealed a positive relationship between fertiliser use efficiency and the sustainability of farming practices. This means that the more sustainable practices a farm system adopts, the higher the possibility of adjusting fertiliser use toward achieving the optimum level. Sustainable practices must be enhanced to achieve an optimum level of fertiliser use.

Finally, the study revealed that the higher the sustainable practices, the higher the technical efficiency level of farmers. This means that to improve their technical efficiency level, maize farmers must increase their sustainability practices.

**Conclusions**

The study findings suggest that some socio-economic characteristics such as sex, access to credit facilities, extension programmes and training should be improved to attain resource efficiency. Moreover, the extent of sustainable practices adopted by the maize farmers was moderate, this means there is more room for maize farmers to improve and fully adopt sustainable farm practices. Furthermore, the study concluded that maize farmers were not using resources such as land, labour, capital, fertiliser, and agrochemicals at their optimum efficiency level. The resources were found to be either overutilised or underutilised. These results were unsurprising because most farmers were not farming sustainably. It was also not surprising to see that the decision-making pattern of the farmers was not fully technically efficient, indicating a technical efficiency gap of almost 50%. Finally, the study found a positive relationship between fertiliser use efficiency and the sustainability of farm practices and between sustainability practices and the technical efficiency of maize farmers. This means that maize farmers would have to adopt more sustainable practices to achieve optimum fertilizer efficiency and technical efficiency.

**Recommendations**

Based on the findings and conclusions of this study, the following recommendations were made:

1. There ministry of agriculture should strengthen extension education to emphasize sustainable agricultural practice among smallholder farmers.
2. Smallholder farmers need to focus on farming sustainable to improve their technical efficiency in maize production.
3. Policy makers and the government should provide support for smallholder farmers such as credit availability and capacity training on sustainable practices.

4. The Ministry of Food and Agriculture must equip extension officers to conduct periodic training and checks on sustainable farming among smallholder maize farmers.

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# APPENDIX I

## STRUCTURED INTERVIEW SCHEDULE

**Section A: Basic information**

1. What is the sex of the respondent? (1) Male (0) Female
2. What is the age of the respondent? …………………………….. years
3. What is the current marital status of the respondent? (1) Single (2) Married (3) Divorced/Widow/Widower
4. What is your highest level of education of respondent? (1) No formal (2) Primary (3) JHS (4) SHS (5) Diploma (6) Degree (7) Masters
5. Aside crop production, do you engage in other economic activities? (1) Yes (0) No
6. How many people are in your household? ……………………………
7. Farm size for the maize crop ………………………………………
8. Did you access any form of finances for the production of maize crop? (1) Yes (0) No

**Section B: The sustainability practices utilised by farmers in maize production**

9. Did you practice the following sustainable/integrated agricultural practices in 2020?

| **Integrated practice** | **(1) Yes (0) No** |
|---|---|
| Row planting | |
| Planting with recommended spacing | |
| Crop rotation | |
| Improved seed varieties | |
| Keeping weed-free farm | |

| | |
|---|---|
| Crop-livestock integration | |
| Organic fertiliser | |
| Bunding | |
| Mulching | |
| Minimum tillage | |
| Contour farming | |
| Pre-emergence weedicides application | |

**Section C: Crop production, inputs and output (Measuring of Fertiliser Efficiency and Technical Efficiency of Farmers)**

10. Which of the following crops did you cultivate in 2020?

| **Crop** | **(1)Yes (0) No** |
|---|---|
| Maize | |
| Rice | |
| Soybean | |

11. Which of these is your major crop? (1) Maize (2) Rice (3) Soybean (4) Others

12. Aside your major crop, how many other crops did you cultivate in 2020? ………..

13. What is the total cultivated area for these other crops/ ………………..acres

14. Please provide the following information on your 2020 farm

| | Maize | Rice | Soybean |
|---|---|---|---|
| Farm size (acres) | | | |

| | | | |
|---|---|---|---|
| Did you cultivate this farmland in 2019? (1) Yes (0) No | | | |
| Source of land (1) Own (2) Family (3) Communal (4) rent | | | |

15. How may acres of land (including the acres cultivated) can you actually have access to for farming? ……………………..acres

16. What quantity of the following inputs did you use on your cultivated crop in 2020?

| Input | | Maize | Rice | Soybean |
|---|---|---|---|---|
| Improved seeds(kg) | | | | |
| Local seeds (kg) | | | | |
| Herbicides (liters) | | | | |
| Inorganic fertiliser | | | | |
| Hired labour | Average number of persons hired for the season | | | |
| | Average number of days a hired labour worked per week | | | |
| | Average number of hours spent on farm each day by hired labourer | | | |
| | Cost per person per day | | | |
| Family labour | Number of family persons who worked on farm for the season | | | |
| | Number of days worked per week | | | |

| | | | | |
|---|---|---|---|---|
| | Number of hours spent on farm each day by each family labourer | | | |
| Personal labour hours | How many days did you spend on the farm in a week? | | | |
| | Averagely, how many hours do you spend on the farm each day? | | | |

17. How much in Ghana cedis did you pay for a unit of the following inputs?

| Input | Unit price |
|---|---|
| Improved seeds (kg) | |
| Local seeds (olonka) | |
| Herbicides (liters) | |
| Ploughing cost (acre) | |

18. Please provide information on how much output you got from 2020 farm and how it was utilized.

| Output/utilization | Maize | Rice | Soybean |
|---|---|---|---|
| How many 50kg bags of output did you get from your 2020 farm? | | | |
| How many 50kg bags of your output did you sell? | | | |
| What is the unit price (50kg bag) at which you sold your produce? | | | |
| Are you satisfied with the unit price of your output? (1) Yes (0) No | | | |
| How many 50kg bags of your output did you consume or reserve for home consumption? | | | |

| | | | |
|---|---|---|---|
| How many 50kg bags of your output did you reserve for planting in 2021? | | | |
| How many 50kg bags of your output can you not account for after harvesting (post-harvest losses)? | | | |

19. Which of the following fertilisers did you use and how much was the unit price

| Fertiliser | Maize | | Rice | | Sorghum | |
|---|---|---|---|---|---|---|
| | Qty (25kg bag) | Unit price (GHS) | Qty (25kg bag) | Unit price (GHS) | Qty (25kg bag) | Unit price (GHS) |
| NPK 15-15-15 | | | | | | |
| NPK 15-20-20 + 0.7Zn | | | | | | |
| NPK 12-30-17+0.4 Zn | | | | | | |
| NPK 17-10-10 | | | | | | |
| NPK 20-10-10 3S+2MgO | | | | | | |
| NPK 25-10-10 | | | | | | |
| NPK 21-10-10 +2S | | | | | | |
| NPK 23-10-5 + 4MgO + 2Zn | | | | | | |
| Urea | | | | | | |
| SoA | | | | | | |

# APPENDIX II

## RESOURCE USE EFFICIENCY CHART