ADOPTION INTENSITY OF SOIL FERTILITY ENHANCEMENT TECHNOLOGIES, AGRICULTURAL EXTENSION METHODS, AND FARMERS' PERCEPTIONS IN THE DRYLANDS OF LOWER EASTERN KENYA

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DECLARATION

This thesis is my original work and has not been presented elsewhere for a degree or any other award.

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DEDICATION

This work is dedicated to my father Mr. Mathews Mbuvi, my mum Zipporah Makumi and my children Alvin Mumo and Doria Ndanu. Your motivation and encouragement were invaluable.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ASALs	Arid and Semi-Arid Lands
BNMSTs	Balance Nutrient Management System Technologies
CSA	Climate Smart Agriculture
DoI	Diffusion of Innovation
FFSs	Farmer Field Schools
FAO	Food and Agriculture Organization
ICT	Information Communication Technology
ITK	Indigenous Technological Knowledge
MEM	Mass Extension Method
RR	Response Ratios
SFET	Soil Fertility Enhancement Technology
SFM	Soil Fertility Management
SSA	Sub-Saharan Africa
SCR	Stock Change Rate
SOC	Soil Organic Carbon
TIMPs	Technologies, Innovations and Management Practices
INM	Integrated Nutrient Management
WMT	Water Management Techniques
SHMP	Soil Health Management Practices
KNBS	Kenya National Bureau of Statistics

DEFINITION OF TERMS

Adoption:	A process where an organization or individual or any entity assimilates a new product, process or a practice, following the five stages of adoption; awareness, interest, evaluation, trial and adoption/confirmation. In the context of this research, adoption refers to the process by which farmers assimilate soil fertility enhancement technologies (SFET).
Effectiveness:	The ability of extension method to successfully facilitate the transfer and adoption of agricultural knowledge, technologies, innovation and practices to farmers.
Adoption intensity:	Proportion of land under SFET in acres or the proportion of resources used in implementing the target SFE technologies and may be measured using any of the following parameter:(I) Proportion of land dedicated to the new technology, (ii) Frequency of use of a target agricultural technique (e.g., how often farmers use improved irrigation methods), (iii) Level of input usage (e.g., how much of a new fertilizer is applied), or (iv) Scale of adoption across various practices (e.g., combining multiple new technologies like seeds, fertilizers, and machinery). For the purpose of this research adoption intensity will be assessed using the first parameter.
Climate change:	Climate change is the cumulative effect of human-caused and naturally occurring changes in the global average, atmospheric circulation and distribution of precipitation over long time periods normally over a period of over 30 years (Anne Vlassopoulos, 2012)
Climate Smart Agriculture:	The term "climate smart agriculture" refers to methods, tools, and techniques used in agriculture that help farmers adapt to changing weather patterns, produce more food while reducing their impact on the environment (FAO, 2015).
Soil fertility enhancement:	The methods and practices used to improve nutrient content, structure and general health of soil in order to promote plant development.

ABSTRACT

The deterioration of soil fertility poses a significant danger to agricultural output, presenting a problem for many resource-limited farmers who rely on farming for their livelihoods, especially in arid regions. Although Soil Fertility Enhancement Technologies (SFET) offer a viable solution, their adoption remains low owing to ineffective agricultural extension strategies in arid regions. This study investigated the adoption intensity of SFET, farmers' perceptions, and the effectiveness of agricultural extension methods in Makueni County, an ASAL region highly vulnerable to climate change. Data were obtained from 414 agricultural families by semi-structured questionnaires and analyzed utilizing descriptive and inferential statistics. Factor analysis was used to characterize soil fertility enhancement technologies applicable in the dry lands' regions. The Heckman two-stage selection model analyzed the impact of socio-economic variables on the intensity of SFET adoption. The multivariate probit and tobit were used to assess the efficacy of extension strategies on the adoption and intensity of adoption of SFET. Heckman two stage selection model was used to assess farmers' knowledge, attitudes, and perceptions regarding SFET. The findings revealed that 90.6% of respondents had adopted at least one SFET. Factor

analysis identified composting, crop rotation, cover cropping, mulching, drip irrigation, crop residue retention, zai pits, and manure application as the most commonly employed technologies. Among both adopters and non-adopters, 50.7% and 41.0% respectively were men. Factors such as off-farm income, participation in SFET-promoting programs, informal agricultural training, education level, reasons for engaging in off-farm income activities, farm size, land use, and limited access to agricultural information significantly influenced adoption of SFET. Additionally, farm size, land use, off-farm income, and livestock holdings significantly affected adoption intensity. The findings indicated that several agricultural extension strategies, including demonstration plots, farmers' field schools, and farm visits, substantially affected the probability of adopting diverse SFET. Farmer field school (FFS), farm visits, and radio programs was significant in influencing adoption intensity of SFET. The perception of labor needs, desire to provide resources, understanding of SFET advantages, and attitude towards access to extension services were identified as factors influencing the adoption of the technology. Perceived advantages, perceived cost-efficiency, and accessibility to extension services were identified as factors influencing the intensity of SFET adoption. The study concludes that there is need to promote the adoption and intensify application of soil fertility enhancement technologies (SFET) among farming households through targeted training, informal agricultural education, and strengthening of extension methods such as farm visits, field schools, and digital platforms. Efforts must concentrate on mitigating limitations associated with farm size, land use, and access to agricultural information. Promoting the use of these technologies and ensuring farmers comprehend their advantages will sustainably enhance agricultural output and soil health in the arid regions of Makueni County and beyond.

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Soil fertility decline is among the biggest obstacles limiting agricultural potential in most developing countries (Mahmud et al., 2021; Spurk et al., 2025). Sub-Saharan Africa (SSA) experience unending prevalence of food insecurity, with rain-fed subsistence agriculture serving as the primary livelihood option for the majority of individuals living in arid regions (Ntuli, 2023). The diminished levels of both micro- and macro-nutrients and degradation of soils are primary factors contributing to the decline in agricultural output across vast landscapes in SSA, thus leading to adverse social externality (Bakri et al., 2024). Soil degradation can be attributed to persistent application of rudimentary practices in crop production which ultimately lower agricultural productivity, leading to poverty, poor diets, and ultimately, higher mortality rates. Adequate and effective up-scaling and adoption of existing and emerging innovations that could promote food supply in response to the fast-expanding population is of paramount importance (Ferreira et al., 2022; Kipkogei et al., 2025).

Prior research has shown that achieving food security and sustainable agriculture in Sub-Saharan Africa necessitates the implementation of diverse agricultural technologies, innovations, and management practices (TIMPs), particularly those that improve soil fertility (Nakashima et al., 2022; Pandeya et al., 2025). Utilizing efficient agricultural extension techniques facilitates the awareness, introduction, and uptake of these technologies among target farmers (Hameed et al., 2023). The efficacy of extension approaches in SSA is, however, hindered by several challenges, including insufficient funding, poor communication, cultural beliefs, inadequate community engagement and ownership, as well as gender and socioeconomic variables. The problem is exacerbated by elevated transit costs, limited access to mainstream media, and increased rates of illiteracy (Witinok-Huber et al., 2023).

The number of individuals living in severe poverty in Sub-Saharan Africa rose by 100 million, while agricultural output decreased from 57% in 1990 to 43% in 2021 (Wudil et al., 2022). Rezaei (2023) noted that, within the framework of climate change and inadequate soil fertility technologies, anticipated crop yield losses may vary from 7% to 23%. Efforts to tackle the issues of low crop production, particularly in Sub-

Saharan Africa, face challenges stemming from the insufficient utilization and adoption of existing soil fertility enhancement technologies by small-scale farmers (Ndegwa et al., 2023).

Food sufficiency and security in Kenya is a persistent goal that has yet to be realized. Food security is attained when all individuals have physical, social, and economic access to safe and nutritious staple foods that meet dietary needs for an active and healthy life (WHO, 2019). KNBS (2019) reports that approximately 70% of the population lives in rural areas, with 29.2% of urban residents living in poverty. Poverty levels in arid and sparsely populated areas such as North-Eastern Kenya are projected to surpass 70% (UNDP, 2011). The analysis indicates that escalating costs of food and non-food items, livestock health issues, conflicts, and crop failures have led to heightened food insecurity in Kenya's ASALs (Karume et al., 2024). This indicates that a considerable number of small-scale farmers in Kenyan arid regions may face food insecurity and are vulnerable to shortages (Ingutia & Sumelius, 2022).

The dry and semi-arid regions of Kenya comprise about 80% of the country's total area and experience below-average rainfall, insufficient for agricultural sustainability. The situation is exacerbated by climatic unpredictability (Mganga, 2022). The nation's farmers experience fluctuating risks of total crop failure and significant harvests annually, exacerbating food insecurity, especially in rural areas. Food insecurity represents a critical challenge in Kenya, impacting 36.5% of the population nationally (FAO, 2018), with 68% facing varying degrees of insecurity.

The primary sector of the Kenyan economy is agriculture, which is responsible for the creation of employment of more than 60%, production of food, and the most significant source of the nation’s exports (Rafael, 2023). Various technologies aimed at improving soil fertility have been promoted in numerous areas of SSA. The practices encompass the integration of organic and mineral fertilizers, alongside crop rotation, manure application, terracing, and composting (Tindwa et al., 2024). Poor uptake of agricultural innovations that result in soil amendment and improvement raises concerns for agricultural extension service providers, who are in charge of providing farmers with information (Kiprotich et al., 2024).

The swift deterioration of soil fertility in the arid regions of lower Eastern Kenya has intensified the ongoing reduction in agricultural productivity. The observed decrease is directly linked to significant nutrient depletion that has taken place without sufficient replenishment from high-quality external sources (Souri et al., 2021). Heavy reliance on inorganic fertilizers adversely affects soil health, thereby diminishing the land's full potential for smallholder farmers (Dimkpa et al., 2023).

Farmer's attitude, perception, and knowledge about soil fertility are recognized as critical factors that influence decision-making processes for adopting SFET in developing nations (Gemtou et al., 2024). Knowledge in relation to SFET is the understanding of soil fertility enhancement technologies held by individuals living in a certain location for a certain duration (Masongo et al., 2022). The dissemination and transmission of these technologies occur within particular social and agroecological contexts, creating a framework for decision-making across diverse social, economic, and environmental activities and livelihoods in agricultural communities (Kamakaula et al., 2024). Farmers' knowledge and perception underline the fact that farmers regularly practice and adopt soil fertility enhancement technologies according to specific patterns of their own cultural, agro ecological, and socio-economic contexts as an adaptation mechanism (Khader, 2024)

Multiple studies in Kenya have identified socio-economic factors influencing the adoption of soil fertility enhancement technology (SFET) among farmers (Javed et al., 2022; Mwaura et al., 2021). The adoption and utilization of SFET by smallholder farmers in Central Kenya are influenced by factors such as occupation, farming experience, perception of soil degradation, external assistance, and household size (Mairura et al., 2022; Musafiri et al., 2022). Factors including gender, farm size, access to extension services, and understanding of soil fertility management affect both the decision to adopt and the degree of adoption of the technology (Martey & Kuwornu, 2021; Mashi et al., 2022). Previous research has examined general soil fertility management patterns; however, there exists a significant gap in studies focused on SFET and the factors influencing the intensity of SFET adoption among farming households in the drylands of lower Eastern Kenya. The limited adoption of agricultural technologies by farmers is attributed to a knowledge gap between them and agricultural extension providers (Antwi-Agyei et al., 2021).

According to Dominguez (2023), the current agricultural extension methods employed in lower Eastern Kenya include Village Based Advisory (VBA), Mass Extension Method (MEM), field days, farmer-to-farmer exchange visits, Farmer Field Schools (FFSs), and a community-based public-private extension system. Inadequate extension staff to keep up with the growing number of farming families poses a significant barrier to their access to knowledge through interpersonal contact (Antwi-Agyei et al., 2021). Further, socio-economic factors would affect the decision to adopt soil fertility enhancement technologies (SFET) in significant ways, that are not well understood in the study area. This study therefore provided the missing information, necessary for policy makers and other relevant stakeholders in the agricultural sector in coming up with strategic interventions to fill the gap.

1.2 Statement of the Problem

Land degradation resulting from soil erosion, nutrient leaching, and organic matter depletion adversely impacts soil fertility. Additionally, continuous cropping and inadequate use of soil amendment technologies, such as biochar, worsen further the condition of soils. This leads to a decrease in agricultural output which impacts food security, causing poor nutrition and hunger. The application of climate-smart technology to improve soil fertility and mitigate the impacts of climatic variability remains constrained. A dearth of knowledge and poor awareness of modern technologies such as SFET among farmers have significantly impeded its implementation. Similarly, inefficient agricultural extension methods hinder the adoption of soil fertility enhancement technology, leading farmers to resort to conventional nutrient-depleting practices such as mono-cropping and continuous cropping. Notwithstanding the promotion of contemporary agricultural technologies like SFET by governmental and private entities, there is less knowledge about its adoption intensity, particularly in Eastern Kenya. This study therefore, sought to determine adoption intensity of soil fertility enhancement technologies, agricultural extension methods, and farmers' perceptions in the dry lands of lower Eastern Kenya

1.3 Research Objectives

1.3.1 General Objective

The main objective of this study is to analyze adoption intensity of soil fertility enhancement technologies, agricultural extension methods, and farmers' perceptions in the dry lands of lower Eastern Kenya

1.3.2 Specific Objectives

1. To characterize soil fertility enhancement technologies applicable in dry lands regions
2. To analyze selected socio-economic factors influencing adoption intensity of soil fertility enhancement technologies among farmers in the dry lands of lower Eastern Kenya.
3. To assess the effectiveness of agricultural extension methods in promoting adoption intensity of soil fertility enhancement technologies among farmers in the dry lands of lower Eastern Kenya.
4. To evaluate farmers' knowledge, attitude and perceptions on the adoption intensity of soil fertility enhancement technologies in the dry lands of lower Eastern Kenya

1.4 Research Questions

1. What are the key soil fertility enhancement technologies catalogs in the dry lands and their specific characteristics?
2. In what ways do socio-economic factors influence adoption intensity of soil fertility enhancement technologies among farmers in the dry lands of Lower Eastern Kenya**?**
3. How are the extension methods effective in promoting adoption intensity of soil fertility enhancement technologies among farmers in dry lands of Lower Eastern Kenya?
4. To what extent does farmer's knowledge, attitude and perceptions affect adoption intensity of soil fertility enhancement technologies in the dry lands of Lower Eastern Kenya?

1.5 Justification of the Study

Arid and semi-arid areas of Makueni County, and more generally, lower Eastern Kenya, are profoundly affected by climate-related hazards, threatening the existence and nourishment of four million households. Moreover, ASALs have considerable rainfall variability, sometimes culminating in severe and sudden precipitation that causes floods, therefore harming agricultural land and property. Projected increases in variability are expected to worsen the situation, highlighting the need for the distribution of location-specific, timely information to enhance soil fertility (Kenya

V.B.O. 2024). This study provides insights into enhancing soil fertility to assist farmers in boosting crop yields through sustainable and resilient agricultural practices.

The study findings aim to improve knowledge and comprehension of SFET among farmers and other stakeholders, including the Ministry of Agriculture and county administration. The study findings delineate the impact of SFET on productivity and food security. The information aids farmers in understanding the impact of implementing SFET on production, allowing them to make informed decisions about appropriate agricultural inputs and prioritize technology. This study further enhances the existing literature on SFET. The initiative aims to enable stakeholders and policymakers to establish a more conducive environment for the adoption of soil fertility enhancement technologies by farming families, thereby enhancing their adaptation and resilience to climate change and variability.

1.6 Scope of the Study

The research was conducted in the arid regions of lower Eastern Kenya, specifically in Makueni County, with an emphasis on agricultural households. The County is classified as an ASAL region and is significantly impacted by the adverse effects of climate change and variability. Nevertheless, the community relies on conventional agriculture as its sole source of income and food. This study focused on assessing farmers' knowledge, attitudes, perceptions, socio-economic factors, and the effectiveness of agricultural extension methods that influence the adoption intensity of soil fertility enhancement technology.

1.7 Limitations of the Study

The scope was limited to participants from Makueni County, which may not accurately represent all farmers in lower Eastern Kenya. The terrain in Makueni County presented challenges to researchers due to the inadequate road network. The results are limited to the surveyed sub-counties due to funding limitations. The results may differ in geographical areas outside of lower Eastern Kenya.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview

This chapter analyzed pertinent research regarding the factors affecting the intensity of adoption of soil fertility enhancement technology. The study evaluated the effectiveness of various agricultural extension methods in increasing the adoption intensity of SFET. The reviews identified deficiencies in the existing literature that this research sought to rectify.

2.2 Empirical Review

2.2.1 Soil Fertility Enhancement Technologies for the Dry lands

Soil fertility enhancement technologies include composting, manure application, Biochar, synthetic fertilizer, micro-nutrient supplements, mycorrhiza fungi, crop rotation, cover cropping, mulching, drip irrigation with fertilization, agroforestry, minimum tillage, no till farming, soil testing and mapping, variable rate technology, remote sensing and drones, legume integration in crop system, crop residue incorporation, Zai pit, terracing and contour farming among others. The effectiveness of various soil fertility enhancement technologies varies by location, and farmers' access to suitable inputs (seeds and fertilizer), suitable information, and a favorable output market all playing a role in the substantial and long-term adoption of suitable technologies (Lampach et al., 2021).

2.2.2 Adoption Intensity of Soil Fertility Enhancement Technologies

The world's arable land and the resources it supports are under threat due to degradation and desertification. Worldwide, degraded land accounts for about 10–20% of dry lands and 24–25% of arable land (AbdelRahman, 2023). There is currently insufficient funding to address land degradation, costing around $490 billion annually (Akca et al., 2022). Land degradation is most severe in the world's poorest regions, which encompass over 40% of the Earth's surface. The health and livelihoods of about 1.5 billion people are endangered due to land degradation. Food security for Africa's growing population has been improved by agricultural growth, even if the continent's arable land has not been substantially enhanced (Weeraratna et al., 2022).

In Zambia 1.78 % of farmers applied improved or natural fallow, 3.87 % use nitrogen-fixing legumes in their crop rotation, 4.76 % apply manure, 0.14% use lime, 33.91% mulch their crop residues, 2.08% use ripping techniques, and 1.32% use basins for minimum tillage. According to (Hamazakaza et al., 2022), large-scale implementation of SFET principles is quite difficult in Zambia and other comparable regions across SSA. There is a significant necessity for further investigation into the obstacles to adoption and possible remedies. Adoption decision of mineral fertilizer by women rice producers in Ghana is positively and significantly impacted by the interaction between gender and land ownership (Addison et al., 2023). Females are 11.32% less likely to use improved cultivars of rice and 15.63% less likely to use mineral fertilizer, according to the statistics. Ownership of land by women is associated with an increase of 11.46% in the adoption of inorganic fertilizer among women.

Study findings using Cragg's double-hurdle model (Kebenei et al., 2023) indicate that various sets of factors influence the probability and severity of Zai technology uptake in SSA. Approximately 45% of the population made use of Zai technology, whereas 55% did not. The research indicates that a farm size of 1.68 acres is ideal for using Zai technology. According to the statistics, married people had an adoption rate of 84%, with men making up the majority at 67%. Maina, (2020) also conducted a study in Ethiopia which showed that, there was a 99% adoption rate for fertilizer use in Ethiopia. The subsequent technologies with notable adoption rates include inter-cropping (80%), manure (50%), crop residues (50%), crop rotation (40%), and grass strips (30%). Informational and financial barriers, individual and family traits, and biophysical factors including precipitation, plot erosion, and slope were all named as factors limiting adoption.

Mwaura et al. (2021) report that 81.3% of households utilized a combination of manure and fertilizer, 96.7% engaged in agroforestry, 14.7% employed compost, 38.7% implemented cover crops, 42.7% practiced crop rotation, 60.7% applied mulch, 72% adopted inter-cropping, and 8.7% used compost alongside manure. In Tharaka-Nithi, the agricultural practices employed include agroforestry techniques by 26.7%, compost by 11.3%, residue incorporation by 11.3%, cover crops by 86.7%, crop rotation by 68%, mulch by 92.7%, inter-cropping by 48.2%, manure by 90%, and a combination of manure and fertilizer by 92%. Many smallholder farmers continue to employ conventional farming practices that deplete soil nutrients and emit significant

greenhouse gases, thereby exacerbating climate change (Ajwera et al., 2024b). This is due to a deficiency in knowledge regarding sustainable soil fertility enhancement technologies.

2.2.3 Farmers' Knowledge, Attitudes, and Perceptions on Adoption Intensity of Soil Fertility Enhancement Technologies.

The selection of appropriate produce and the reduction of profit disparities are significantly hindered in various global regions due to insufficient soil-specific knowledge. It is crucial to have accurate data on soil properties in order to identify soil restrictions and the management approaches needed to boost crop productivity. Local farmers have a wealth of information on soil types and how to classify them, which may be used to enhance soil-specific technologies on a worldwide scale (Shaheb et al., 2022). Classification involves cognitive soil knowledge and soil-related actions, such as land usage, crop appropriateness, and soil fertility management; farmers' reasoning is included in the process (Maynard et al., 2023). Effective soil management strategies must consider the soil expertise of farmers (Albaladejo et al., 2021). Khatri et al. (2021) reported that 64.89% of surveyed Nepalese farmers possessed a medium level of understanding of Indigenous technological knowledge (ITK), whereas slightly over 9% exhibited a low level of understanding. The study indicated that 25.84% of farmers possess an enhanced understanding of Indigenous Technical Knowledge (ITK).

A study conducted in the semi-arid region of Rwanda (Cyamwesh et al., 2023) indicated that education positively influenced farmers' attitudes toward the impact of trees on soil fertility ($P < 0.05$), whereas farm size exhibited a negative effect ($P < 0.1$). In the humid region, family size exhibited a positive effect ($P < 0.1$). Gender ($P < 0.05$) in the humid zone and farmers' expertise ($P < 0.1$) in the semi-arid region influenced farmers' perceptions of the effects of agroforestry on soil moisture. Farmers in semi-arid and humid regions who planted trees experienced enhanced yields of beans, maize, and potatoes. This study employed an ordered logistic regression model to identify the factors that influence farmers' perceptions of soil fertility in tree-lined farms. The soils of high fertility plots were dark-colored (94%), according to a survey in Upper Eastern Kenya conducted by (Wawireet et al., 2021), whereas the soils of low fertility plots were light-colored. Additionally, the majority of farmers (86%) saw earthworms as a sign of healthy soil. Whether the soil was

fruitful (91%) or barren (74%), farmers admitted that certain weed species were present in the field. With the exception of soil workability, all of the descriptive indicators performed considerably better in productive locations than infertile ones.

The level of effort put into addressing soil fertility concerns can have resulted to farmers' acceptance and the degree of technological acceptance. (Fadeyi et al., 2022) found that farmers' responses about knowledge, attitude, and perception offer useful insights for technology development and improvement. Our work highlights the importance of enhancing farmers' understanding of soil fertility, which has policy implications. Because accurate information encourages adoption, this will also help farmers better withstand misleading messaging (Spurk et al., 2025). A study by Muriithi (2021) indicates that most farmers in Kenya's lower Eastern region are aware of climate change and the resources available for disseminating climate information. Conversely, early rainfall and recurrent droughts adversely affect household food security. Various communication channels, such as television, extension agents, and local administrations, facilitated the increased adoption of conservation agriculture, agroforestry, and intercropping practices. The adoption of agroforestry and agricultural diversification was diminished by the influence of radio, mobile phones, and social networks.

2.2.4 Socio-economic Factors Influencing Adoption Intensity of Soil Fertility Enhancement Technologies

The agricultural sector is particularly vulnerable to the effects of climate variability, which are already evident in various forms (Al-Tawaha et al., 2021). These factors encompass alterations in water availability and quality, increased soil erosion, and diminished crop yields. A systematic assessment of soil skill acceptance forms globally, including the SSA region, identified educational qualifications, farm size, farmer age, and access to agricultural information as significant predictors in 51-64% of the studies (Jones-Garcia and Krishna, 2021).

The adoption rates of various agricultural technologies and developments in Kenya are affected by multiple socio-economic factors (Ngaiwi, et al., 2023). Gender influences the degree of adoption of sustainable farming and ecological techniques (SFET) and the achievement of sustainable food security at the household level (Jabbar et al., 2022). The relationship between gender and soil fertility enhancement

technologies affects the adoption roles of male and female-headed households (Sujakhu et al., 2023). Decision-making is influenced by the stronger control that males have over essential production resources compared to females, a disparity rooted in socio-cultural values and norms (Mwinuka et al., 2022). Tufa et al. (2022) observed higher adoption rates of SFET among male farmers compared to female farmers. In certain instances, women may not directly make decisions but instead exert influence over them. This research conducted in Cameroon and Mali indicates that in several instances of increased agricultural technology adoption, males required the involvement of women to enhance labor supply (Lesthaeghe et al., 2023). The predominant contribution of women to household work is essential in subsistence farming in Africa.

According to a survey conducted in Nigeria (Haruna et al., 2023), five of the twelve explanatory variables significantly influence the decision to adopt enhanced technology for rice production. The number of oxen owned by the household, mobile phone ownership, livestock count, the educational level of the family head, and the number of extensions contacted were the primary factors influencing the first hurdle of the Probit Model. In the surveyed population of rice farmers, 81.8% identified as male and 77.3% were reported as married, based on demographic data. This indicates that a larger proportion of participants remains in the productive active age and is likely capable of participating in farming activities, as the average household size of respondents was 7.41 and the average age was 43.81 years (Haruna et al., 2023).

Older farmers are considered to have greater knowledge and experience, which may enable them to evaluate new technologies more effectively than younger farmers (Masere & Worth, 2022). Conversely, Spurk et al. (2025) found that older farmers exhibited a restricted time horizon in their decision-making and the adoption of soil fertility enhancement technologies, whereas younger farmers possessed a broader time horizon that enabled quicker decision-making and the implementation of recommended technologies. The varied effects of age may stem from the particular technology employed. The integration of ICT into various sectors necessitates an examination of the impact of age on the intensity of SFET adoption (Jabbar et al., 2022).

Additionally, farm size affects adoption, as larger farmers tend to be less risk-averse and are more inclined to dedicate part of their land to experimenting with new technologies (Hu et al., 2022). Sargani et al. (2023) found that small-scale farmers utilizing SFET and relying on family labor experience a low opportunity cost. Research by Kom et al. (2022) presents a differing viewpoint, suggesting that large-scale farmers are more inclined to adopt SFET due to their financial resources and assets, which enable them to invest in solutions with significant costs. Farmers with stable land titles or dependable asset tenure systems typically invest in long-term SFET at the farm level.

Research by Mogaka et al. (2021) on the socio-economic determinants influencing farmers' decisions to adopt climate-smart soil practices in Western Kenya indicates that 20% of farmers had an elementary education, 48% had secondary education, and 32% had higher education. Society has not adequately acknowledged the significance of women's education, which may account for the disparity in post-secondary completion rates, with 38% of males and 10% of females achieving this level of education. Women exhibited a deficiency in knowledge regarding climate change and appropriate responses, attributable to their comparatively lower educational attainment.

Land ownership affects the execution of land management practices. The influence of property rights and long-term investments in SFET adaptation measures substantially impacts smallholders' ability to adopt new agricultural practices (Tessema, 2024). The adoption of certain technologies, including soil conservation measures and irrigation equipment, is notably influenced by tenure security (Chavula et al., 2022). In large-scale agriculture, the cost-effectiveness of conservation measures increases compared to small-scale farmers due to economies of scale, highlighting the necessity of advocating for significant land management investments (Yu et al., 2022). The inability of farmers to manage economic incentives and allocate their time or capital substantially affects overall agricultural output (Teye et al., 2022). This study aimed to evaluate the influence of specific socio-economic factors on the adoption intensity of soil fertility enhancement technologies in Lower Eastern Kenya, with the goal of improving food security for rural households and beyond.

2.2.5 Effectiveness of Agricultural Extension Methods on Adoption Intensity of Agricultural Technologies

Agricultural extension methods link farmers with various economic stakeholders, promoting the exchange of information, technology, and expertise within the agricultural sector (Gebremariam et al., 2021). Agricultural extension disseminates information derived from both local and global research, enhancing knowledge transfer and refining management skills among farmers. It enhances decision-making among farmers and boosts productivity, which may foster agricultural innovation and elevate profits. Agricultural extension services are globally prevalent, with over 90% of public extension agents employed in low-income countries (Nettle et al., 2022).

Public resources for extension services are limited, and the adoption of advanced, knowledge-intensive technology is restricted in many countries; however, the spread of agricultural innovations and the growth in agricultural production continue in numerous nations. Total agricultural production globally rises by approximately 2.5% annually, with total factor productivity (TFP) growth accounting for nearly 75% of this increase. Productivity growth has unfortunately contributed less to agricultural advancement in Sub-Saharan Africa, where both public and private extension services are notably lacking. Total Factor Productivity (TFP) growth has averaged approximately 1% in recent years; however, it appears to be rising in numerous countries over the past decade (Varshney et al., 2022). The economic rates of return for agricultural extension in Sub-Saharan Africa are reported to range from 30% to 100%. However, methodological concerns have been raised regarding the reliability of these figures in certain studies (Ebhuoma et al., 2022). A meta-analysis of the economic rates of return on agricultural research and extension indicated an average return rate of 58% for extension, based on 289 studies (Girma et al., 2022). The extension service serves as a crucial agent of change required to advance subsistence farming to contemporary commercial agriculture. Addressing poverty, enhancing household incomes, and promoting food security are critically important (Ozkan et al., 2022).

Audiovisuals, traditional media, practical, hands-on, learning by experimentation, training, field schools for farmers, demonstration plots, participatory approaches, and farm-to-home visits are just a few of the many extension approaches used globally (Maulu et al., 2021). A countrywide assessment by (Molina -Maturano et al., 2021)

found that ,33% of production units utilize ICT for agricultural purposes. In addition, a Nigerian study found that 76% of users accessed extension services through WhatsApp, while 53% utilized Facebook. These apps increased vegetable output by 58%, upland rice production by 47%, and lowland rice production by 65% (Eze et al., 2021). Evaluating the applicability of this concept with small holder farmers across diverse beliefs in both industrialized and emergent countries would be supposedly and almost valuable, as the use of mobile apps in knowledge acceptance can change from one place to another. In addition to the software itself, fundamental requirements and enabling factors like a smartphone and stable Internet connection are required (Ruzzante et al., 2021).

Furthermore, (Yekinni and Afolabi, 2019) found that among the extension communication strategies utilized by Nigerian farmers, the most common ones were home visits (89.2%), home visits (78.5%), contact farmers (73.3%), and method demonstration (51.7%). The most common forms of extension communication that agencies use are home visits, farm visits, and contact farmers. Among these methods, farm visits are the most preferred for receiving information and technologies. Respondents rated the effectiveness of these methods as moderate. According to the research, extension agents should think about how farmers would like to receive information and use that to their advantage.

(Sseguya et al., 2021) opined that a 13%-17% increase in the likelihood of purchasing enhanced inputs was associated with access to demonstration plots with small packs in a Tanzanian survey. According to this research, demonstration plots with tiny packs are a great way to boost technology adoption, and the effectiveness of these models is much more amplified when the necessary inputs are located within a 5-kilometer radius. Research conducted by Gebrehiwot (2023) aimed to evaluate the effect of a novel participatory extension service on farmers' production in a semi-arid region of Ethiopia, in comparison to the traditional extension service, and identified literature pertaining to places with comparatively favorable climatic circumstances. Therefore, if extension administrators endeavor to elevate the performance of average and below-average farmers to higher productivity levels, total agricultural output and living conditions might significantly be enhanced in the study area and even replication in parts of the country.

According to Das (2022), 41% of farmers believe that technology dissemination programs on radio and television are beneficial, 74.36% obtain their news from these media, and approximately 17% of farmers listen to agricultural shows. Extension methods in Kenya encounter several challenges, including insufficient private sector engagement, reduced public sector funding, inadequate coordination in the provision of pluralistic extension services, and weak linkages to supportive factors (Mapiye et al., 2021). Effective in-service training is crucial for any extension service, particularly given the rapid evolution of ICT technologies alongside agricultural advancements. Historically, robust extension systems, exemplified by the National Federation of Coffee Growers in Colombia, conduct regular in-service training while maintaining a demand-driven approach to the overall system. Successful extension relies on sustaining robust connections to the most recent innovations emerging from both public and private research sectors. (Irmak et al., 2023).

2.3 Research Gaps

Water shortages, poor agricultural management, and diminished soil fertility have significantly impacted food security in recent decades (Kogo et al., 2021). Despite the availability of various soil fertility enhancement technologies, farmers in lower Eastern Kenya and other regions have not fully utilized them due to insufficient knowledge regarding their benefits. The majority of farmers do not fully implement soil fertility enhancement technologies (SFET) due to a lack of understanding of the interdependent benefits of these methods. While efforts have been made to evaluate the impact of agricultural extension methods on the adoption of improved farming practices and technologies aimed at increasing agricultural productivity, less attention has been given to assessing the effectiveness of these methods in promoting the adoption of technologies that improve soil fertility (Wordofa et al., 2021). Therefore, in the arid regions of lower Eastern Kenya, it is essential to examine the influence of farmers' perspectives, socio-economic factors, and extension methods on the intensity of adoption of soil fertility enhancement technologies.

2.4 Theoretical Framework

2.4.1 Diffusion of Innovation Theory

According to (Rogers et al., 2008), the theory of Diffusion of Innovation (DoI) describes how ideas traverse across a society. Using this theory, we can trace the five steps—awareness, interest, trial, evaluation, and adoption, farmers in the lower

Eastern region took to learn about soil fertility enhancement technologies. This theory was useful in determining which socio-economic factors influence the uptake of SFET. Based on its relative benefits, complexity, and compatibility, an innovation can be either adopted or rejected according to DOI. (Akouwerabou et al., 2022) utilized DOI in Burkina Faso to elucidate how small holder farmers embraced climate-smart agricultural practices.

2.4.2 Adoption Theory

Adoption theory is a framework within information systems that seeks to explain user acceptance and utilization of new technology. This hypothesis posits that numerous variables influence individuals' decisions regarding the timing and manner of adopting new technology in 1993 (Davis, 2022). The openness of farmers to new technologies is influenced by three factors: the relative benefits of the approach, the visibility of its effectiveness prior to adoption, and the compatibility of the method with existing farming operations (Nguyen et al., 2024). This study utilized adoption theory to analyze the factors influencing farmers in lower Eastern Kenya to adopt soil fertility enhancement technologies, focusing on their knowledge, attitudes, and perceptions. To evaluate the dissemination of agricultural technology in underdeveloped countries, Ruzzante (2021) utilized adoption theory.

2.4.3 Media Richness Theory

(Suh,1999) argues that media richness is best understood as the capacity of information to alter comprehension across time. The information richness processed by various communication media varies. The capacity for feedback, the routes of communication, the range of languages used, and the individual's focus all play a role in this. This theory, was used to better understand how agricultural extension methods facilitates knowledge transfer from research institution to the farmers. This domain facilitates the advancement, dissemination, and application of new information and expertise (Shams et al., 2022).

2.5 Conceptual Framework

The study identified several factors influencing the intensity of adoption of soil fertility enhancement technologies. Figure 2.1 illustrates the relationship among farmers' knowledge, attitudes, perceptions, socio-economic factors, and extension methods that affect the intensity of adoption of soil fertility enhancement

technologies. Decrease in crop yield is credited to low implementation of SFET. Adoption intensity of particular SFET was used as dependent variable while socio - economic, farmer's altitude, knowledge and perception and extension methods formed the independent variables and increased household income, improved household food security and Improved ecosystem resilience was the expected outcome.

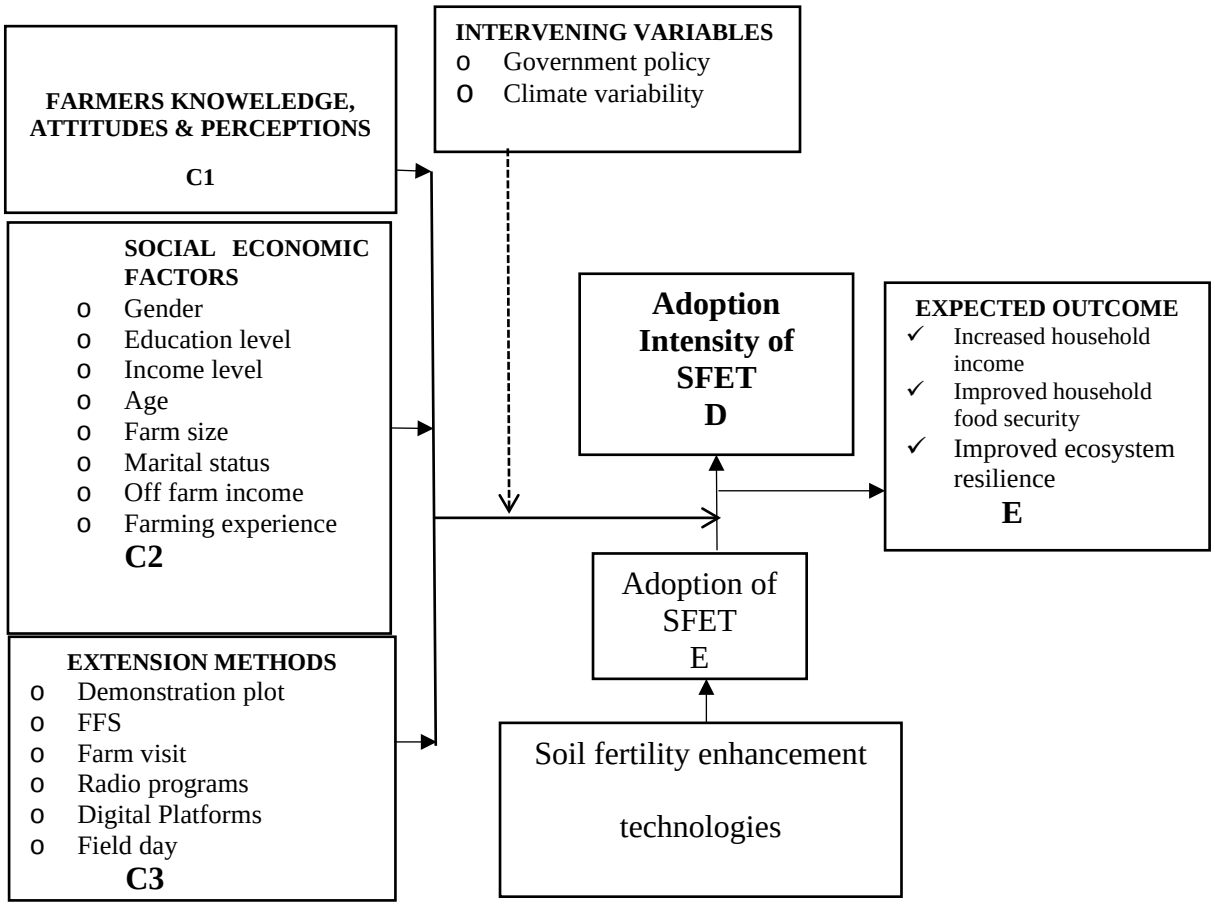

Figure 1: Conceptual Framework C1, C2, C3 = Independent variables; D = Dependent variable; E= Expected outcome

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Description of the Study Site

This research was carried out in lower Eastern Kenya, specifically in Makueni County. As an ASAL, the County experience severe climatic change and variability, leading to frequent droughts. The County comprises the Sub Counties of Makueni, Mbooni, Kibwezi East, Kibwezi West, Kaiti, and Kilome. The County extends to an area of 8,176.7 km², and it is located between 1º 35' and 3º 00' South latitude and 37º 10' and 38º 30' East longitude, as reported by (KNBS ,2019). Rainfall ranging from 300 mm to 400 mm on the lower slopes makes agriculture, the County's primary economic sector very difficult to rely on sustainably. The study focused on agro-ecological zones of LM 5 and LM 6 where common crops grown are beans, maize, green grams, cowpeas, mangoes, and vegetables (RoK, 2017). The County was selected because most SFET have been promoted in the region yet adoption intensity of such strategies is still low and much about it has not been documented (Mwaura et al., 2021).

3.2 Research Design

A cross-sectional survey method was employed to collect data from farming households in the arid regions of Makueni County, specifically in Lower Midland 5 and 6. This method was preferred because it was cost-effective and accommodates collection of both qualitative and quantitative data (Kothari, 2004). It also allowed researcher to describe, analyze and interpret variables under investigation more effectively (Mertler et al. ,2021)

3.3 Target Population and Sample Size

The research focused on agricultural households in the dry land region of Makueni County, specifically within lower midland zones 5 and 6. A sample size of 384 was randomly selected using the Cochran formula outlined below, derived from a sample frame to be established with the aid of the sub-county agricultural officer.

$$N = \frac{Z^2 PQ}{e^2} \quad \text{.....1}$$

Therefore, the sample size was calculated as follows:

$$N = \frac{1.96^2\, x(0.5)x\,(1-0.5)}{0.05^2} = 384$$

Where N is the desired sample size, Z= (1.96) represents the standard normal at deviate 95% confidence level, P= (0.5) represents the estimated proportion of the target population having characteristics under observation, q = 1 − p = 0.5 = the proportion of the population without the characteristics being measured and e = 0.05 = the level of statistical significance. However, since 384 is the minimum representative sample, the study used a sample size of 414 farming households to answer the research questions.

3.4 Sampling Procedure

The research employed a multistage stratified sampling method. Makueni County was selected in the initial stage due to its classification as an ASAL area significantly impacted by climate change and variability, while the community relies on conventional agriculture as its sole source of income and food. In the second stage, two sub-counties were randomly selected from the three located in the dry land region: Kibwezi West and Makueni sub-counties. Furthermore, two wards were randomly chosen from each of the two selected sub-counties, resulting in a total of four wards. Additionally, two locations were randomly chosen from the four wards, resulting in a total of eight locations. Subsequently, one sub-location was randomly selected from each location, yielding a total of eight sub-locations. The proportionate size sampling technique was employed to ascertain the number of farmers sampled in each sub-location. Assistant chiefs and village elders facilitated the determination of household numbers in each sampled sub-location, leading to the preparation of a sampling frame. The study randomly selected specific households from the sampling frame.

Simple random sampling was used to pick farmers for administration of questionnaires.

Table 3. 1: Households Interviewed

Sub-county	Wards	No. of respondent
Makueni	Mbitini Nzaui/Kilili/kalamba	244
Kibwezi west	Nguumo and Makindu	170

3.5 Instruments of Data Collection

Primary data was collected by use of semi-structured questionnaire. The questionnaires were administered by trained research assistants to the farming households. The questionnaire addressed issues of socio-economic factors influencing adoption intensity of SFET. Data on farmers' attitude and perception and effectiveness of extension method was also collected.

3.6 Reliability and Validity of Instruments

A total of 38 questionnaires, gathered before the actual investigation, were evaluated. Selection was based on the rule of pretesting 10% of the total sample using a pilot sample with unknown characteristic (Mugenda, 2023). Split halve reliability test was employed to determine the consistency of research instrument. To compare correlation coefficient between halves of the item Pearson product linear correlation coefficient formula was applied. In this study, content validity was attained through analysis and evaluating the survey instrument by supervisor and colleagues to ensure adequate coverage of questions.

3.7 Data Analysis

The collected data was analyzed using descriptive and inferential statistics, facilitated by STATA software version 15. Descriptive statistics were subsequently presented using frequencies, percentages, tables, and graphs. Empirical models, including Tobit and Heckman, were employed to address the research questions.

3.7.1 Objective 1: Characterization of Soil Fertility Enhancement Technologies Applicable in Drylands Regions

To characterize Soil Fertility Enhancement Technologies (SFET) in the drylands, Factor Analysis was employed. This statistical technique is suitable for identifying latent structures that explain patterns of correlation among observed variables (Shrestha, 2021). It enables the grouping of related SFET based on shared underlying characteristics, providing a clearer understanding of adoption trends among farming households. The Principal Component Factors (PCF) method was employed for factor extraction. This method focuses on extracting factors from shared variance, rather than total variance, thereby improving the accuracy of latent structure identification. The method is appropriate and effective in situations where the goal is to reduce dimensionality and reveal meaningful latent constructs in complex datasets (Alavi et al., 2020). To improve interpretability, varimax rotation was applied. This orthogonal rotation technique maximizes the variance of squared loadings across factors, enhancing the clarity and distinctiveness of each factor. Technologies with strong loadings on the same factor were interpreted as sharing a common underlying attribute or function.

The factor model is expressed as:

$Y_i = \alpha_1 X_1 + \alpha_2 X_2 + \ldots \alpha_n X_n$ ……………………………………………………..2

where Y_i represents the extracted factors, $\alpha_1 \ldots \alpha_n$ are factor loadings indicating the strength of association between each observed SFET and the factor, and $X_1 \ldots X_n$ specific SFET

3.7.2 Objective 2. Analysis of Selected Socio-economic Factors Influencing Intensity of Adoption of Soil Fertility Enhancement Technologies

To determine the influence of socio-economic factors on adoption intensity of SFET Heckman two stage selection model was employed. This model is appropriate because it addresses selection bias, which occurs when not all farmers opt to adopt SFET leading to potential bias in the observed adoption intensity data. In the first stage, an 'adoption equation' is formulated using probit to identify factors influencing the adoption decision of SFET, and to derive Inverse Mill’s Ratio (IMR). In the second

stage, the intensity of adoption is assessed by utilizing the IMR as an explanatory variable to address selection bias.

The specification of the models for the two stages are as follows:

Adoption equation from probit is specified as (Eqn. 4).

$Y_i = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \dots \alpha_n X_n + \varepsilon$ 4

Where Y_i is the latent dependent variable representing the decision to adopt or not to adopt SFET, $X_1, X_2 \dots X_n$ are explanatory variables that effect adoption decision measured on the i^{th} farmers choosing to adopt SFET, $\alpha_1, \alpha_2 .. \alpha_n$.is coefficient of the explanatory variable and ε is the error term assumed to be independent and normally distributed with zero mean and constant variance. Lambda (λi), associated with the conditional probability of an individual household's choice to adopt, is defined by the following formula:

$\lambda_i = \frac{f(x\beta)}{1-F(X\beta)}$.....5

Where λ_i is the IMR, f (x β) denotes the standard normal probability density function, and 1−F (Xβ) indicates the cumulative distribution function for a standard normal random variable. The value of Xi remains unknown; however, the parameters (β) can be estimated using a probit model that is informed by the observed binary outcome (Yi). Subsequently, it will be used in the outcome equation to ensure the model's consistency.

Ordinary Least Squares (OLS) was used to model the outcome equation expressed as in Eqn. 6:

Outcome equation

$Yi=\alpha_0+\alpha_1X_1+\alpha_2X_2+...+\alpha_nX_n+ p\lambda\_i+u_i$.....6

Y_i is land area under SFET, $\alpha_{0\ is}$ intercept term, X_1, X_2,...X_n independent variables, $\alpha_1,\alpha_2...\alpha_n$ are coefficients of independent variable, ρ is coefficient of IMR, λ_i is the IMR and μ_i is error term

3.7.3 Objective 3. Assessment of Effectiveness of Agricultural Extension Methods in Promoting Intensity of Adoption of Soil Fertility Enhancement Technologies

Multivariate probit (MVP) model was used to determine the influence of selected extension methods on farmers' decision to adopt Soil Fertility Enhancement Technologies (SFET). Farmers often adopt multiple technologies simultaneously, meaning their choices are interdependent and correlated. MVP model enables the simultaneous estimation of multiple correlated binary outcome equations using a shared set of predictor variables (Otara, 2023).

$Yi1 = Xij1\ \beta1+\varepsilon i1$; $Yi2 = Xij2\ \beta2+\varepsilon i2$; $Yi3 = Xij3\ \beta3+\varepsilon i3$; $Yi4 = Xij4\ \beta4+\varepsilon i4$;

$Yi5 = Xij5\ \beta5+\varepsilon i5$; $Yi6 = Xij6\ \beta6+\varepsilon i6$; $Yi7 = Xij7\ \beta7+\varepsilon i7$

Where i is the household identification number,Y_{i1} = 1 if the household practices compost manure and 0 if otherwise, Y_{i2}=1 if the household practices Zai pits and 0 if otherwise, Y_{i3}=1 if the household practices micro nutrient supplements and 0 if otherwise, Y_{i4}=1 if the household practices cover cropping and 0 if otherwise, Y_{i5}=1 if the household practices crop rotation and 0 if otherwise,Y_{i6}=1 if the household practices zero tillage and 0 if otherwise,Y_{i7}=1 if the household uses irrigation and 0 if otherwise,X_i is the vector of factors influencing uptake of regenerative agriculture technologies, $\beta_j = \beta_1, \beta_2,\beta_3, \beta_4 , \beta_5, \beta_6,\beta_7$ are the vectors of unknown parameters and $\varepsilon_i$is the disturbance term.

Tobit regression model was specifically used to evaluate how extension methods affect adoption intensity of SFETs**.** The model was favorable due to its advantages over other analytical models, such as logistic or probit regression models, as it provides insights into the probability of adoption intensity of technology use. Model specification is as follows:

$Y_i=\beta_0+\beta_1X_1+\beta_2X_2+...+\beta_nX_n+\varepsilon$……7

(Yi= Yi* if Yi≥ 0, Yi= 0 If Yi*≤ 0)

Where Y_i is adoption intensity,$X_1,X_2\ldots X_n$ are explanatory variables.$\beta_1,\beta_2\ldots\beta_n$ are the regression coefficients of the independent variables and ε is the error term.

3.7.4. Objective 4. Evaluation of Farmers' Knowledge, Attitude and Perceptions on the Adoption Intensity of Soil Fertility Enhancement Technologies

Heckman two-stage selection model was employed to evaluate farmers' knowledge, attitude and perceptions on the adoption intensity of soil fertility enhancement technologies. In the first stage, probit model was run to determine the decision to adopt technologies as expressed in equation 8:

$Y_i = \alpha X_i + \ldots + \alpha X_n + \varepsilon$ ……...8

Where Y_i is decision of a farmer to adopt SFET technologies, X_i is the vector of explanatory variables, α is the vector of the parameter estimates hypothesized to effect chances of i^{th} farmer choosing the technologies and ε is error term. Ordinary Least Squares (OLS) consistently estimated parameters in the second stage by including the Inverse Mills Ratio from the probit model as an additional explanatory variable as expressed below;

$Y_i = \alpha_0 + \alpha_i X_i + \mu_i \lambda_i + \nu_i$ ……..……...……9

Where Y_i is adoption intensity, X_i involves explanatory variables, α_0 is a constant term in the OLS regression model, α_i is parameter to be estimated in second stage, λ_i is the inverse mills ratio, μ_i is correlation of first and second stage error and ν_i is error term in second stage. In Heckman outcome model, the dependent variable was continuous and below is its specification;

$Y_i = \emptyset X_i + \ldots + \emptyset X_n + \mu_i$ ……10

Where Y_I= land area under SFET technologies, $X_i \ldots X_n$ independent variables, ∅ is the vector of parameter estimates of independent variables and μ_i are error terms.

CHAPTER FOUR
RESULTS AND INTERPRETATION

4.1 Overview

This chapter presents a summary of the findings from both descriptive and inferential analyses conducted in the study. This study characterizes soil fertility enhancement technologies suitable for dryland regions, drawing on farmers' experiences and practices. This chapter examines specific socio-economic factors that affect the intensity of adoption of soil fertility enhancement technologies among farmers in the drylands of Lower Eastern Kenya. This study also examines the effectiveness of different agricultural extension methods in enhancing the adoption intensity of these technologies. This chapter assesses farmers' knowledge, attitudes, and perceptions concerning the intensity of adoption of soil fertility enhancement technologies in the drylands of Lower Eastern Kenya.

4.2 Reliability and Validity of the Research Tool

Split half approach was used to test the validity and reliability of the research instrument that was used in obtaining data to achieve the study objective. The findings of the Spearman-Brown coefficient revealed that the two halves had correlation coefficient of 0.684. The equal and unequal lengths of the Spearman-Brown coefficient displayed a strong association of 0.812. Guttmann Split-Half coefficient which showed the internal consistency was 0.795. This affirms that the instrument had high internal consistency of scores and was fit to be applied in conducting this research.

4.3 Descriptive results

4.3.1 Characterization of Soil Fertility Enhancement Technologies Used by Farming Households in the Drylands

Results in Table 4.1 display the factor analysis findings. These results reflect the four factors with Eigenvalues greater than one, being Factor1, Factor2, Factor3, and Factor4. Factor1 had the highest Eigenvalue at 3.611, accounting for a variance of 25.8%. Factor2 had an Eigenvalue of 1.702, representing a variance of 12.2%, Factor3 with an Eigenvalue of 1.289 representing a variance of 9.2%, and Factor4 with an Eigenvalue of 1.181 representing a variance of 8.4%. All these four factors collectively explain more than the halfway mark (55.6%) variance, implying that the factors have a decisive contribution in explaining the underlying structure in the data.

Cumulative Variance was 97.3% at Factor12, which implies that the initial factors captured the bulk of the variance in the data. Cover crops (0.756), composting (0.538), mulching (0.723), zai pit (0.635), crop rotation (0.612), drip irrigation (0.537) and crop residue (0.509) loaded highly on Factor1. These variables are normally aimed at enhancing soil health and fertility while conserving water. The conservation and incorporation of organic matter and nutrients through cover cropping significantly enhances soil fertility, controls erosion, and promotes biodiversity. Mulching is a fundamental technique of soil conservation, as it facilitates water retention, controls erosion, and maintains appropriate soil temperatures, all of which are essential for environmentally responsible crop production. The inclusion of composting activity in this component highlights the critical role of organic matter in supporting microbial activity and maintaining optimal soil structure. One of the critical factors in ensuring optimal water usage in agriculture is irrigation, a moderate-loading variable that indicates the necessity for water-efficient irrigation practices. Zai pit contribute to sustainable farming practices and the advancement of new agricultural technologies. Legume intercropping, represents an important practice that enhances soil nitrogen levels and fertility, while maintaining environmental stability. This component emphasizes the importance of maintaining healthy soil, optimizing water usage, and integrating both organic practices and technological advancements to enhance long-term productivity while reducing adverse environmental effects.

In Factor2, manure application (0.533) and terracing (0.534) loaded highly showing that the component involves organic farming methods and practices set to stabilize soil fertility and prevent erosion. Manure application plays a crucial role in nutrient management and it enhances soil fertility through the restoration of organic matter and the promotion of microbial populations. Terracing not only retains water and protects soil integrity, but it also mitigates land deterioration by minimizing water runoff. This factor is centered to advance organic farming and landscape management techniques that utilize nature-based, low-input strategies to enhance soil fertility. Zero tillage (0.576) loaded highly in Factor 3 and this emphasizes the importance of soil protection and the implementation of low-disturbance farming techniques. The importance of reducing soil disturbance in maintaining soil structure, preventing erosion, and retaining water is possible through zero tillage. Inorganic fertilizer (0.553) was significant element in Factor4. It shows that application of chemical

inputs in conventional farming practices aimed at maximizing yields is closely associated with Factor4. Plants depend on synthetic fertilizers to provide crucial macro nutrients necessary for crop growth, including nitrogen, phosphorus, and potassium.

Table 4. 1: Loadings of four components of SFET Technologies

Variable	Factor1	Factor2	Factor3	Factor4
Composting	0.538	-0.295	-0.143	0.060
Manure application	0.132	0.533	0.344	0.397
Biochar	0.273	-0.465	0.377	-0.181
Synthetic fertilizer	0.246	0.413	0.337	0.553
Micronutrient supplementation	0.401	-0.446	0.462	-0.079
Crop rotation	0.612	-0.058	-0.362	0.157
Cover cropping	0.756	-0.129	-0.227	0.102
Mulching	0.723	-0.000	-0.296	0.155
Drip irrigation	0.537	-0.420	0.105	0.402
Zero tillage	0.320	-0.129	0.576	-0.132
Legume intercropping	0.355	0.364	0.218	-0.452
Crop residue	0.614	0.243	-0.121	-0.426
Zai pit	0.635	0.236	-0.020	-0.203
Terracing	0.493	0.534	0.073	-0.096
Eigenvalues	3.611	1.702	1.289	1.181
Cumulative variance (%)	25.8	38.0	47.1	55.6
Variance explained (%)	25.8	12.2	9.2	8.4

Table 4.2 illustrates the variability in the uptake rates of soil fertility enhancement technologies (SFET) among adopters. Results show that compost manure was implemented by 14% of users, while 86% did not utilize the technique. Conversely, farmyard manure demonstrated the highest adoption rate at 90%, with 10% of adopters failing to implement it. Inorganic fertilizer was utilized by 51% of the respondents, while 49% did not apply it. Approximately 4% of individuals use micronutrient supplements, while 96% did not. Crop rotation was applied by only 37% of individuals, while 63% did not. The majority of adopters (79%) did not plant cover crops, while only 21% did. Approximately 20% of the farms utilized mulch,

while the remaining 80% did not. Only 13% of adopters practiced irrigation, while 87% reported that they do not. The technique of zero tillage was implemented by only 1% of the population, while 99% did not employ the technology. Soil testing and mapping were conducted by only 3% of adopters, while 97% found it to be unhelpful. Only 7% of individuals employed legume intercropping, while 93% did not engage in this practice. Crop residue incorporation and Zai pit technology were implemented by only 6% of adopters, while 94% did not. Terracing was implemented by 31% of the adopters, while 69% did not use this practice. Although being adopters, it is evident that a variety of methods are employed in varying capacities to enhance soil fertility. For example, a substantial number of individuals apply farmyard manure, however, fewer implement practices such as the incorporation of micronutrients and zero tillage.

Table 4. 2: Distribution of soil fertility enhancement technologies (SFET) among adopters (n=375)

Variable	Category	Adopters(n=375) Frequency	Percentage
Compost manure	Yes	54	14
	No	321	86
Farmyard manure	Yes	338	90
	No	37	10
Inorganic fertilizer	Yes	192	51
	No	183	49
Micro-nutrient	Yes	15	4
supplementation	No	360	96
Crop rotation	Yes	137	37
	No	238	63
Use of Cover crops	Yes	80	21
	No	295	79
Mulching	Yes	75	20
	No	300	80
Irrigation	Yes	46	13
	No	329	87

Variable	Category	Adopters(n=375) Frequency	Percentage
Zero tillage	Yes	4	1
	No	371	99
Soil testing and mapping	Yes	12	3
	No	363	97
Legume intercropping	Yes	27	7
	No	348	93
Crop residue	Yes	23	6
	No	352	94
Zaipit	Yes	22	6
	No	353	94
Terracing	Yes	117	31
	No	258	69

4.3.2 Socio-economic Determinants of Respondents (Categorical Variables)

Results in Table 4. 3 shows the distribution of selected factors influencing adoption among adopters and non-adopters in the study. The results show that gender was not statistically significant but higher percentage of males (50.7%) adopted SFET in comparison to females (49.3%). The educational profile indicates that it significantly influenced the adoption. This could mean that farmers who possess a high level of educational attainment can be efficient in integrating knowledge of adoption in their farming systems. The proportion of adopters who have attained secondary and higher levels of education stands at 62.1%, in contrast to the 33.4% of non-adopters who have achieved the same educational milestones. This suggests that education is linked to the development of cognitive skills necessary for the adoption of advanced agricultural technology and simultaneously provides the capability to execute SFET.

Access to knowledge and training is a critical factor that can influence adoption. Conversely, only 6.7% of adopters' report difficulties in accessing information, whereas 64.1% of non-adopters experience such issues. Participation in SFET programs and informal agricultural training indicates that over 50 % of adopters are engaged, whereas the remaining 40% of adopters exhibit less involvement. On the

other hand, the proportion of non-adopters engaged in programs of SFET was 5.1%, while the proportion of non-adopters involved in informal agricultural training was 7.7%. Structured training and programs that promote the use of technologies are essential for equipping farmers with the necessary information and skills for the adoption and maintenance of SFET practices. Off-farm income serves as a significant factor in adoption of SFET. About 71.5% of adopters reported earnings from off-farm sources, whereas only 23.1% of non-adopters reported similar earnings. This suggests that adopters are likely equipped with the tools necessary to invest in new technologies and effectively manage the associated risks through financial diversification. Similarly, adopters demonstrated a higher prevalence of off-farm activities, utilizing these engagements to supplement household expenses and enhance their farming operations. The primary reason non-adopters engage in these activities is insufficient income which in most cases they use to supplement income.

Study results also show that adopters exhibit a more varied land use pattern, allocating a considerably larger percentage of their land to cash crops (27.5%) and grazing (51.7%). In comparison, non-adopters primarily allocate a substantial portion of their land to food crops (94.9%). The adopters are implementing a strategy that is more resource-intensive and commercialized, as evidenced by the increased diversity of land uses, they are supporting. Individuals who have not adopted the practice exhibit limited diversification and do not allocate any land for activities such as woodlots or bushes. This may be attributed to insufficient comprehension of the advantages associated with the use of SFET or due to constraints in available resources. Therefore, land usage patterns represent a critical factor that warrants careful consideration. Adopters exhibit an increased willingness to invest in agricultural practices that prioritize diversification and sustainability. Further, adopters revealed diverse occupations, with self-employment representing 38.7% and government service accounting for 27.5%. This contrasts with the non-adopters, who are exclusively involved in farming at a rate of 82.1%. This diversification may provide adopters with an enhanced financial framework for investing in emerging productive agricultural technologies.

Table 4. 3: Summary of categorical variables affecting adoption of SFET technologies

Variable	Category	Non-Adopters (n=39) (Frequency/Percentage)	Adopters (n=375) (Frequency/Percentage)	Pooled (n=414) (Frequency/Percentage)	Chi^2
Gender	Male	16 (41.0%)	190 (50.7%)	206 (49.8%)	1.3134
	Female	23 (59.0%)	185 (49.3%)	208 (50.2%)	
Education	None	8 (20.5%)	28 (7.5%)	36 (8.7%)	25.397***
	Primary	18 (46.2%)	77 (20.5%)	95 (23.0%)	
	Secondary	9 (23.1%)	144 (38.4%)	153 (37.0%)	
	College	3 (7.7%)	92 (24.5%)	95 (23.0%)	
	University	1 (2.6%)	34 (9.1%)	35 (8.5%)	
Challenge on information access	Yes	25 (64.1%)	25 (6.7%)	50 (12.1%)	109.747***
	No	14 (35.9%)	350 (93.3%)	364 (87.9%)	
Main occupation	Farming	32 (82.1%)	230 (61.3%)	262 (63.3%)	40.2749***
	Self-Employed	7 (17.9%)	145 (38.7%)	152 (36.7%)	
	Civil servant	1 (2.6%)	103 (27.5%)	104 (25.1%)	
	Retired	7 (17.9%)	36 (9.6%)	43 (10.4%)	
Reason for off-farm	Supplement farming	3 (7.7%)	123 (32.8%)	126 (30.4%)	36.499***
	Manage financial risk	1 (2.6%)	70 (18.7%)	71 (17.1%)	
	Insufficient income	12 (30.8%)	93 (24.8%)	105 (25.4%)	
		4 (10.3%)	164 (43.7%)	168 (40.6%)	
		0 (0%)	44 (11.7%)	44 (10.6%)	

Variable	Category	Non-Adopters (n=39) (Frequency/Percentage)	Adopters (n=375) (Frequency/Percentage)	Pooled (n=414) (Frequency/Percentage)	Chi^2
	Support expenses				
	Expand investment				
Land use	Food	37 (94.9%)	365 (97.3%)	402 (97.1%)	25.482**
	crop	4 (10.3%)	103 (27.5%)	107 (25.8%)	
	Cash	5 (12.8%)	194 (51.7%)	199 (48.1%)	
	crop	0 (0%)	11 (2.9%)	11 (2.7%)	
	Grazing	0 (0%)	25 (6.7%)	25 (6.0%)	
	Woodlots				
	Bushes				
Off-farm income	Yes	9 (23.1%)	268 (71.5%)	277 (66.9%)	37.360***
	No	30 (76.9%)	107 (28.5%)	137 (33.1%)	
Participation in SFET programs	Yes	2 (5.1%)	191 (50.9%)	193 (46.6%)	29.783***
	No	37 (94.9%)	184 (49.1%)	221 (53.4%)	
Informal training	Yes	3 (7.7%)	218 (58.1%)	221 (53.4%)	36.117***
	No	36 (92.3%)	157 (41.9%)	193 (46.6%)	

4.3.3 Socio-economic Determinants of Respondents (Continuous variables)

Table 4.4 presents significant differences in various key variables between adopters and non-adopters of SFET. The mean age of adopters was 47.6 years, compared to 54.2 years for non-adopters, revealing a statistically significant difference with a t-value of 2.5743***. Young farmers may exhibit a heightened willingness to adopt new technologies, likely influenced by their idealistic perspective on agricultural innovation. Households of adopters averaged 6 members, whereas non-adopter households averaged 7 members. The observed difference is statistically significant, indicated by a t-value of 1.750**. Smaller households may face fewer labor

constraints, enabling adopters to allocate resources more effectively for the implementation of SFET.

The farming experience varies considerably between the two groups, with a t-value of 1.8159**. Non-adopters reported an average of 17.7 years of experience, while adopters reported 14.7 years. This finding suggests that increased experience may correlate with a dependence on conventional practices, potentially leading to a reduced likelihood of adopting new technologies among farmers. Interestingly, while adopters possess a greater average of 9 livestock compared to the 4 livestock held by non-adopters, the variance is notable and inversely related when it comes to land under cultivation. Non-adopters manage a larger area of land, averaging 5.6 acres, in contrast to adopters, who average 4.2 acres. However, this difference is only marginally significant, with a t-value of 1.4531*, suggesting potential variations in resource allocation priorities.

The utilization of labor demonstrates significant differences, with adopters depending on hired labor at a rate of 34.9%, in contrast to non-adopters, who stand at 6.9%. During family labor, non-adopters displayed a greater reliance, with 90.5% compared to 64.0% for adopters. However, there was a notable difference for family labor (t = 5.515***), which was highly significant. This suggests that adopters are accessing a wider range of labor sources, potentially placing them in a more advantageous position to implement scale- and labor-intensive SFET, which non-adopters may struggle to adopt due to their reliance on family labor.

Table 4. 4: Summary of continuous characteristics affecting adoption of SFET technologies

Variable	Unit	Adopters Mean (Std. Dev.)	Non-adopters Mean (Std. Dev.)	Pooled Mean (Std. Dev.)	T-value
Age	Years	47.6(14.1)	54.2(15.3)	48.2(14.3)	2.574***
Household size	Number	6(2.9)	7(3.0)	6(2.8)	1.750**
Years spent farming	Years	14.7(9.9)	17.7(9.9)	15.0(9.9)	1.816**
Farm size	Acres	5.5(6.0)	6.5(6.5)	5.6(4.9)	0.954
Livestock size	Number	9(14.2)	4(8.3)	8(13.8)	-3.349
Land under cultivation	Acres	4.2(3.5)	5.6(6.0)	4.3(3.9)	1.453*
Family labor	Percentage	64.0(40.3)	90.5(27.2)	66.5(40.0)	5.515***
Hired labor	Percentage	34.9(39.7)	6.9(2.8)	32.3(39.2)	-6.671

4.3.4 Challenges on Accessing Extension Services

The results in Table 4.5 show that farmers' access to extension information is hindered potentially by a number of factors, with the most common being a lack of awareness and insufficient extension information both accounting to (32%). These suggest that a sizable portion of farmers lack knowledge about the extension services that are now available and receive insufficient information, which limits their capacity to implement sustainable agricultural practices. It reflects weak dissemination approaches being used by extension service providers, which may be brought on by a lack of outreach initiatives and inefficient channels for disseminating information. The cost of service (10%) and distance to training facilities (11%), was also significant barriers, implying that some areas still encounter geographic and financial constraints. It reflects the need for a decentralized extension strategy that includes training facilities at the village level, mobile-based advising systems, and extension

subsidization to provide smallholder farmers who live far away with equitable access to information.

Respondents accounting to 16% also reported lack of practical's, which is a prerequisite for shaping positive attitude in cutting-edge technologies. Even though it was not common, 2% of respondents were pessimistic about the effectiveness of extension services. Other respondents 4% reported lack of follow up, indicating that farmers have doubts about the efficacy of extension services because they are unable to offer assistance after training. It necessitates a participatory extension strategy that allows for ongoing communication with farmers following training sessions. Due to availability of alternative information sources, farmers do not perceive group affiliation as a significant hindrance to their work, as evidenced by the relatively low influence (7%). On overall, the challenges were experienced by smaller proportion as compared to those who are not experiencing challenges. Low challenges can be attributed to the increase in private sectors, devolution and digitized systems of extension services.

Table 4. 5: Distribution of challenges experienced in accessing extension services

Challenge	Category	Frequency	Percentage
Lack of awareness	Yes	132	32
	No	282	68
Distance to training centers	Yes	44	11
	No	370	89
Insufficient extension information	Yes	133	32
	No	281	68
Cost of the services	Yes	42	10
	No	372	90
Doubt on the effectiveness	Yes	10	2
	No	404	98
Lack of follow-ups	Yes	18	4
	No	396	96
Lack of demonstrations	Yes	66	16
	No	348	84
Group membership	Yes	28	7
	No	386	93

4.3.5 Extension Methods Accessed by Farmers

Results in a Table 4.6 shows the distribution extension methods by those who access extension services. Training and workshops were the most favored among farmers, with 89% participation. This suggests that structured, pragmatic training integrating theoretical and practical knowledge produces optimal outcomes since farmers can seek direct instruction from the educator to attain a comprehensive awareness of contemporary techniques. Only 11% had never attended such programs and this may be attributed to conflicting schedules. Radio programs, were used by 65% of the respondents to receive extension information. Radio programs are known to be vital in promoting agriculture knowledge dissemination to a broad audience, especially individuals residing in remote areas with limited access to other sources of extension services. However, 35% of the respondents did not depend on radio programs probably because they easily access other sources of extension.

About 25% of the respondents reported that they have conducted farm visits which is a lower turnover compared to those who have not (75%). This suggests that although the method is advantageous, it is constrained by the available resources and the logistical difficulty of visiting each farm. The use of digital platforms was notably low (19%) indicating that most respondents might be experiencing limited internet access and smartphones. Nevertheless, (81%) suggests that the majority of farmers favor practical experience and most might be bearing that internet demonstrations are engineered by artificial intelligence. Farmer field schools and demonstration plots also exhibited a lower response of 25% and 15%, respectively. Despite their importance these methods may be constrained by the degree of inevitable commitment.

Table 4. 6: Distribution of extension methods on those who access extension services (n=261)

Variable	Frequency	Percentage
Demonstration plot	66 (yes)	25
	195 (No)	75
Farmer fields school	38 (Yes)	15
	223 (No)	85
Farm visit	65 (Yes)	25
	196 (No)	75
Radio programs	170 (Yes)	65
	91(No)	35
Digital platforms	50 (Yes)	19
	211(No)	81
Training and workshops	28 (Yes)	11
	233 (No)	89

4.3.6 Farmers' Knowledge, Attitude and Perceptions on the Adoption Intensity of Soil Fertility Enhancement Technologies

Figure 2 and Figure 3 present the level of awareness, attitude and perception of the respondents on the adoption of Soil Fertility Enhancement Technologies (SFETs). Most of the respondents were aware of SFET with 45% agreeing and 14% strongly agreeing that they have knowledge on it (Figure 1). This indicates a moderate awareness level of the technologies among the study population. Moreover, 50% of the respondents had knowledge on how SFETs function, meaning that a fair idea exists on how it works, though a large percentage holds a neutral view, indicating a possible gap in information.

A notable finding reveals that 55% of respondents believe that SFET promotes sustainable farming, with 61% expressing a willingness to adopt it. This indicates a positive attitude towards the technology, suggesting that individuals recognize its potential advantages in supporting agricultural practices. Furthermore, 58% of the

participants expressed a willingness to invest in SFET, with 27% indicating strong agreement. This indicates a robust inclination to adopt SFET, demonstrating that the respondents are willing to allocate their resources for its application, contingent upon the availability and adequacy of the SFETs. Regarding the accessibility of SFETs, it is evident that there is a significant barrier, as only 3% of respondents strongly agreed that SFETs were easily accessible, while a substantial 94% disagreed, indicating that access is a major obstacle to their widespread adoption.

The respondents exhibited a range of perspectives concerning access to extension services. On one hand, 11% agreed that agricultural extension services actively contribute to the promotion of SFET, while on the other hand, 26% strongly disagreed, indicating that the majority perceived the extension services as lacking effectiveness in encouraging the adoption of SFETs. Additionally, 45% agreed that the information provided by Agricultural Extension Methods (AEM) was beneficial in advancing SFET, while 24% remained neutral, indicating that some respondents recognized the utility of the information but suggested there is room for enhancement in its quality and relevance. Findings suggest that the levels of engagement in extension programs significantly influence the adoption of SFET. Approximately 41% agreed that higher participation rates in extension services positively influenced SFET adoption, while 28% remained neutral and 12% disagreed. This indicates that, although participation is significant, its effects may not be universally experienced by all respondents.

Findings on perceptions that "SFET requires intensive labor," were pointed by 55% of the respondent’s implying conformity with the view that SFET involves a heavy labor input, even though 45% were against this view (Figure 2). This indicates that SFET efforts are seen to be quite demanding but nearly a half of the respondents' perception does not identify labor as the primary constraint, which shows that labor-intensive operations may be possible with support mechanisms. Majority (83%) of the respondents reported that they were aware that SFET had advantages over other approaches, and this wide awareness could be the key to adoption if it leads the respondent's interest and willingness to use the technology. In the case of cost-effectiveness, only 20% expressed the view that SFET is cost-effective, whereas a higher proportion of respondents (80%) disagreed. This indicates a major issue among the respondents, as the estimated SFET cost may be a critical limit to adoption despite being aware of the advantages.

Results further indicate that a considerable majority of the respondents (62%) think that limited land constrains the adoption of SFET, whereas 38% did not concur. This indicates that the constraint on land could be a consideration in the adoption, particularly if SFET takes up larger space or requires more intensive management. In the case of the accessibility of extension support, a total of 37% agreed that extension support assists in the adoption of SFET, whereas 63% did not agree, which indicates that the gap in the provision or accessibility of extension support exists. A majority of the respondents totaling 92% indicated that SFET had a high level of access, which indicates a strong belief among the respondents that the technology is easily accessible, a good sign for future adoption. However, the disparity with the perception of the lack of suitable extension support indicates that access by itself might not be sufficient in promoting extensive adoption.

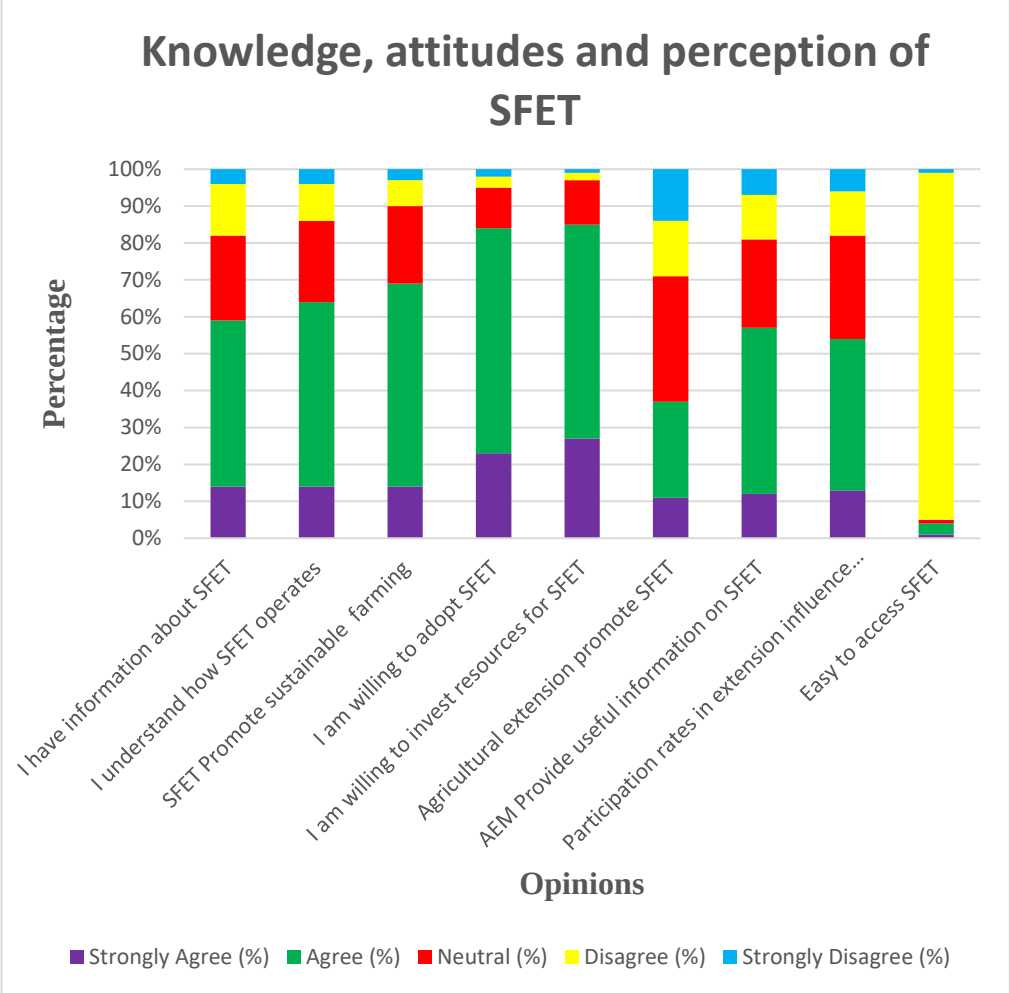

Figure 2: Likert scale measurements

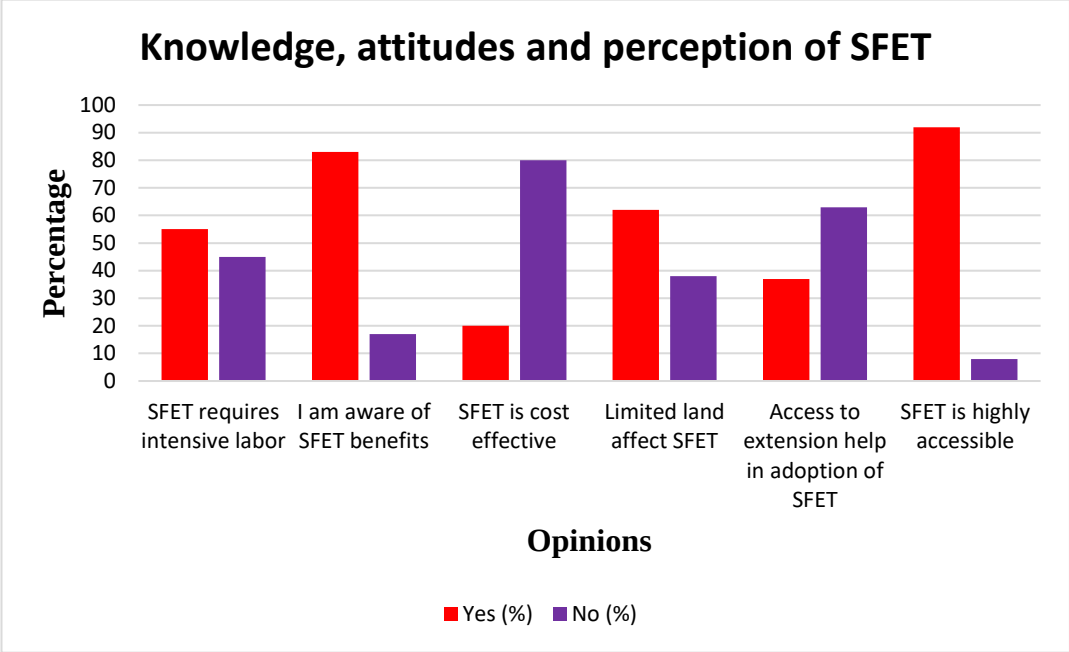

Figure 3: Binary measurements

4.4 Socio-economic Factors Influencing Adoption of Soil Fertility Enhancement Technologies

The study found that the reason for engaging in off-farm activities, number of off-farm income sources, education level, land use, participation in SFET programs, informal training, limited access to agricultural information, and farm size influenced the likelihood of technology adoption (Table 4.7). The model was fit as indicated by R-Square of 0.543, meaning that the independent variables can explain up to 54.3% of the dependent variable. Engagement in off-farm activities and the number of off-farm income sources were both positively associated with adoption. This implies that for every one-unit increase in the off-farm sources, there would be an approximate increase of 0.069 on the adoption of the technologies, indicating that adoption levels are higher for those who have clear reasons for engaging in off-farm sources.

Education also showed a positive relationship with the adoption of SFET, with a coefficient of 0.268 at a p-value of 0.055 even though it was significant at a 10%, indicating that higher levels of education somewhat enhance adoption. However, the broad confidence interval of -0.006 to 0.541 suggests that the effect may vary. Participation in SFET-related programs significantly increased the likelihood of adoption. This implies that such programs play a critical role in transferring knowledge, demonstrating practical skills, and offering institutional support that

encourages farmers to adopt soil fertility practices. Similarly, households that made intensive use of their land were more likely to invest in maintaining or improving soil productivity, suggesting a close link between land management and conservation behavior.

Conversely, limited access to agricultural information negatively influenced adoption. This suggests that when farmers lack access to timely, relevant, and reliable agricultural knowledge, their ability to make informed decisions about adopting SFETs is greatly reduced. Access to information appears to be a foundational factor in technology uptake. Farm size had a negative effect on adoption, indicating that households with smaller land parcels were more likely to adopt SFETs than those with larger holdings. This finding may be attributed to the fact that small-scale farmers tend to intensify land use and are more motivated to preserve soil fertility to sustain productivity on limited land.

Table 4. 7: Selected factors affecting adoption of SFET technologies

SFET Adoption	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Reason for off farm	.069	.034	2.04	.041	.003	.136	**
Age	-.020	.012	-1.57	.117	-.044	.005	
Education	.268	.139	1.92	.055	-.006	.541	*
Sources off farm	.969	.344	2.82	.005	.295	1.643	***
Livestock size	.02	.015	1.34	.179	-.009	.050	
Land use	.183	.089	2.05	.040	.008	.358	**
Participation in SFET	1.439	.492	2.93	.003	.476	2.403	***
Informal training	.744	.368	2.020	.043	.022	1.465	**
Main occupation	-.051	.053	-0.970	.334	-.155	.053	
Farming experience	-.010	.016	-0.640	.519	-.041	.021	
Limited access to agric info.	-1.426	.315	-4.520	.000	-2.044	-.808	***
Family labor	-.007	.005	-1.36	.175	-.018	.003	
Farm size	-.104	.034	-3.09	.002	-.17	-.038	***
Household size	.072	.057	1.26	.206	-.039	.182	
Gender	-.112	.279	-0.40	.687	-.659	.434	
Constant	.478	1.153	0.42	.678	-1.781	2.738	

Mean dependent var	0.906	SD dependent var	0.292
Pseudo r-squared	0.543	Number of obs	414
Chi-square	140.417	Prob > chi2	0.000
Akaike crit. (AIC)	150.048	Bayesian crit. (BIC)	214.461

**** p<.01, ** p<.05, * p<.1*

4.5 Socio-economic Factors Influencing Adoption Intensity of Soil Fertility Enhancement Technologies

The Ordinary Least Squares (OLS) regression was employed in the second stage to identify factors influencing the adoption intensity of SFET (Table 4.8). The model explains a substantial portion of the variation in adoption intensity, demonstrated by an R-squared value of 0.709, indicating that 70.9% of the variation in the dependent variable is accounted for by the independent variables in the model. The model exhibits substantial significance ($F = 54.552$, $p < 0.01$), confirming its validity. The inverse Mills ratio was significant at the 10% level ($p<0.1$), indicating that the model accounts for selection bias. The results indicate that farm size significantly influenced adoption intensity ($p < 0.01$). This indicates that an increase in farm size is associated with a rise in the likelihood and intensity of SFET adoption by 0.647. The quantity of off-farm income sources exerted a negative and statistically significant influence on the intensity of adoption. This indicates that households with greater off-farm income sources generally allocated less effort or land to soil fertility technologies. This finding may be linked to a shift in emphasis toward non-agricultural activities, potentially resulting in decreased reliance on farming and diminished incentive to invest in long-term soil health.

Number of livestock owned by a household affected adoption intensity negatively. This could suggest that farming households with high number of livestock focused less on intensifying adoption of SFETs. This study attributed this issue to a likely competition between crop and livestock enterprises for land and resources, that ultimately limit adoption if the latter is favored. Similarly, the intended use of land had a negative and significant influence on adoption intensity of SFET. This means that households with more preoccupied activities in the land decrease the propensity to adopt and apply SFETs intensively, possibly due to initial land-use priorities. The size of the farm size owned by a household had a strong positive impact on adoption intensity of soil fertility enhancement technologies. This depict that households with sizeable portions of land were more likely to intensify adoption of SFETs. This may be because larger farms have greater capacity to experiment with and scale up soil fertility technologies, and may also benefit from economies of scale.

Table 4. 8: Selected factors affecting adoption intensity of SFET technologies

Adoption intensity	Coef.	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
Reason for off farm	-.078	.048	-1.63	.104	-.173	.016	
Age	.015	.012	1.31	.190	-.008	.039	
Education	.107	.081	1.31	.190	-.053	.267	
Sources of off farm inc.	-1.273	.517	-2.46	.014	-2.29	-.257	**
Livestock size	-.037	.01	-3.66	.000	-.057	-.017	***
Land use	-.097	.041	-2.39	.018	-.178	-.017	**
Participation in SFET	-.014	.237	-0.06	.955	-.480	.453	
Informal agric training	-.231	.221	-1.05	.296	-.665	.203	
Main occupation	-.023	.037	-0.63	.527	-.096	.049	
Farming experience	-.009	.013	-0.70	.482	-.034	.016	
Limited access to agric info.	-.408	.433	-0.94	.346	-1.259	.442	
Family labor	-.005	.003	-1.63	.103	-.011	.001	
Household size	.067	.042	1.58	.114	-.016	.149	
Gender	-.255	.211	-1.21	.226	-.670	.159	
Farm size	.647	.032	20.39	.000	.585	.709	***
IMR	-2.512	1.52	-1.65	.099	-5.502	.477	*
Constant	3.252	1.019	3.19	.002	1.249	5.256	

Mean dependent var	4.154	SD dependent var	3.538
R-squared	0.709	Number of obs	375
F-test	54.552	Prob > F	0.000
Akaike crit. (AIC)	1581.745	Bayesian crit. (BIC)	1648.503

**** p<.01, ** p<.05, * p<.1*

4.6 Effectiveness of Agricultural Extension

4.6.1 Influence of Extension Methods on Adoption of Soil Fertility Enhancement Technologies

Multivariate probit model was used to determine the influence of selected extension methods on farmers' decision to adopt Soil Fertility Enhancement Technologies (SFET). The extension methods considered in this study include demonstration plots, farm visits, farmer fields schools, radio programs and trainings and workshops were considered in this study. Results (Table 4.9) show that demonstration plots positively influenced adoption of both composting and Zai pit technologies at 10% and 1% respectively. This reflects the need of practical when promoting incipient technologies to enhance uptake by farmers.

Training and workshops emerged as the most influential method, significantly promoting the adoption of micronutrient supplements, crop rotation, cover cropping, irrigation, legume intercropping, crop residue use, terracing, and zai pit. Similarly, farmers field schools had strong positive effects on the use of organic manure, micronutrient supplements, crop rotation, and irrigation, suggesting their effectiveness in delivering practical and participatory learning. Farm visits also had a positive influence on the adoption of inorganic fertilizer, micronutrient supplements, cover cropping, irrigation, and terracing, highlighting the importance of personalized and on-site advisory services.

Digital platforms significantly influenced the use of composting, biochar, micronutrient supplements, and irrigation, indicating their potential for reaching farmers with targeted information. Radio programs had mixed effects—positively associated with adoption of organic manure, inorganic fertilizer, legume intercropping, and terracing, but negatively associated with practices such as crop rotation and cover cropping, possibly due to limitations in message depth or clarity.

Table 4. 9: Influence of extension methods on adoption of soil fertility enhancement technologies

Variables	Composting	Organic manure	Biochar	Inorganic Fertilizer	Micronutrient Supplements	Crop Rotation	Cover Cropping	Irrigation	Zero tillage	Legume Intercropping	Crop Residue	Terracing	Zai pit
Demonstration Plot	0.379*	-0.281	0.444	-0.269	-0.066	-0.051	-0.226	-0.135	0.666	0.219	0.468	0.311	0.513**
Farmers Field School	0.184	1.040**	0.200	0.489*	0.765**	0.992***	0.281	1.509***	0.331	-0.544	-0.259	-0.087	0.544*
Farm Visit	0.056	0.920***	-0.564	0.864***	0.733**	0.072	0.515**	0.750***	0.739	-0.186	0.154	0.700***	0.714***
Radio Programs	-0.24	0.510***	-0.472	0.329**	-0.049	-0.456***	-0.354**	-0.566***	0.132	0.408*	0.145	0.407***	-0.507*
Digital Platforms	0.365*	-0.178	1.251***	0.225	0.708**	-0.082	0.396	0.548**	0.703	0.096	0.421	0.164	0.495*
Training and Workshops	0.639**	0.181	0.168	0.284	0.917***	1.539***	1.128***	0.469*	0.524	1.251***	1.854***	1.212***	1.272***
_cons	-1.253	0.667	-2.605	-0.442	-2.525	-0.367	-1.182	-1.606	-3.403	-1.931	-2.245	-1.100	-2.272

4.6.2 Effect of Extension Methods on Adoption Intensity of Soil Fertility Enhancement Technologies

Tobit regression model was used to measure how extension methods affect adoption intensity of SFET. Results (Table 10) shows that farmer field school, farm visits and radio programs was significant in influencing adoption intensity of SFET. Farmer field schools was positively significant at 5% in influencing adoption intensity. This reveal that increasing participation and frequency of FFS by one unit can augment adoption of SFET by 0.86 units. Ideally, farmers who engage in FFS are better positioned to use SFET to a greater extent since they are able to learn and obtain information on proper application of such technologies for better production. With FFS, farmers are able to gain hands-on training and the opportunity to tap more information from experts and their peers. This approach likely capacitated farmers with practical knowledge, increasing their confidence and encouraging them to scale up SFETs.

The method of farm visits also influenced adoption intensity. The study findings suggest that visits allowed extension officers to offer targeted aid that addressed individual farmer needs. The resultant direct engagement likely persuaded further the target farmers to implement SFETs more intensively. Radio programs affected adoption intensity of SFETs. Being a communication tool, radio programs enhanced access to a broad audience by creating awareness of SFETs and encouraging farmers to apply such technologies.

Table 4. 10: Effect of extension methods on intensity of adopting soil fertility enhancement technologies

Adoption intensity	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Demonstration plot	.073	.263	0.28	.783	-.445	.591	
Farmers field school	.860	.333	2.58	.01	.205	1.515	**
Farm visit	.778	.261	2.98	.003	.265	1.291	***
Radio programs	.545	.188	2.90	.004	.175	.915	***
Digital Platforms	.127	.254	0.50	.618	-.373	.627	
Training and workshops	.348	.343	1.02	.310	-.326	1.023	
Constant	-.574	.185	-3.11	.002	-.938	-.211	
var (e	2.89	.211	. b	. b	2.503	3.336	
Mean dependent var	3.404		SD dependent var			3.477	
Pseudo r-squared	0.268		Number of obs			375	
Chi-square	535.737		Prob > chi2			0.000	
Akaike crit. (AIC)	1482.143		Bayesian crit. (BIC)			1521.412	
*** *p<.01, ** p<.05, * p<.1*							

4.7 Farmers' Knowledge, Attitude and Perceptions

4.7.1 Farmers' Knowledge, Attitude and Perceptions on the Adoption of Soil Fertility Enhancement Technologies

Results in Table 4.11 were obtained from a probit model that sought to determine the relationship between farmers` knowledge, attitudes and perception towards adoption of SFET technologies. The findings showed that perception on labor requirement had a significant positive influence on adoption of SFETs (p = 0.005). This implies that when farmers perceive labor requirement for adopting SFETs to be manageable, their decision to adopt increases by 83%. The amount of labor accompanying adoption of a technology can dictate farmer's perception to implement it. Farmers willingness to use resources in implementing SFET technologies had a significant negative

relationship on adoption (p = 0.041). The negative association implied that farmers who are less willing to invest resources in SFET adoption were less likely to lower adoption by 39%. Farmers could be more willing to adopt technologies if returns on investment in SFETs is quick and favorable, however, they might hesitate to invest in a technology whose benefits are not immediately apparent.

The farmers` awareness of the benefits of SFETs was also showed a significant positive in influencing adoption (p = 0.044). When farmers have knowledge and are aware of technology benefits associated with SFETs, adoption can rise by 55%. This suggests that deep understanding of the returns of SFETs motivates farmers to adopt them, especially those who doubt technologies benefits. Attitude of a farmer toward access to extension services had a strong positive relationship on adoption of SFETs (p = 0.001), with adoption decision increasing by 86%. Access to extension services offer farmers with training, information, and technical support, all of which contribute to better adoption outcomes. Extension services help streamline the adoption process by offering farmers the necessary tools and knowledge to make informed decisions about adopting SFETs.

Table 4. 11: Influence of knowledge, attitudes and perception on adoption of soil fertility enhancement technologies

Adoption	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Information on SFET	.269	.191	1.41	.158	-.105	.644	
Understanding of SFET	-.254	.206	-1.24	.217	-.658	.149	
Willingness to adopt SFET	-.196	.162	-1.21	.226	-.513	.121	
Labor requirement	.83	.295	2.82	.005	.252	1.407	***
Benefits of SFET in farming	-.141	.17	-0.83	.407	-.475	.193	
Willingness to invest resources	-.391	.192	-2.04	.041	-.768	-.015	**
Awareness of their benefits	.549	.272	2.02	.044	.015	1.082	**
Cost effectiveness	.492	.396	1.24	.214	-.283	1.267	
Limited land	.499	.279	1.79	.074	-.048	1.046	*
Extension service	.863	.271	3.18	.001	.331	1.394	***
AEMs	-.065	.213	-0.31	.759	-.482	.352	
Participation	.068	.195	0.35	.728	-.315	.451	
Access to SFET	-.151	.135	-1.12	.265	-.417	.114	
Constant	.817	.676	1.21	.226	-.507	2.141	

Mean dependent var	0.865	SD dependent var	0.342
Pseudo r-squared	0.441	Number of obs	414
Chi-square	144.678	Prob > chi2	0.000
Akaike crit. (AIC)	213.438	Bayesian crit. (BIC)	273.826

**** p<.01, ** p<.05, * p<.1*

4.7.2 Influence of Knowledge, Attitudes and Perception on Adoption Intensity of Soil Fertility Enhancement Technologies

The coefficient for understanding of SFET was negative and statistically significant at the 10% level (p = 0.064), indicating that a higher level of understanding was associated with lower adoption intensity (Table 4.12). This meant that as farmers gained more in-depth knowledge of the technologies, they may have become more cautious or selective in their application. It implied that increased understanding could reveal limitations or risks of certain technologies, leading to more deliberate and

perhaps reduced implementation. This finding suggests that knowledge alone does not necessarily lead to widespread use, especially if it uncovers perceived challenges or complexities.

Perceived benefits of SFET in farming had a positive and significant effect on adoption intensity ($p = 0.064$), implying that when farmers saw clear advantages of the technologies, they were more likely to implement them on a larger scale. This meant that perception of practical benefits such as improved soil productivity and higher crop yields encouraged farmers to invest more resources in the technologies. The result emphasized the importance of demonstrating practical gains of SFETs in ways that resonate with farmers' priorities.

Perceived cost effectiveness of SFETs was significant at the 5% level ($p = 0.027$) and positively associated with adoption intensity. This implied that when farmers felt the technologies offered favorable value for money, they were more inclined to adopt them intensively. It meant that affordability and return on investment played a central role in decision-making. Farmers are more likely to increase their use of SFETs if they feel that the input costs are justified by the expected benefits, highlighting the need for policy measures that reduce costs or offer incentives to enhance perceived economic viability.

Access to extension services showed a significant and strong positive effect on adoption intensity ($p = 0.012$). This meant that farmers who had greater access to or positive attitudes toward extension support adopted SFETs more extensively. It implied that training, demonstrations, and technical advice provided by extension agents helped build farmers' confidence and capacity to implement technologies on a larger scale. This finding underscored the critical role of extension services not just in introducing SFETs, but also in enabling farmers to scale their use through continuous support and problem-solving.

Table 4. 12: Effect of knowledge, attitudes and perception on adoption intensity of soil fertility enhancement technologies

Adoption intensity	Coef.	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
Information on SFET	.091	.202	0.45	.653	-.307	.489	
Understanding of SFET	-.421	.227	-1.86	.064	-.868	.025	*
Willingness to adopt SFET	-.25	.221	-1.13	.26	-.685	.186	
Labor requirement	.174	.268	0.65	.516	-.353	.701	
Benefits of SFET in farming	.385	.207	1.86	.064	-.023	.792	*
Willingness to invest resources	-.351	.226	-1.55	.122	-.796	.094	
Awareness of their benefits	-.481	.363	-1.33	.186	-1.195	.232	
Cost effectiveness	.823	.371	2.22	.027	.093	1.553	**
Limited land	-.251	.257	-0.98	.329	-.758	.255	
Extension service	.794	.314	2.53	.012	.176	1.413	**
AEMs	.012	.18	0.07	.946	-.341	.366	
Participation	-.057	.172	-0.33	.741	-.395	.282	
Access to SFET	.148	.136	1.09	.275	-.119	.415	
Imr	-1.291	.505	-2.56	.011	-2.285	-.298	**
Constant	1.372	.91	1.51	.133	-.419	3.162	

Mean dependent var	3.165	SD dependent var	3.561
R-squared	0.690	Number of obs	337
F-test	44.462	Prob > F	0.000
Akaike crit. (AIC)	1451.040	Bayesian crit. (BIC)	1515.981

**** p<.01, ** p<.05, * p<.1*

CHAPTER FIVE

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Overview

This chapter presents a discussion of the results of the current study, comparing its findings with those of previous studies. It interprets the findings outlined in Chapter 4 and summarizes the conclusions, and recommendations for future studies

5.2 Discussion

5.2.1 Characterization of Soil Fertility Enhancement Technologies

The factor analysis reveals distinct clusters of farming techniques that highlight broader concepts in both traditional and sustainable agriculture, whose primary concept is to safeguard the soil and maintain its health. Soil fertility enhancement technologies such as cover cropping, mulching, composting, and legume intercropping emphasize the utilization of organic amendments and sustainable practices to enhance soil fertility and promote long-term environmental stability. These methods contribute to the environment by preventing erosion, safeguarding microorganisms, and replenish soil nutrients. A further theme involves conventional techniques for soil protection, including the application of manure and the implementation of terracing. These methods emphasize the preservation of soil structure and fertility through low-input, nature-based approaches.

Zero tillage represents a farming method that minimize soil disturbance and enhances water retention within the soil. This indicates a shift towards conservation agriculture practices. Conversely, the incorporation of inorganic fertilizer indicates that conventional, resource-intensive approaches for enhancing food production continue to be employed. The evidence indicates that farmers are attempting to achieve a balance between environmental protection and the production of high-yield crops. Their approach involves employing a combination of organic and conventional technologies, tailored to the resources available to them and aligned with their production objectives.

5.2.2 Socio-economic Factors Influencing Adoption of Soil Fertility Enhancement Technologies

The study results indicated that off-farm income had a positive and significant impact on the adoption of SFET. This show that households involved in off-farm activities, which manifest more income streams, are better positioned to implement soil fertility technologies. Improved financial capacity and reduced reliance on farm income alone, is deemed to offer greater flexibility in adopting beneficial technologies. Education level and farmers` informal training also displayed a positive effect on adoption. This suggests that farmers with high education level and those who have benefited from informal training, are more likely to comprehend, appreciate, and use enhanced soil fertility technologies. These forms of knowledge access likely improve awareness of technology benefits and build confidence in their application. This study aligns with the findings of Tadesse and Ahmed (2023) who found that education was positively significant in determining decision to adopt climate smart agricultural technologies. Studies of Branca and Perelli (2020) and Neway and Zegeye, (2022) associated education with efficiency of inculcating technology into the farming system.

Sources of other income other than farming, displayed a strong and positive relationship on adoption of SFET. This means that more diversified sources of income substantially improve adoption. This is inconsistent with the report that sources of off farm income decreased adoption of improved varieties of wheat (Kidane et al., 2024). Land use revealed a positive impact on adoption of SFET. This means that good land use contributes to more adoption of technologies. It can be deduced that farmers are more likely to embrace SFET if they make efficient use of their land, possibly by diversifying their crop production or maximizing its usage for sustainable activities. As a result, one of the most effective methods to encourage wider usage of these technologies could be to promote better land management practices. The study of Kolady et al. (2021) reported that allocated land to crop production affected adoption of precision agriculture technology.

Participation in specific programs was associated with adoption of SFET. This implies that participation in programs related to SFET technologies is an important factor that enhances adoption. The study of Kolady et al. (2021), concluded that there is need to put up programs that promote the use of technologies such practices of precision agriculture. Informal agricultural training showed a positive influence on adoption of

SFET. This suggests that access to informal agricultural training greatly increases adoption of the technologies. It has been observed that technical training encourages farmers who have not received training to embrace technology, and it has also improved information exchange among farmers in the same community (Altalb, 2017). Training was effective in influencing adoption of low carbon technologies among rice farmers (Liu et al., 2019). This buttress the need to orient programs of SFET to be farmer centered for better adoption.

Limited access to information showed that it can lower adoption of the technologies. This further depicts that access to information plays a very important role in improving the outcomes. The study of Dalango and Tadesse (2019) found that access to input information was significant in adopting mineral fertilizer. Gemtou et al. (2024) also reported that access to reliable information affected decision to adopt climate smart agriculture practices. Farm size also contributed negatively towards adoption of SFET. This indicates that increasing farm size by one unit decreases adoption of the technologies. This could insinuate that the higher the size of the farm, the less the adoption, probably as a result of higher demands on time or resources. This report relates well with the findings of Tadesse and Ahmed (2023) who found that the size of land negatively affected adoption of irrigation systems. However, farm size positively influenced adoption of soil and water conservation technologies as reported by (Kifle 2021; Mosissa et al., 2019; Maru et al., 2022).

5.2.3 Socio-economic Factors Influencing Adoption Intensity of Soil Fertility Enhancement Technologies

Most extensive farms tend to possess more resources, such as land and capital, which can facilitate the adoption of SFET and they tend to be in a stronger position to take advantage of economies of scale, which can render investments in sustainable technologies more feasible and cost-effective. The study of Asravor et al. (2022) reported that the use intensity of mobile banking services was influenced by the size of land of a household.

A notable negative correlation between livestock size and the intensity of adoption indicating that as livestock size increases, farmers show a reduced tendency to enhance the adoption intensity of SFET. This might arise from the fact that more land can be allocated to livestock production when it is given priority than in integrating

SFET. Additionally, livestock operations may already depend on conventional farming methods and may view SFET as not immediately advantageous to their livestock-focused endeavors. Hence, these farmers might allocate additional resources to livestock management, thereby restricting their capacity to embrace new technologies. These results conflict the findings that livestock size positively affected the extent of adopting organic related soil fertility management technology such as farmyard manure (Mwaura et al., 2021). Similarly, results do not correlate with the report that livestock size positively influence intensity of adopting agriculture conservation technologies (Ngaiwi et al., 2023).

Land use was negatively significant in influencing adoption intensity of SFET. This implies that purpose to which land is set to serve could reduce adoption intensity of the technologies. This finding suggests that a farmer's choice to utilize their entire land exclusively for other practices such as grazing or woodlot development rather than crop production likely diminishes their motivation to adopt new SFET. It is possible that land uses may not align with the primary objective of this SFET advancement aimed at enhancing crop cultivation. Size of land allocated to crop cultivation had a positive effect on uptake of precision agriculture practices as reported (Kolady et al., 2021).

The relationship between non-farm sources of income and adoption intensity was negatively significant. This implies that farming would experience significantly reduced burden and pressure with income from various sources, as reliance solely on farm-derived livelihood would not be the primary incentive for adopting improved farming technologies. Therefore, it demonstrates that enhancing off-farm income would redirect focus and concentration in farming activities. Similar finding was reported by Ishara et al. (2023) that income from sources other than farming decreased the adoption intensity of mineral fertilizer.

5.2.4 Influence of Extension Methods on Adoption of Soil Fertility Enhancement Technologies

Demonstration plots positively influenced adoption of both composting and Zai pit technologies. This reflects the need for practical when promoting incipient technologies to enhance uptake by farmers. Demonstration plots provided farmers with a platform to observe their value of technologies and apply the same practices in

growing crops. According to Aslam et al. (2023), farmers are more willing to employ new technologies if they can be assured on how they will benefit. Sseguya et al. (2021) affirms that demonstration can guarantee adoption of new technologies.

The Farmer's Field School (FFS) affected positively adoption of organic manure, Inorganic fertilizer, micronutrient supplementation, crop rotation, irrigation and Zai pit technologies. The FFS is well-known for its potential to assimilate practical experience with academic understanding in the real world. This is accomplished by enriching farmers with the information and techniques required that can foster adoption. Berg et al. (2020) revealed that FFS helps farmers learn how to implement integrated soil fertility strategies, such as crop rotation and applying organic manure, which makes them more likely to use them. Moreover, Lwala et al. (2016) found that FFS helps to augment the acceptance of the promoted technologies.

Farm visits was significant in affecting adoption of both organic and inorganic fertilizer, cover cropping, irrigation, micronutrient supplementation, terracing and Zai pit technologies. Farm visits is seen as a key aspect that allow the farmer to observe how technologies such as terracing, irrigation, and manure application benefit crops. Omulo and Kumeh (2020) reported that farm visits are crucial for the farmer since they provide an opportunity for exposure, thereby helping to eliminate uncertainty and promote acceptance. In the same vein, Ritta et al. (2019) acknowledges the effectiveness of the farm visits in changing farmer attitudes and satisfaction towards sustainable technologies. According to Izuchukwu et al. (2023), adoption of sustainable practices depends on the social element which required to create networks amongst farmers, and this is made possible through farm visits. This suggests that when farmers share their expertise with one another, the technology in question is more likely to be trusted and adopted.

Radio programs was significant in influencing adoption of organic and inorganic fertilizer, cover cropping, irrigation, crop rotation, micronutrient supplementation, legume intercropping, terracing and Zai pit technologies. This shows that Radio is a crucial medium of communication that enable dissemination of agricultural knowledge and information, particularly to those who live in rural locations and are difficult to reach and may not have other sources of information accessible to them (Haruna & Ibrahim, 2024). According to Ragasa et al. (2021), radio shows enhance

the uptake of modern agriculture technologies. These initiatives provide farmers accurate knowledge regarding the advantages of adopting SFETs and the possibilities of their application. Similarly, Ango et al. (2013) observed that radio shows concerning farming guarantee knowledge and awareness of applying sustainable agricultural techniques. Radio programs thus make it possible for farmers to learn about modern technologies and how to apply them since they obtain advice of experts, success stories, and practice ideas in the language they can easily understand.

Digital media affected adoption of composting, biochar, irrigation, micronutrient supplementation, and terracing technologies. This implies that evolvement of Digital tools such as internet and mobile apps allow the farmer to quickly access real-time information, advice, and most current knowledge on farming. Farmers can thus learn how to integrate technologies such as biochar and precision irrigation in their farming systems to enhance crop production (Choruma et al., 2024). The study of Mushi et al. (2022) reported that farmers who use digital platforms have easier access to a greater spectrum of agricultural technologies and can consult professionals of diverse fields in crop management. Therefore, digital platforms let farmers access the most recent advancements in SFETs, so enabling them to make better decisions and boost its usage. However, literacy level is a major concern that needs to be addressed to improve the use of digital media (Gumbi & Twinomurinzi, 2023).

Workshops and training were significant in influencing adoption of composting, legume intercropping, crop rotation, cover cropping, irrigation, micronutrient supplementation, terracing and zai pit technologies. Through these platforms farmers are able to learn a lot and acquire practical experience, that help them feel more confident in using SFETs. Workshops and trainings can offer courses that helps farmers with better knowledge required in applying sustainable farming techniques Raji et al. (2024). The study of Hag et al. (2021) also demonstrated how formal training and workshop sessions allow farmers to acquire the necessary knowledge to apply intricate climate smart strategies in crop production. Workshops provide farmers with an opportunity to interact with professionals, exchange ideas on issues they are encountering, and learn how to implement the new strategies.

5.2.5 Effect of Extension Methods on Adoption Intensity of Soil Fertility Enhancement Technologies

Farmer field schools was positively significant in influencing adoption intensity. Previous study indicated that participatory methods offered through FFS can enable farmers improve at what they do and learn more (Berg et al., 2020). Similarly, Bakker et al. (2021) reported that field schools encouraged farmers to apply soil fertility and crop management techniques. Participating in field schools significantly enhanced farmers' capacity to make crucial decision about application of soil conservation technologies (Berg et al. 2021). However, study of Huluka et al. (2016) conflicts the findings of the study since they found that there was no linear relationship between attendance to FFS and increased adoption.

Farm visits was positive and significant in affecting adoption intensity of SFET. Farmers visit other well-developed farms where they can observe how SFET have been integrated. It thus offers a personal experience on how these techniques enhance the nutrients in the soil, water conservation, and resultant crop yields. Showing real-life situations helps to dispel uncertainty over the efficacy of SFET and increase intensity adoption. Previous research has indicated that visiting farms is a good approach to disseminate knowledge and motivate farmers to adopt sustainable farming techniques (Fabrigas et al. 2017). Additionally, Swanson and Rajalahti (2010) informed that farm visits is a practical means of disseminating new ideas and knowledge to farmers particularly on sustainable technologies. Similarly, Kumar et al. (2020) posited that farm visits foster trust and raise adoption possibilities of agriculture technologies.

Radio programs affected positively adoption intensity of SFET. Radio programs seal the literacy gaps and also act as the fastest means of communication that enhance learning in rural areas. The positive correlation indicates that farmers who have access to radio-based farming information have a good chance of intensifying adoption of SFET. This is due to the fact that farmers listen to agriculture radio broadcasts to gain advice from experts, hear success stories about other farmers, and obtain technical aid. Extant studies reveal that, radio is a device that is still relied upon in disseminating information and creating awareness especially to individuals living in remote regions (Adeye & Salawu, 2025; Sahu et al., 2024). Moreover, Musingizi et al. (2021) reveal that radio-extension helped farmers apply new agricultural technologies efficiently.

5.2.6 Farmers' Knowledge, Attitude and Perceptions on the Adoption Intensity of Soil Fertility Enhancement Technologies

Findings showed that perception on labor requirement had significant positive effect on adoption. This suggests if the amount of required labor to adopt a technology is perceived to be manageable farmers will be more inclined to apply them. During their study, the results of Mwaura et al. (2021) and Mairura et al., (2022) showed that access to labor affected adoption and intensity of uptake of soil organic amendments. Adoption of soil fertility technologies can be difficult if labor is inadequate in the farm (Jabbar et al., 2022).

Willingness to invest resources was used to judge the attitude towards adoption. The implication of this is that individuals will be reluctant to acquire a product if they are prepared to invest resources in it. This may also suggest that farmers are speculating about the actual cost of the adoption process due to concerns regarding the number of resources that would be necessary. Hence, may not likely embrace situations in which there is a perceived degree of risk regarding the return on investment. This can be linked by the returns of the technology which might take a longer period before it is realized (Kwadzo & Quayson, 2021). Similarly, farmers who perceive that soil management technologies can render positive outcome are willing to invest in it (Spurk et al., 2025).

Awareness of benefits of the technologies was associated with adoption of technologies. This indicates that farmers are prone to adopt technologies when they have a deeper understanding of the advantages linked to it. This emphasizes the important role of education and training in the context of adoption in informing farmers about the benefits, and in return impact their chances of embracing new techniques, particularly for those who are unsure of benefits. The study of Anang et al. (2021) reported that improved awareness has the potential of accelerating uptake of soil and crop management technologies.

Attitude toward access to extension services was positively significant in influencing adoption of SFET. This finding implies that training, information sharing, and farmer support are all part of extension services, which are crucial for increasing the chances of adoption. These services would certainly provide prospective information which are essential for adoption, and it can also streamline the process, making it easier for

those interested in adopting technologies to make a choice (Jabbar et al., 2022). Access to extension has been linked with influence on adoption of integrated soil management practices (Kiprotich et al., 2024; Mairura et al., 2022).

5.2.7 Influence of Knowledge, Attitudes and Perception on Adoption Intensity of Soil Fertility Enhancement Technologies

Farmers who have a broader perspective on the issue may be reticent to support the approach. To increase the number of farmers that use SFET, efforts that demonstrate the technology's benefits and how to use it can be implemented. The level of farmer technology knowledge and skill is critical in adoption and extent of adoption (Wawire et al., 2021).

Perception that SFET is cost effective significantly affected adoption intensity positively. This indicates that economic factors strongly influence farmers' decision regarding adoption. It is more probable that farmers may make the necessary effort to implement SFET in their farms as it becomes increasingly apparent that it will enhance returns. This demonstrates that the economic benefits have mutual ability to encourage adoption. A critical factor in encouraging farmer to adopt the technology more extensively and more intensively could be the demonstration of reduced expenses and long-term benefits. The study agrees with that of Meshesha et al. (2022) who emphasized that when farmers perceive a technology as cost-effective and beneficial, they are more likely to integrate it into their farming practices.

Attitude towards access to extension services was significantly positive influencing adoption intensity of SFETs. This demonstrates that the promotion of more adoption of SFET is significantly influenced by access to extension services, which often focus on training, guidance, and assistance with issues related to farming. Similarly, extension services have the potential to provide farmers with the resources, information, and confidence they need to overcome obstacles and simplify the implementation process of the technologies. This evidence emphasizes the importance of providing hands-on assistance in the process of fostering a more adoption of agricultural practices. Further, extension services facilitate the transmission of knowledge and practical assistance by establishing tangible connections with the practice, thereby increasing the likelihood of more persistent and intensified adoption. The study was in tandem with that of Nyairo et al. (2021) who highlighted that positive

attitudes towards extension services were associated with higher adoption rates of agricultural innovations among smallholder farmers.

Perception on the benefits of SFET in farming was positively significant in influencing adoption intensity. This suggest that farmers might be willing to intensify adoption of SFETs if they are aware of potential benefits. Intensity of adoption is a second phase of implementation, and when proper training and education is done farmers will be able to witness the returns and might easily intensify their use. In concurrence (Mwaura, 2021) found that farmers who strongly agreed with the benefits of organic-based soil fertility management technologies such as improved yields and soil fertility, were more likely to adopt them intensively.

5.3 Conclusions

The findings highlight the importance of integrating agricultural technologies to address the intricate challenges associated with soil fertility and overall soil health. This involves organic and environmentally-friendly farming methods which provide long-term benefits to the soil and enhanced crop yields. Therefore, simultaneous application of these methods indicates a developmental phase in agriculture where sustainability and productivity are aligned, enhancing each other rather than opposing.

While identifying commonly utilized practices among farming households and examining their underlying patterns through factor analysis the study concludes that technologies such as cover cropping, composting, mulching, Zai pit, and legume intercropping loaded on the first factor, highlighting their role in improving soil health, enhancing water retention, and supporting sustainable farming. Manure application and terracing were associated with the second factor, reflecting a focus on organic nutrient inputs and erosion control. Zero tillage defined the third factor, emphasizing the importance of minimal soil disturbance practices. The fourth factor captured the use of inorganic fertilizer, indicating a reliance on synthetic inputs for productivity.

It was noted that socio-economic factors such as sources of off farm income, participation in programs promoting SFET, informal agricultural training, education, reasons for sourcing in off farm income, farm size, limited access to agricultural information and land use contributed the most in the adoption of SFET, which implies the need to disseminate information and knowledge about the skills of seedbed

management. Adoption intensity was affected by farm size, land use, sources of off farm income and livestock size

The findings demonstrate the importance of various extension methods in influencing farmers' decisions to adopt and intensify the use of SFET and hence, the study concludes that demonstration plots had a substantial impact on the uptake of composting and Zai pit technologies, highlighting the importance of practical demonstrations in building farmers' confidence in new technologies. Farmer Field Schools (FFS) had a beneficial impact on the adoption of numerous SFETs, highlighting the value of hands-on learning experiences that integrate practical knowledge with theoretical understanding. Similarly, farm visits helped to increase the use of organic and inorganic fertilizers, irrigation, terracing, and micronutrient supplementation by giving farmers firsthand experience with effective implementations of these technologies. Radio also played a crucial role in promoting understanding and implementation of SFETs such as crop rotation, cover cropping, and intercropping by presenting expert insights in understandable formats. Digital media affected adoption of composting, biochar and irrigation and this illustrate the expanding role of technology in modern agriculture, albeit literacy barriers still exist. Additionally, workshops and training had a substantial impact on the uptake of numerous SFETs by providing farmers with important technical knowledge and chances for peer learning. Farmer field school (FFS), farm visits, and radio programs was significant in influencing adoption intensity of SFET.

Further, perception of labor requirements, willingness to invest resources, awareness of SFET benefits, and attitude toward access to extension services were found to influence adoption of the technologies. Perceived benefits, perceived cost-effectiveness, and access to extension services were found to influence the adoption intensity of Soil Fertility Enhancement Technologies (SFET).

5.4 Recommendations

Policy makers and agricultural extension service providers should to prioritize the provision of training and resources that enable farmers to adopt technologies that enhance and sustain soil fertility. This is possible if farmers are provided with education, access to sustainable and affordable farming inputs, and development of support systems for practices such as mulching, composting, and terracing. Further,

policy makers should promote use of integrated soil fertility management, which employs a balanced combination of organic and inorganic methods, which is essential for enhancing crop production and maintaining good soil health.

The targeted capacity-building programs should be set up to enhance farmers' knowledge and understanding of SFETs. These programs should focus on practical training, demonstrations, and farmer-to-farmer extension approaches to address the knowledge gaps that hinder adoption. Moreover, agricultural extension services should be strengthened to provide consistent support and tailored services, especially in areas prone to erratic weather conditions.

To achieve full-scale adoption, policies should ensure access to intensified training programs, improvement in the dissemination of knowledge, better land management promotion, and integration of SFET into diversified farming systems. Besides, targeted interventions that address income diversification and maximum exploitation of farm size will further increase the level of adoption to ensure sustained agriculture and livelihoods.

Agricultural extension programs should be centered in promoting practical, engaging, and easily accessible information-dissemination approaches which comprise of demonstration plots, farm visits, and field schools. To fully realize the potential of digital technologies, investments in them must be combined with literacy training. Scaling up radio-based farming initiatives and connecting them with digital technologies can improve farmers' access to real-time expert guidance. Similarly, training sessions and seminars should be expanded to provide farmers with the most recent information and confidence in deploying SFETs to improve sustainable crop production.

To enhance the adoption and adoption intensity of Soil Fertility Enhancement Technologies (SFET), it is essential to design labor-efficient technologies to address farmers' concerns about the labor requirements. Additionally, reducing the perceived cost barriers through financial support, subsidies, or demonstrating long-term financial benefits will encourage investment in SFETs. Increasing awareness of the technologies' advantages, particularly through targeted education and extension programs, will also foster greater adoption. Strengthening access to agricultural

extension services is crucial, as these services provide the necessary training, support, and information for effective implementation.

REFERENCES

AbdelRahman, M. A. (2023). An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications. *Rendiconti Lincei. Scienze Fisiche e Naturali*, *34*(3), 767-808.

Addison, M., Anyomi, B. K., Acheampong, P. P., Wongnaa, C. A., & Amaning, T. K. (2023). Key drivers of adoption intensity of selected improved rice technologies in rural Ghana. *Scientific African*, *19*, e01544.

Ajwera, F., Ayaga, G., Kersting, D., Mudavadi, P., Manyengo, J., Mulielie, C., Khasakhala,E. D., Cheboi, P., Mukhwana, D., Ajwera, F., Ayaga, G., Kersting, D., Mudavadi,P., Manyengo, J., Mulielie, C., Khasakhala, E. D., Cheboi, P., & Mukhwana, D.(2024). *Protection and Rehabilitation of Degraded Soils in Western Kenya:Experiences from Two Decades of Research and Development*. IntechOpen.https://doi.org/10.5772/intechopen.113977

Akça, E., Nagano, T., Kume, T., Zucca, C., & Kapur, S. (2022). Traditional land use systems' potential as the framework for soil organic carbon plans and policies. In *Plans and policies for soil organic carbon management in agriculture* (pp. 59-93). Singapore: Springer Nature Singapore.

Akinbode, S. O., Folorunso, O., Olutoberu, T. S., Olowokere, F. A., Adebayo, M., Azeez, S. O., ... & Busari, M. A. (2024). Farmers' Perception and Practice of Soil Fertility Management and Conservation in the Era of Digital Soil Information Systems in Southwest Nigeria. *Agriculture*, *14*(7), 1182.

Akouwerabou, D. B., Zanré, P. K., Savadogo, K., & Kaboré, P. J. (2022). Promoting farmers' adoption of climate-smart agricultural technologies in Burkina Faso: the role of coordination along the value chain. *International Journal of Agricultural Resources, Governance and Ecology*, *18*(3), 287-308.

Albaladejo, J., Díaz-Pereira, E., & de Vente, J. (2021). Eco-holistic soil conservation to support land degradation neutrality and the sustainable development goals. *Catena*, *196*, 104823.

Al-Tawaha, A. R. M., Günal, H., Křeček, J., Zamfir, R. H. C., Patel, H. K., Vyas, R. V., ... & Al-Ramamneh, E. A. D. (2021). Soil fertility decline under climate change. In *Sustainable Soil and Land Management and Climate Change* (pp. 127-145). CRC Press.

Angon, P. B., Anjum, N., Akter, M. M., KC, S., Suma, R. P., & Jannat, S. (2023). An overview of the impact of tillage and cropping systems on soil health in agricultural practices. *Advances in Agriculture*, *2023*(1), 8861216.

Anne Vlassopoulos, C. (2012). Competing definition of climate change and the post-Kyoto negotiations. *International Journal of Climate Change Strategies and Management*, *4*(1), 104-118.

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, *32*, 100304

Bakri, S., Yuwono, S. D., Sulistiowati, R., Septyastuti, S., Nurhaida, I., & Kurniasari, N. (2024). can the application of agroforestry at monocultural food crop areas support manufacturer chemical fertilizer reduction programs without sacrificing farmers'income? *The American Journal of Social Science and Education Innovations*, *6*(05), 101-114.

Bolinder, M. A., Crotty, F., Elsen, A., Frac, M., Kismányoky, T., Lipiec, J., ... & Kätterer, T. (2020). The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: a synthesis of reviews. *Mitigation and Adaptation Strategies for Global Change*, *25*, 929-952.

Chavula, P., & Turyasingura, B. (2022). Land Tenurial system influence among smallholder farmers' climate smart agriculture technologies adoption, Sub-Sahara Africa: a review paper. *International Journal of Food Science and Agriculture*, *6*(1).

Chen, Z. D., & Chen, F. (2022). Socio-economic factors influencing the adoption of low carbon technologies under rice production systems in China. *Carbon Balance and Management*, *17*(1), 19.

Cyamweshi, R. A., Nabahungu, N. L., Mukashema, A., Ruganzu, V., Gatarayiha, M. C., Nduwumuremyi, A., & Mbonigaba, J. J. (2014). Enhancing nutrient availability and coffee yield on acid soils of the central plateau of southern Rwanda. *Global Journal of Agricultural Research*, *2*(2), 44-55.

Das, S. (2022). The role of radio and television in the dissemination of agricultural technologies among farmers of Bangladesh. *Bangladesh Journal of Agriculture*, *44-46: 55-64*, 55–64. https://doi.org/10.3329/bjagri.v46i1-6.59974

Davis, F. D. (1993). User acceptance of information technology: system characteristics, user perceptions and behavioral impacts. *International journal of man-machine studies*, *38*(3), 475-487.

Degaga, J., Alemu, G., & Angasu, B. (2020). Factors affecting adoption of improved haricot bean (Phaseolus Vulagris L) technology in West Hararghe zone of Oromia region, Ethiopia: A Heckman two-step approach.

Dimkpa, C., Adzawla, W., Pandey, R., Atakora, W. K., Kouame, A. K., Jemo, M., & Bindraban, P. S. (2023). Fertilizers for food and nutrition security in sub-Saharan Africa: an overview of soil health implications. *Frontiers in Soil Science*, *3*, 1123931.

Dominguez, C. (2023). Emerging concepts in plant breeding and their use for the design of seed delivery and dissemination strategies: a systematic review.

Ebhuoma, E. E. (2022). Factors undermining the use of seasonal climate forecasts among farmers in South Africa and Zimbabwe: implications for the 1st and 2nd sustainable development goals. *Frontiers in Sustainable Food Systems*, *6*, 761195.

Eze, S., Dougill, A. J., Banwart, S. A., Sallu, S. M., Mgohele, R. N., & Senkoro, C. J. (2022). Assessing soil system changes under climate-smart agriculture via farmers' observations and conventional soil testing. *Land Degradation & Development*, *33*(14), 2635-2646.

Fadeyi, O. A., Ariyawardana, A., & Aziz, A. A. (2022). Factors influencing technology adoption among smallholder farmers: a systematic review in Africa

Ferreira, C. S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. *Science of the Total Environment*, *805*, 150106.

Gebrehiwot, K. G. (2023). The impact of agricultural extension on farmers' technical efficiencies in Ethiopia: A stochastic production frontier approach. *South African Journal of Economic and Management Sciences*, *20*(1), 1-8.

Gebremariam, Y. A., Dessein, J., Wondimagegnhu, B. A., Breusers, M., Lenaerts, L., Adgo, E., ... & Nyssen, J. (2021). Determinants of farmers' level of interaction with agricultural extension agencies in northwest Ethiopia. *Sustainability*, *13*(6), 3447.

Gemtou, M., Kakkavou, K., Anastasiou, E., Fountas, S., Pedersen, S. M., Isakhanyan, G., ... & Pazos-Vidal, S. (2024). Farmers' transition to climate-smart agriculture: A systematic review of the decision-making factors affecting adoption. *Sustainability*, *16*(7), 2828.

Girma Asefa, Y., & Ayalew Muluken, A. (2024). Land size and efficiency in agriculture: The case of Ethiopian smallholder farmers. A meta-analysis. *Frontiers in Sustainable Food Systems*, *8*, 1447186

Hamazakaza, P., Kabwe, G., Kuntashula, E., Egeru, A., & Asiimwe, R. (2022). Adoption of sustainable agriculture intensification in maize-based farming systems of Katete District in Zambia. *Land*, *11*(6), 880

Hameed, T. S., & Sawicka, B. (2023). role of agricultural extension in adoption of sustainable agriculture practices. *Anbar Journal of Agricultural Sciences*, *21*(1).

Haruna, L. Z., Sennuga, S. O., Bamidele, J., Bankole, O. L., Alabuja, F. O., Preyor, T. J., & Barnabas, T. M. (2023). factors influencing farmers' adoption of improved technologies in Maize Production in Kuje Area Council of FCT-Abuja, Nigeria. *GPH-International Journal of Agriculture and Research*, *6*(04), 25-41.

Hu, Y., Li, B., Zhang, Z., & Wang, J. (2022). Farm size and agricultural technology progress: Evidence from China. *Journal of Rural Studies*, *93*, 417-429.

Ingutia, R., & Sumelius, J. (2022). Determinants of food security status with reference to women farmers in rural Kenya. *Scientific African*, *15*, e01114.

Irmak, S. (2023). Agriculture and Agricultural Water Management: Historical Perspectives and Integration of Research and Extension/Outreach for Large-Scale Technology Adoption in Production Fields. *Journal of the ASABE*, *66*(1), 167-192.

Jabbar, A., Liu, W., Wang, Y., Zhang, J., Wu, Q., & Peng, J. (2022). Adoption and impact of integrated soil fertility management technology on food production. *Agronomy*, *12*(10), 2261.

Javed, A., Ali, E., Afzal, K. B., Osman, A., & Riaz, S. (2022). Soil fertility: Factors affecting soil fertility, and biodiversity responsible for soil fertility. *International Journal of Plant, Animal and Environmental Sciences*, *12*(1), 21–33.

Jones-Garcia, E., & Krishna, V. V. (2021). Farmer adoption of sustainable intensification technologies in the maize systems of the Global South. A review. *Agronomy for Sustainable Development*, *41*(1), 8.

Kamakaula, Y., & Fenetiruma, O. A. (2024). Knowledge-Based Approaches to Adaptive Agriculture: An Ethnoecological Case Study of Indigenous Communities in Climate Change Adaptation. *Agro Bali: Agricultural Journal*, *7*(3), 916-930.

Karume, K., Mondo, J. M., & Kiyala, J. C. K. (2024). Drought, the War in Europe and Its Impacts on Food Insecurity in Sub-Saharan Africa, East Africa. *Climate Change and Socio-political Violence in Sub-Saharan Africa in the Anthropocene: Perspectives from Peace Ecology and Sustainable Development*, 91-111.

Kassem, H. S., Alotaibi, B. A., Muddassir, M., & Herab, A. (2021). Factors influencing farmers' satisfaction with the quality of agricultural extension services. *Evaluation and Program Planning*, *85*, 101912.

Kebenei, M. C., & Mucheru-Muna, M. (2023). The potential of Zai pit technology and Integrated soil fertility management to enhance crop productivity in semi-arid regions of Sub-Sahara Africa: A review. *International Journal of Environment, Agriculture and Biotechnology*, *8*(1).

KENYA, V. B. O. (2024). *CAN SORGHUM BECOME THE NEW MAIZE (AGAIN)?* (Doctoral dissertation, Ghent University).

Khader, A. (2024). Challenges, barriers, and determinants of farmers' adoption of agroecological practices in Tunisia*: A Case study of Hamam biadha and Elles* (Doctoral dissertation).

Kipkogei, S., Han, J., Mwalupaso, G., Tanui, J., & Brenya, R. (2025). The synergistic effects of microcredit access and agricultural technology adoption on maize farmer's income in Kenya. *PLoS One*, *20*(1), e0316014.

Kiprotich, S., Mogaka, H., Ndirangu, S. N., & Onyari, C. N. (2024). Determinants of adoption and adoption intensity of integrated soil fertility management technologies among sorghum farmers in Upper Eastern Kenya. *Soil Use and Management*, *40*(1), e12958.

Kogo, B. K., Kumar, L., & Koech, R. (2021). Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, development and sustainability*, *23*(1), 23-43.

Kom, Z., Nethengwe, N. S., Mpandeli, N. S., & Chikoore, H. (2022). Determinants of small-scale farmers' choice and adaptive strategies in response to climatic shocks in Vhembe District, South Africa. *GeoJournal*, *87*(2), 677-700.

Kothari, C. R. (2004). Research Methodology: Methods and Techniques. New Age International.

Lampach, N., To-The, N., & Nguyen-Anh, T. (2021). Technical efficiency and the adoption of multiple agricultural technologies in the mountainous areas of Northern Vietnam. *Land use policy*, *103*, 105289.

Lee, Y. C., Dervishi, I., Mousa, S., Safiullin, K. I., Ruban-Lazareva, N. V., Kosov, M. E., ... & Elyakova, I. D. (2023). Sustainable development adoption in the high-tech sector: A focus on ecosystem players and their influence. *Sustainability*, *15*(18), 13674.

Lesthaeghe, R. J. (Ed.). (2023). Reproduction and social organization in sub-Saharan Africa. Univ of California Press.

Li, C., Li, X., & Jia, W. (2022). Non-Farm Employment Experience, Risk Preferences, and Low-Carbon Agricultural Technology Adoption: Evidence from 1843 Grain Farmers in 14 Provinces in China. *Agriculture*, *13*(1), 24.

Mahamood, A. F., Mohammed, R., Ahmad, M. K., Ridzuan, A. H., Hamzah, M. R., Abdullah, S., & Shaffril, H. A. (2016). Applying diffusion of innovation theory and unified theory of acceptance and use of technology (UTAUT) on farmers' use of communication technology. *Journal of Human Development and Communication (JoHDEC)*, *5*, 27-40.

Mahmud, A. A., Upadhyay, S. K., Srivastava, A. K., & Bhojiya, A. A. (2021). Biofertilizers: A Nexus between soil fertility and crop productivity under abiotic stress. *Current Research in Environmental Sustainability*, *3*, 100063.

Maina, W. N. (2020). Factors affecting the adoption of soil organic carbon enhancement technologies and their spatial distribution among small-scale farmers in Kenya and Ethiopia (Doctoral dissertation, University of Nairobi).

Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., ... & Ngetich, F. K. (2022). Farm factors influencing soil fertility management patterns in Upper Eastern Kenya. *Environmental Challenges*, *6*, 100409.

Mapiye, O., Makombe, G., Molotsi, A., Dzama, K., & Mapiye, C. (2021). Towards a revolutionized agricultural extension system for the sustainability of smallholder livestock production in developing countries: The potential role of icts. *Sustainability*, *13*(11), 5868.

Martey, E., & Kuwornu, J. K. (2021). Perceptions of climate variability and soil fertility management choices among smallholder farmers in northern Ghana. *Ecological Economics*, *180*, 106870.

Maru, B., Maryo, M., & Kassa, G. (2022). Socio-economic determinants of crop diversity in Bule Hora Woreda, Southern Ethiopia. *Heliyon*, *8*(5).

Masango, C. A., & Mbarika, V. W. (2022). Indigenous knowledge application in increasing food security: A measure to consider? *Inkanyiso*, *14*(1), 10.

Masere, T. P., & Worth, S. H. (2022). Factors influencing adoption, innovation of new technology and decision-making by small-scale resource constrained farmers: The perspective of farmers in lower Gweru, Zimbabwe. *African Journal of Food, Agriculture, Nutrition and Development*, *22*(3), 20013-20035

Mashi, S. A., Inkani, A. I., & Oghenejabor, O. D. (2022). Determinants of awareness levels of climate smart agricultural technologies and practices of urban farmers in Kuje, Abuja, Nigeria. *Technology in Society*, *70*, 102030.

Maulu, S., Hasimuna, O. J., Mutale, B., Mphande, J., & Siankwilimba, E. (2021). Enhancing the role of rural agricultural extension programs in poverty alleviation: A review. *Cogent Food & Agriculture*, *7*(1), 1886663.

Maynard, J. J., Yeboah, E., Owusu, S., Buenemann, M., Neff, J. C., & Herrick, J. E. (2023). Accuracy of regional-to-global soil maps for on-farm decision-making: are soil maps "good enough". *Soil*, *9*(1), 277-300.

McCormack, M., Buckley, C., & Kelly, E. (2022). Using a Technology Acceptance Model to investigate what factors influence farmer adoption of a nutrient management plan. *Irish Journal of Agricultural and Food Research*, *60*(1), 142-151.

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W., & Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International journal of agricultural sustainability*, *13*(1), 40-54.

Mertler, C. A., Vannatta, R. A., & LaVenia, K. N. (2021). Advanced and multivariate statistical methods*: Practical application and interpretation*. Routledge.

Mganga, K. Z. (2022). Agricultural Land Degradation in Kenya. In *Impact of Agriculture on Soil Degradation I: Perspectives from Africa, Asia, America and Oceania* (pp. 273-300). Cham: Springer International Publishing.

Mogaka, B. O., Bett, H. K., & Karanja Ng'ang'a, S. (2021). Socioeconomic factors influencing the choice of climate-smart soil practices among farmers in western Kenya. *Journal of Agriculture and Food Research*, *5*, 100168.

Molina-Maturano, J., Verhulst, N., Tur-Cardona, J., Güereña, D. T., Gardeazábal-Monsalve, A., Govaerts, B., & Speelman, S. (2021). Understanding smallholder farmers' intention to adopt agricultural apps: The role of mastery approach and innovation hubs in Mexico. *Agronomy*, *11*(2), 194.

Mugenda, O. M., & Mugenda, A. G. (2003). Research methods: Quantitative & qualitative approaches (Vol. 2, No. 2). Nairobi: Acts press.

Muriithi, L. N. (2021). Adoption of Selected Climate Smart Agriculture Technologies among Smallholder Farmers in Lower Eastern Kenya (Doctoral dissertation, University of Embu).

Musafiri, C. M., Kiboi, M., Macharia, J., Ng'etich, O. K., Kosgei, D. K., Mulianga, B., Okoti, M., & Ngetich, F. K. (2022). Adoption of climate-smart agricultural

practices among smallholder farmers in Western Kenya: Do socioeconomic, institutional, and biophysical factors matter? *Heliyon*, *8*(1), e08677. https://doi.org/10.1016/j.heliyon.2021.e08677

Mwaura, G. G., Kiboi, M. N., Bett, E. K., Mugwe, J. N., Muriuki, A., Nicolay, G., & Ngetich, F. K. (2021). Adoption Intensity of Selected Organic-Based Soil Fertility Management Technologies in the Central Highlands of Kenya. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.570190

Mwinuka, L., & Hyera, E. O. (2022). Effect of socio-cultural factors on gendered decision-making in the adoption of improved maize storage technologies. *Cogent Food & Agriculture*, *8*(1), 2132849.

Nakashima, K., Yanagihara, S., Muranaka, S., & Oya, T. (2022). Development of sustainable technologies to increase agricultural productivity and improve food security in Africa. *Japan Agricultural Research Quarterly: JARQ*, *56*(1), 7-18. Olatunde OA, Peter OF, Oluseye OO, Olatunji AR. Determinants of Soybean Farmers' adoption of green revolution technologies in Oyo State. Nigeria J Dev Areas. 2021;55(3):365–76.

Ndegwa, J. K., Gichimu, B. M., Mugwe, J. N., Mucheru-Muna, M., & Njiru, D. M. (2023). Integrated soil fertility and water management practices for enhanced agricultural productivity. *International Journal of Agronomy*, *2023*.

Nettle, R., Major, J., Turner, L., & Harris, J. (2022). Selecting methods of agricultural extension to support diverse adoption pathways: a review and case studies. *Animal Production Science*, *64*(1), NULL-NULL.

Ngaiwi, M. E., Molua, E. L., Sonwa, D. J., Meliko, M. O., Bomdzele, E. J., Ayuk, J. E., ... & Latala, M. M. (2023). Do farmers' socioeconomic status determine the adoption of conservation agriculture? Empirical evidence from Eastern and Southern Regions of Cameroon. *Scientific African*, *19*, e01498.

Nguyen, L. L. H., Khuu, D. T., Halibas, A., & Nguyen, T. Q. (2024). Factors that influence the intention of smallholder rice farmers to adopt cleaner production practices: An empirical study of precision agriculture adoption. Evaluation fReview, 48(4), 692-735.

Nshakira-Rukundo, E., Tabe-Ojong Jr, M. P., Gebrekidan, B. H., Agaba, M., Surendran-Padmaja, S., & Dhebibi, B. (2023). Adoption and impacts of agricultural technologies and sustainable natural resource management practices in fragile and conflict affected settings: A review and meta-analysis.

Ntuli, N. C. (2023). Adaptation strategies against drought: The case of rain-fed subsistence crop farmers in Mphego village in the Vhembe District of Limpopo province, South Africa.

Ozkan, B., Dube, A. K., & Reed, M. R. (2022). Role of agricultural extension in building climate resilience of food security in Ethiopia. In *Food Security and Climate-Smart Food Systems: Building Resilience for the Global South* (pp. 219-239). Cham: Springer International Publishing.

Pandeya, S., Gyawali, B. R., & Upadhaya, S. (2025). Factors influencing precision agriculture technology adoption among small-scale farmers in Kentucky and their implications for policy and practice. *Agriculture*, *15*(2), 177.

Rafael, B. M. (2023). The importance of agricultural development projects: a focus on sustenance and employment creation in Kenya, Malawi, Namibia, Rwanda, and Uganda. *Journal of Agricultural Chemistry and Environment*, *12*(2), 152-170.

Rezaei, M., Sadraei, R., Jafari-Sadeghi, V., & Vrontis, D. (2023). Knowledge is of no value unless to be shared. A synthesis of knowledge-sharing drivers in born-globals. *Asia Pacific Journal of Management*, 1-31.

Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. In *An integrated approach to communication theory and research* (pp. 432-448). Routledge.

Ruzzante, S., Labarta, R., & Bilton, A. (2021). Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. *World Development*, *146*, 105599.

Sargani, G. R., Shen, Y., Liu, Y., Joyo, M. A., Liu, J., Jiang, Y., & Zhang, H. (2023). Farm risks, livelihood asset allocation, and adaptation practices in response to climate change: a cross-country analysis. *Frontiers in Environmental Science*, *10*, 1066937.

Shaheb, M. R., Sarker, A., & Shearer, S. A. (2022). Precision agriculture for sustainable soil and crop management. In *Soil Science-Emerging Technologies, Global Perspectives and Applications*. IntechOpen.

Shams Vala, A., Moosavi, S. S., & Jafari Baghiabadi, S. (2022, December 30). Effective Knowledge Transfer*: Application of the Media Richness Theory* (Journal Article (Paginated) 2). Informology; Informology Center. http://eprints.rclis.org/44365/

Souri, Z., Khanna, K., Karimi, N., & Ahmad, P. (2021). Silicon and plants: current knowledge and future prospects. *Journal of Plant Growth Regulation*, *40*, 906-925.

Spurk, C., Koch, C., Bürgin, R., Chikopela, L., Konaté, F., Nyabuga, G., ... & Fliessbach, A. (2025). Farmers' innovativeness and positive affirmation as main drivers of adoption of soil fertility management practices–evidence across sites in Africa. *The Journal of Agricultural Education and Extension*, 1-25.

Sseguya, H., Robinson, D. S., Mwango, H. R., Flock, J. A., Manda, J., Abed, R., & Mruma, S. O. (2021). The impact of demonstration plots on improved agricultural input purchase in Tanzania: Implications for policy and practice. *Plos one*, *16*(1), e0243896.

Suh, K. S. (1999). Impact of communication medium on task performance and satisfaction: an examination of media-richness theory. *Information & Management*, *35*(5), 295-312.

Sujakhu, N. M., Ranjitkar, S., Su, Y., He, J., & Xu, J. (2023). A gendered perspective on climate change adaptation strategies: a case study from Yunnan, China. *Local Environment*, *28*(1), 117-133.

Suri, T., & Udry, C. (2022). Agricultural technology in Africa. *Journal of Economic Perspectives*, *36*(1), 33-56.

Tessema, B. T. (2024). Assessing the uptake of sustainable land management programs towards improved land management, tenure security, food security, and agricultural production: Evidence from South Wello, Ethiopia.

Teye, E. S., & Quarshie, P. T. (2022). Impact of agricultural finance on technology adoption, agricultural productivity and rural household economic wellbeing in Ghana: a case study of rice farmers in Shai-Osudoku District. *South African Geographical Journal*, *104*(2), 231-250.

Tindwa, H. J., Semu, E. W., & Singh, B. R. (2024). Circular Regenerative Agricultural Practices in Africa: Techniques and Their Potential for Soil Restoration and Sustainable Food Production. *Agronomy*, *14*(10), 2423.

Tufa, A. H., Alene, A. D., Cole, S. M., Manda, J., Feleke, S., Abdoulaye, T., ... & Manyong, V. (2022). Gender differences in technology adoption and agricultural productivity: Evidence from Malawi. *World Development*, *159*, 106027.

Varshney, D., Joshi, P. K., Kumar, A., Mishra, A. K., & Dubey, S. K. (2022). Examining the transfer of knowledge and training to smallholders in India: Direct and spillover effects of agricultural advisory services in an emerging economy. *World Development*, *160*, 106067.

Wawire, A. W., Csorba, Á., Kovács, E., Mairura, F. S., Tóth, J. A., & Michéli, E. (2021). Comparing farmers' soil fertility knowledge systems and scientific assessment in Upper Eastern Kenya. *Geoderma*, *396*, 115090.

Weeraratna, S. (2022). Effects of Land Degradation. In *Understanding Land Degradation: An Overview* (pp. 23-38). Cham: Springer International Publishing.

Witinok-Huber, R., Radil, S., Sarathchandra, D., & Nyaplue-Daywhea, C. (2021). Gender, place, and agricultural extension: a mixed-methods approach to understand farmer needs in Liberia. *The Journal of Agricultural Education and Extension*, *27*(4), 553-572.

Wordofa, M. G., Hassen, J. Y., Endris, G. S., Aweke, C. S., Moges, D. K., & Rorisa, D. T. (2021). Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. *Agriculture & Food Security*, *10*, 1-12.

Wudil, A. H., Usman, M., Rosak-Szyrocka, J., Pilař, L., & Boye, M. (2022). Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). *International Journal of environmental research and Public Health*, *19*(22), 14836.

Yekinni, O. T., & Afolabi, C. O. (2019). Farmers' Assessment of the Effectiveness of Extension Communication Methods Used in Ogbomoso Agricultural Zone of

Oyo-State, Nigeria. *Journal of Agricultural Extension, 23*(3), Article 3.https://doi.org/10.4314/jae.v23i3.11

Yu, P., Fennell, S., Chen, Y., Liu, H., Xu, L., Pan, J., ... & Gu, S. (2022). Positive impacts of farmland fragmentation on agricultural production efficiency in Qilu Lake watershed: Implications for appropriate scale management. *Land Use Policy, 117*, 106108.

APPENDICES

Appendix 1: Operationalizing the Study Variables

This table shows study variables, descriptions, measurements and expected signs. Positive effect is indicated by (+) and negative effect indicated by (-)

Variable	Description	Measurement	Expected sign
Gender	Sex of respondent	1=male 2=female	+
Household size	No. of family members	categorical	+
Income	Proportion of income	In KES	+
Education	Farmers level of education	categorical	+
Farm size	Number of hectares	categorical	+
Age	Age of farmer.	In years	+/-
Land ownership	Possession of the land	1=yes 2=no	+
Extension services	Access to extension services	Frequency	+
Farmers occupation	Farmers occupation	1=farming, 2=others	+
External labour	Assess to external labour	1=yes 2=no	+
Farmers experience	Experience of the farmer	In years	+
Livestock	Number of cattle	1=yes, 2=no	+
Agricultural group membership	Access, types, information, prices, distance, perception	1=yes 2=no	+/-
Title deed	Possession of tittle deed	1=yes 2=no	+
Effectiveness	Availability, accessibility, reliability	Likert scale 1 to 5	+
Training	Soil fertility enhancement training	1=yes 2=no	+

Appendix 2: Study area

Study area	**Makueni County**
Approximate total area	8,176.7 km2
Approximate number of fa rmers	300,000
Rainfall	Bimodal rainfall 300-400 mm annually
Temperature	18°C - 24°C
Longitude	37o10’E and 38030’E
Latitudes	1035’S and 3o00S
Soil	Primarily sandy and generally low in organic matte r
Crops	Maize, beans, green grams, cowpeas, mangoes, and vegetables
Main economic activity	Subsistence farming

Appendix 3: Questionnaire

DEMOGRAPHIC CHARACTERISTICS

SECTION A

SOCIO-ECONOMIC INFORMATION

A1	Gender	1=Male 0=Female
A2	What is your age in years?	…….. (Years)
A3	What is your marital status?	1=Single 2=Married 3=Widowed 4=Divorced 5= Separated
A4	What is your highest education level?	1=Never attended school 2=Primary, 3=Secondary 4=College, 5=University
A5	Household size?	….……(Number)
A6	What is your main occupation?	1=Farming, 2=Self-employed, 3=Government employee 4=Retired, 5=Other-specify
A7	What is your average income per month? (KES)	……. (KES)
A8	Do you have any sources of income other than farming?	1=Yes, 2=No
A8.1	If yes, what are the sources of your off-farm income?	1=Employment, 2=Small business, 3=Money from family members, 4=Others (specify)
A8.2	What is your average off-farm income per month? (KES)	……. (KES)
A8.3	Why do you engage in off-farm income activities?	1=To supplement my farming income, 2=To manage financial risks associated with farming, 3=Due to insufficient income from farming alone, 4=To support household expenses, such as education and healthcare, 5=To save or invest for future needs 6=Others (specify)
A9	How many years have you been farming?	……. (Years)
A10	What is the size of your farm?	……. (Acres)
A10.1	What size of land is under cultivation?	……. (Acres)
A10.2	What is your livestock size?	….……(Number)
A11	What is the type of ownership of your land?	1=Communal, 2=Rented/Leased, 3=Own, 4=Family, 5=Other-specify

A11.1	How do you use your land?	1=Food crop cultivation, 2=cash-crop cultivation, 3= grazing, 4=woodlot, 5=bushes
A11.1.1	What proportion of your land is allocated to each use in acres	1=Food crop cultivation ……(Acres) 2=Cash-crop cultivation……(Acres) 3= Pasture/grazing ……. (Acres) 4=Woodlot …….. (Acres) 5=Bushes……. (Acres)
A12	What is the source of labor for your farm?	1=Family, 2=Hired, 3=Other-specify
A12.1	What proportion of the total labor used on your farm comes from each source	1=Family……. (percentage) 2=Hired……. (percentage) 3=Other-specify ….……(percentage)
A13	Are you aware of any Soil fertility enhancement technologies?	1=Yes 0=No
A13.1	If YES, which ones?	1=Composting, 2=Manure application, 3=Biochar, 4=Synthetic fertilizer, 5=Micro nutrient supplements, 6=Crop rotation, 7=Cover cropping, 8=Mulching, 9=Drip irrigation with fertilization, 10=Agroforestry, 11=Minimum tillage, 12=No till farming, 13=Soil testing and mapping, 14=Variable rate technology, 15=Remote sensing and drones, 16=Legume integration in crop system,17=Crop residue incorporation, 18=Zai pit, 19=Terracing, 20=Contour Farming
A13.2	How did you learn about SFET?	1=Radio, 2=Fellow farmers, 3=mobile application ,4=farmers group,5=Others (specify)
A13.3	If no, why?	1=Limited access to information, 2=Lack of exposure to training or demonstrations, 3=Lack of interest,4=Others (specify)
A14	Do you have any farming-related skills or technical know-how in SEFT?	1=Yes ,2=No
A14.1	If yes, what farming-related skills or technical know-how do you possess?	1=Experience on use of SFET, 2=Informal training, 3=Formal short courses or workshops, 4=Degree or diploma in agriculture,5= Others (specify)
A15	Have you ever participated in any	1=Yes ,2=No

	training programs related to soil fertility enhancement?	
A15.1	If yes, which kind of training?	1= Crop management, 2= Soil and water conservation, 3=Climate-smart agriculture, 4=Organic farming, 5=Others-specify
A15.2	What was the source of the training program?	1 = Ministry of Agriculture or other government institutions, 2 = Non-Governmental Organizations (NGOs), 3 = Private companies, 4 = Community-based organizations (CBOs), 5 = Development partners (e.g., UN agencies, international development programs), 6 = Farmer groups or cooperatives, 7 = Academic institutions (e.g., universities, colleges, research institutions), 8 = Others (specify).
A15.3	If not, why?	1= Lack of awareness, 2=Training programs are conducted too far from my location, 3= Cost of attending training programs is high, 4=I doubt the usefulness of these training programs, 5=Others (specify)
A15.4	Was the training received in A15.1 relevant in improving soil fertility and water management?	1=Yes, 2=No
A15.5	If yes, how relevant was it?	1=Very relevant, 2=Moderately relevant, 3=Slightly relevant, 4=Not relevant, 5=Outdated or irrelevant information, 5=Others (specify)
A15.6	If not, why?	1=Topics that did not address the specific soil and water challenges I face, 2=Lack of practical application, 3=Inadequate follow-up support, 4=Others(specify)
A16	Are you aware of credit facilities?	1=Yes, 2=No
A16.1	Do you have access to credit sources?	1=Yes, 2=No
A16.2	If yes, which ones?	1=Banks, 2=Sacco, 3=Farmer cooperatives, 4=Table banking, 5=Other-specify
A16.3	If No, why?	1=High interest rates, 2=Lack of collateral 3=Lack of awareness about available credit options 4=Other-specify

A16.4	How much credit did you receive for the last one year?	……. (KES)
A16.5	How much of the credit received have you allocated to improving soil fertility?	……. (KES)
A16.6	Did you face any challenges when accessing credit facilities?	1=Yes,2=No
A16.7	If yes, which challenges?	1=Lack of nearby financial institutions, 2=Lack of financial literacy, 3=Short repayment periods ,4=Unfavorable loan terms, 5=Other-specify
A16.8	Do you receive farm incentives?	1=Yes, 2=No
A16.9	If yes, which kind of farm incentives do you receive?	1=Fertilizers, 2=Agro chemicals, 3=Planting materials, 4=Storage equipment, 5= Others (specify)
A16.10	If no, why?	1=Lack of information, 2=Am not am registered member, 3=Long distance, 4=others (specify)
A16.11	What is the source of the farm incentives?	1 = Government programs, 2 = Non-Governmental Organizations (NGOs), 3 = Farmer cooperatives or associations, 4 = Private companies, 5 = Community-based organizations (CBOs).

SECTION B: INFORMATION ON FARMER'S KNOWLEDGE, ATTITUDE AND PERCEPTIONS ON THE ADOPTION OF SFET

1. To what extent are you informed about the specific types of soil fertility enhancement technologies available in your area**?**

1=To a very large extent, 2=Large extent, 3=Moderate extent, 4=Low extent, 5=Very low extent

2. To what extent do you understand the benefits of using soil fertility enhancements for improving soil fertility? 1= To a very large extent, 2= Large extent, 3=Moderate extent, 4=Low extent, 5=Very low extent
3. To what extent do you understand how to implement soil fertility enhancement technologies on your farm? 1= To a very large extent, 2= Large extent, 3=Moderate extent, 4=Low extent, 5=Very low extent
4. How willing are you to adopt soil fertility enhancement technologies on your farm? 1= Very willing, 2=Willing, 3=Neutral, 4=Unwilling, 5= Very unwilling
5. To what extent do you believe soil fertility enhancement technologies improve crop yields and productivity? 1= To a very large extent, 2= Large extent, 3=Moderate extent, 4=Low extent, 5=Very low extent
6. To what extent do you believe soil fertility enhancement technologies promote sustainable farming practices? 1= To a very large extent, 2= Large extent, 3=Moderate extent, 4=Low extent, 5=Very low extent
7. To what extent do you believe lack of training or knowledge is a challenge in adopting Soil fertility enhancement technologies? 1 =Very large extent, 2= Large extent, 3=Moderate extent, 4=Low extent, 5=Very low extent
8. If very low extent why? …….
9. How willing are you to invest resources (time, money, and labor) in adopting soil fertility enhancement technologies? 1=Very willing, 2=Willing, 3=Neutral, 4=Unwilling, 5 = Very unwilling
10. How accessible is information on soil fertility enhancement technologies in your area? 1=Highly accessible, 2=large extent, 3=Moderate extent, 4=Low extent, 2=Very low extent
11. Which of these technologies do you consider as the most effective? 1=Composting, 2=Crop rotation, 3=Manure application, 4=Minimum tillage, 5=Others (select all that apply.
12. How often do you use soil fertility enhancement technologies? 1=once a week 2=once a fortnight, 3=once a month, 4=once a year, 5=Not at all

13. What factors have influenced your decision to use Soil fertility enhancement technologies? 1=Awareness of their benefits, 2=Cost effectiveness, 3=Advice from agricultural extension workers, 4=Peer influence, 5=Others (specify)

SECTION C: INFORMATION ON SFET

A1. Do you utilize soil fertility enhancement technologies on your farm	1= Yes, 0=No
A1.1 If yes, which of these soil fertility enhancement technologies have you implemented in your farm? (select all that apply)	1=Composting, 2=Manure application, 3=Biochar, 4=Synthetic fertilizer, 5=Micro nutrient supplements, 6=Crop rotation, 7=Cover cropping, 8=Mulching, 9=Drip irrigation with fertilization, 10=Agroforestry, 11=Minimum tillage, 12=No till farming,13=Soil testing and mapping, 14=Variable rate technology, 15=Remote sensing and drones, 16=Legume integration in crop system, 17=Crop residue incorporation, 18=Zai pit, 19=Terracing, 20=Contour Farming
A1.2 What proportion of land is under the technologies you have specified in acreage?	……(acres)
A1.3 How often do you employ the use of SFET technologies?	1=Once a week, 2=Once a fortnight, 3=Once a month,4=Not at all,5=Once a year ,6=Others (specify)
A1.4 What are your main reasons for utilizing SFET technologies in your farm? (select all that apply)	1=Improve soil moisture, 2=Reduce soil erosion, 3=Reduce runoff, 4= Improve crop yields, 5=Others (specify)
A1.5 Why are you not implementing other technologies?	1=Lack of knowledge, 2=Limited land, 3=Others (specify)
A2. Do extension providers guide you on how to get support for farming?	1=Yes, 2=No
A2.1. If yes, what kind of support do they give you?	1=Financial support, 2=Market access support, 3=Equipment and input support, 4= Training and capacity building, 5=Others (specify)
A2.2. If no, why do you think extension service providers do not guide you on how to get support for your farming activities? (select all that apply)	1=Lack of knowledge among providers, 2=Inadequate resources or capacity of providers, 3=Lack of trust or communication, 4=Others (specify

A3.1 Do extension officers do follow up on SFET?	1=Yes, 2= No
A3.2 If YES, how are the follow ups carried out?	1=At the individual farm visits, 2=Through use of contact farmers, 3=In group meetings, 4=Through use of phone calls, 5=Any other(specify)
If no, why do you think extension service providers do not guide you on how to get support for your farming activities? (select all that apply)	1=Lack of knowledge among providers, 2=Inadequate resources or capacity of providers, 3=Lack of trust or communication 4=Others (specify
A3.3 How frequently are following ups conducted in your area?	1=Week, 2=Monthly, 3=Quarterly, 4=Twice a year, 5=Annually ,6=After 1 year, 7=Others
A5. What constraints do you face in utilizing SFET technologies?	1=Lack of knowledge on SFET techniques, 2=Labor intensive,3=Insufficient performance of technologies, 4=Lack of materials, 5=Inadequate capital ,6=Inadequate skills lack of equipment
A6. What support do you need to address the challenges?	1=Adequate Training, 2=Input provision, 3=Enhancing access to Credit provision, 4=Extension follows ups and monitoring activities, 5=Enhancing access to required equipment, 6= Others (specify)

SECTION D: INFORMATION ON AGRICULTURAL EXTENSION METHODS

1. Have you ever received agricultural extension services in the last year? 1=Yes, 0=No
2. If yes which ones? 1=Crop management 2=Soil and water conservation, 3=Climate-smart agriculture, 4=Organic farming, 5=Others-specify
3. Which extension methods were used to deliver extension services? 1=Demonstration; 2=Farmers field school, 3=Farm and home visits, 4= Radio programs, 5=Digital platforms, 6=Others specify
4. If no why? 1 = Lack of awareness of which extension methods were used, 2 = Services are not accessible in my area, 3 = I don't see the need for these services, 4 = Extension services are too expensive or require resources I cannot afford.
5. Were the agricultural extension methods effective? 1=Yes, 2=No
6. If yes, how effective were the agricultural extension methods?
7. What tools do agricultural extension service providers provide? 1=Printed materials, 2=Digital tools, 3=Demonstration kits, 4=Others (specify) (select all that apply).
8. Please tick your agreement level of the statements given in the following table. Indicate in the table a tick with a scale of; 1= Showing a very large extent, 2=To a large extent, 3=To a moderate extent, 4=To a low extent, 5=Very low extent

EFFECTIVENESS OF AGRICULTURAL EXTENSION METHODS	**1**	**2**	**3**	**4**	**5**
1. Agricultural extension services are readily available when needed					
2. It is easy to access AEM in my area					
3. I can rely on AEM to provide information and support					
4. The agricultural extension services are provided promptly					
5. The agricultural extension services align with your farming priorities and needs					

6. The goal of the agricultural extension methods is communicated to you					
7. Participation rates in extension services have led to increased adoption of soil and water conservation technologies					
8. Since receiving agricultural extension services, have you noticed improvements in your productivity?					
9. 4 AES provided me with useful information on soil and water conservation technologies					

10. Have agricultural extension providers helped you apply SFET technologies? 1=Yes 2=No
11. If yes, how have agricultural extension s services helped you apply SFET technologies? 1=Increased knowledge, 2=Improved skills, 3=Provided resources, 4=Others (specify). (select all that apply).
12. How many of the technologies learnt through extension service providers have you utilized?
13. What challenges do you face in accessing AES? 1=Distance to service centers, 2=Cost of services, 3=Lack of awareness, 4=Inadequate information, 5=Other (specify) (select all that apply).
14. Have you ever received agricultural extension services on SFET? 1=Yes, 2=No
15. If yes, how frequent do extension services visit your farm? 1=Weekly, 2=Monthly, 3=Yearly, 4=Quarterly, 5=Never
16. How effective do you find the advice from extension officers on SFET? 1=Very effective, 2=Effective, 3=Neutral, 4=Ineffective, 5=Very ineffective
17. What communication methods have agricultural extension officers used to share information about soil fertility enhancement technologies? (Select all that apply) 1= Face to face meetings, 2=Radio programs, 3=Field days ,4=Written materials, 5=Others (specify)
18. Have you ever participated in a training or workshop on soil fertility enhancement technologies? 1=Yes, 2=No
19. If yes how often do you attend the training? 1=Once a week, 2=Once a fortnight, 3=Once a month, 4=Once a year, 5=Not at all, 6=Others(specify)
20. If no, give reasons for lack of training? 1=Lack of interest in SFET, 2=Inadequate/few extension experts to offer the training, 3=Long distances

to be covered to the training centers, 4=Inadequate finances, 5=I don’t believe in technology, 6=Others(specify)

21. Do you believe that increased access to extension services would lead to higher adoption of soil fertility enhancement technologies? 1=Strongly agree, 2=Agree ,3=Neutral, 4=Disagree, 5=Strongly disagree

THANK YOU

Appendix 4: Research Gaps

Author/year	Title	Variable	Indicator	Findings	Gap
Hamazakaza, 2022	Adoption rate of techniques related to sustainable food management	Dependent: Soil fertility Independent: Adoption intensity	Natural fallow Use of lime Mulching Use of minimum tillage	Data showed that implementation of SFET principles was difficult in Zambia	Barrier to adoption of SFET
Ajwera, 2024	Protection and Rehabilitation of degraded soil in western Kenya	Dependent: soil fertility Independent: Adoption intensity	Agroforestry Compost manure Residue in cooperation Crop rotation mulching	Most of the farmers are still using conventional method that deplete the nutrients	Barriers to adoption of soil rehabilitation technologies
Albaladejo, 2021	Eco holistic soil conservation to support land degradation neutrality and the sustainable development goals	Dependent: Soil fertility Independent: farmers attitude, knowledge and perception		Low percentage of farmers had better knowledge of ITK	Factor influencing farmers decision to implement SFET is scantly discussed.
Cyamwesh, 2023	Enhancing nutrient variability and coffer yield on acid soil of Rwanda.	Dependent: Soil fertility Independent: Farmers attitude, knowledge and perception		Education had positive effect on farmers attitude on trees effect on soil fertility. Farm size had negative effect on farmers attitude of trees	Factor influencing farmers attitude and knowledge are inadequately determined.

Author/year	Title	Variable	Indicator	Findings	Gap
				effect on soil fertility.	
Haruma 2023	Factor influencing farmers Adoption of improved technologies in maize production	Dependent: Soil fertility Independent: Socio – economic factors	Household oxen count Mobile phone ownership Livestock count Level of education of head of family	Age of the farmer had positive effect on adoption of improved technologies in maize production.	Socio-economic factors influencing the adoption of SFET
Mogaka, 2021	Socio-economic factors impacting farmers decision to implement climate smart soil practice	Dependent: Soil fertility Independent: Socio – economic factors	Education Gender	Society had failed to recognize the importance of education for women	Inadequate climate smart soil practice knowledge among women
Maulu, 2021	Enhancing the role of rural agricultural extension programs in poverty alleviation	Dependent: soil fertility Independent: Effectiveness of agricultural extension methods	What's app Face book	The study showed recommended the use of mobile app to disseminate agricultural technologies	Effectiveness of agricultural extension method used to disseminate SFET is not adequately explored
Sseguya, 2021	Impact of demonstration plot on improved	Dependent: soil fertility Independent:	Demonstration plots	Use of demonstration with tiny packs was highly	Effectiveness of other agricultural extension

Author/year	Title	Variable	Indicator	Findings	Gap
	agricultural input purchase in Tanzania	Effectiveness of agricultural extension methods	Demonstration plots with small packs	recommended to boost technology adoption	method was not examined.