EFFECTS OF AGROECOLOGICAL VEGETABLE CROPPING SYSTEMS ON SMALLHOLDER FARMERS' PERFORMANCE IN KIAMBU AND MURANG'A COUNTIES, KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Agribusiness Management of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

Signature: Date: 08/09/2025

Essy Chemutai Kirui

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Recommendation

This thesis has been submitted for examination with our approval as supervisors.

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DEDICATION

This research thesis is dedicated to my parents, Mr. Robert Kiprono Kirui, and Mrs. Rose Kirui, for their unwavering love, support and encouragement that have been the foundation of my journey.

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ABSTRACT

Brassica and Traditional African Vegetable (TAV) farming is a source of employment opportunities and income for smallholder farmers in Kenya. However, the production of these vegetables is hindered by various challenges which lead to lower incomes for the smallholder farmers. Agroecological cropping systems present solutions to these production problems, but there is insufficient evidence of their economic advantages. This study, therefore, sought to determine the effect of agroecological vegetable cropping systems on the performance (net income and technical efficiency) of smallholder farmers in Kiambu and Murang'a counties. The specific objectives were to characterize smallholder farmers implementing agroecological vegetable cropping systems; to determine the factors that influence the adoption of agroecological vegetable cropping systems; and to assess the effect of agroecological vegetable cropping systems on the performance of smallholder farmers in Kiambu and Murang'a counties. Multistage purposive sampling was carried out to collect data from 546 households using standardized, semi-structured questionnaires. Descriptive statistics were used to characterize the smallholder farmers. Multivariate probit model was used to assess the factors that influence adoption of agroecological cropping systems. The multinomial endogenous switching regression model was used to assess the effect of adoption on smallholder farmers' performance. Study results indicated that most of the smallholder farmers (78%) had adopted crop rotation but the rate of adoption for other cropping systems was low. The findings indicated that the gender and occupation of the household head, gender of the plot owner and manager, gross income from vegetable production, number of trainings attended, availability of market information, income from non-vegetable farming activities, distance to input and output markets, access to extension services and the location of the farm were the major factors influencing adoption. Additionally, adopting crop rotation alone significantly ($p<0.05$) led to a decrease in smallholder farmers' net incomes, whereas adopting multiple cropping alone led to a significant ($p<0.05$) increase in the farmers' net incomes. Regarding technical efficiencies crop rotation alone was associated with a negative and significant ($p<0.01$) effect, whereas adopting both multiple cropping alone and the combination of multiple cropping and crop rotation contribute significantly and positively to farmers' technical efficiencies at ($p<0.01$) and ($p<0.1$) respectively. The study recommended that policies and programs aimed at promoting the adoption of agroecological cropping systems that boost farmers' net incomes and technical efficiencies should be developed.

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LIST OF ABBREVIATIONS

ATE	Average Treatment Effects
ATT	Average Treatment effects on Treated
DEA	Data Envelopment Analysis
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
HHH	Household head
IVs	Instrumental Variables
KES	Kenyan Shilling
KCSAS	Kenya Climate Smart Agriculture Strategy
MERSRM	Multinomial Endogenous Switching Regression Model
MVP	Multivariate Probit
NGO	Non-Governmental Organization
PSM	Propensity Score Matching
SDG	Sustainable Development Goal
SFA	Stochastic Frontier Analysis
TAV	Traditional African Vegetables
TE	Technical Efficiency
USD	United States Dollar
VIF	Variance Inflation Factor

CHAPTER ONE
INTRODUCTION

1.1 Background of the Study

Vegetable farming is not only critical to Kenya's agricultural GDP but also serves as a vibrant sector for entrepreneurship, job creation, and value addition (Bokelmann *et al*., 2022; Joseph *et al*., 2020). The vegetable value chain supports a wide range of agribusiness activities including input supply, production, marketing, and retail in both rural and urban economies (Bokelmann *et al*., 2022). *Brassicaceae* plants, also known as crucifers or brassica (Favela-González *et al.,* 2020; Sahu *et al*., 2020), include vegetables such as cabbages, kales and Ethiopian mustard and are among the major vegetables grown in Kenya (Ngowi, 2019). Their annual production in the country is estimated at approximately 562,681 metric tonnes (Daniel *et al*., 2023; Ngowi, 2019). Traditional African vegetables are also extensively grown in Kenya with over 200 indigenous plant species that are eaten as food (Bokelmann *et al*., 2022). Some of these vegetables are amaranth, spider plant and African nightshade (Mvungi *et al*., 2020). The overall production of traditional African vegetables in Kenya is approximately 299,628 metric tonnes, valued at KES 8.84 billion (Nzomoi *et al*., 2022; Republic of Kenya, 2019).

The cultivation of vegetables is therefore a major activity that provides smallholder producers in Kenya with employment and income (Chepkoech *et al*., 2018; Mukiri *et al*., 2020; Ngowi, 2019). These producers, however, are besieged with constraints ranging from pests and diseases to climatic factors and widespread marginalization (Ntawuruhunga *et al*., 2020). This results in reduced yields and product quality. As a result, many smallholder producers resort to the conventional methods of production in which artificial fertilizers and chemical pesticides are used (Chepkoech *et al*., 2020). Although this provides some relief in the short term, the inputs, besides soil degradation and loss of biodiversity, also increase the cost of production, reducing smallholder farmers' incomes and undermining vegetable business competitiveness (Altieri & Nicholls, 2020; Guenat *et al*., 2019; Nyangau *et al*., 2022).

With the growing concern regarding the long-term ramifications of these conventional methods, there is an increasing shift towards agroecological cropping systems as a viable sustainable option to the problems besetting vegetable cultivation (Jacquet *et al*., 2022; Scherf, 2018; Wezel *et al*., 2018). Agroecological cropping systems apply agroecological precepts, using ecological concepts as well as indigenous knowledge, to re-design cropping systems to enhance production and environmental outcomes (Duchene *et al*., 2017; Gliessman, 2004; Van der Ploeg *et al*., 2019; Wezel *et al*., 2014, 2015). These approaches are valuable in contributing to various Sustainable Development Goals (SDGs) and lead to the transformation of the food and agriculture sector by addressing the primary causes for the problems (Scherf, 2018). Agroecological approaches deliver comprehensive long-term solutions to producers' problems by integrating traditional and empirical knowledge with relevant multi-disciplinary science (FAO, 2018). Agroecology promotes farming systems that can fulfil the increasing demand for crop production with minimum disturbance to the environment and ecological functions (Boeraeve *et al*., 2020; Nguyen, 2021).

Approximately one million farmers in Kenya are farming 0.5 million hectares of land through agroecological and organic farming methods to produce a broad variety of food crops like vegetables (Paracchini *et al*., 2020). In rural areas, initiatives are emerging among producer associations concerning the toxicity of chemical pesticides. Consumer demand for healthy vegetables is also on the increase and in response, there has been an increase in urban markets with farmers offering vegetables that have been produced using agroecological practices (Côte *et al.,* 2019). Smallholder farmers, NGOs, governments, analysts, and researchers from all around the world have also gained interest in these farming systems, likely due to their benefits linked to improved productivity, yields and to increased and diversified income. For some farmers, reducing the expenses associated with inputs was also a motivating factor (Paracchini *et al*., 2020).

Within Kiambu and Murang'a Counties, the most common agroecological vegetable cropping systems in place include row intercropping, mixed cropping, border cropping, strip cropping as well as crop rotation (Juma *et al*., 2020; Karuga, 2022). These agroecological cropping systems lead to improved quality of products (D'Annolfo *et al*., 2021). Production of vegetables is a key economic activity in these areas due to their proximity to Nairobi, Kenya's capital city, which provides a substantial market for vegetables (Karuga, 2022; Mutoro, 2022). However, despite the availability of market, farmers that adopt agroecological cropping systems are also likely to experience higher labor and set-up costs compared to conventional practices (Nijenhuis, 2022). Due to the weak networks among the farmers and customers, many customers are not yet aware of the distinct characteristics of products in the markets and therefore often perceive agroecological and conventional produce as equal in quality (Karuga, 2022). As a result, marketing agroecological products is challenging when farmers raise farm product prices to compensate for the additional costs associated with agroecological cropping (Karuga, 2022). This may therefore result in farmers not achieving the desired levels of profits.

Agroecology has already been extensively reviewed as a scientific discipline and practice but majority of the research on this topic has been directed towards promoting its application and showcasing its potential (Gliessman, 2016; Jacobi *et al*., 2018; Karuga, 2022; Stassart *et al*., 2018) rather than evaluating the efficiency of the applied practices (Karuga, 2022). According to D'Annolfo *et al*. (2017) and Mottet *et al*. (2020) there is still inadequate evidence and limited data that can confirm the economic merits due to application of agroecological practices on the farm. Furthermore, very little of the available literature focuses on agroecological vegetable cropping systems and on its effects on the performance of smallholder farmers in Kenya. Karuga (2022) recommends more research should be done about agroecological systems to increase awareness about their effect on agricultural performance through resource-conserving systems.

This study therefore intended to fill this research gap by contributing to the current thin literature regarding the effects of agroecological cropping systems on performance of smallholder vegetable farmers. It aimed to provide this information through systematically exploring the net incomes of smallholder farmers within Kiambu and Murang'a counties, Kenya as the primary measure of their performance. Net income was used in this study as a significant indicator of farm performance since it accounts for the benefits of production while also taking the costs incurred into consideration (Zheng *et al*., 2021). Additionally, this study also investigated farmers' technical efficiency as a further measure of their performance because it highlights the degree to which inputs used account for disparities in yield (Gori Maia *et al*., 2022; Ochilo *et al*., 2019). Brassicas and traditional African vegetables were the focus of this study because their production is a key economic activity within the study areas, and they are also a significant contributor to the economy of the country.

1.2 Statement of the Problem

Smallholder farmers in Kenya are often faced with numerous of challenges such as pests, diseases and adverse weather changes which usually affect their yields leading to farmers' poor quality of livelihoods due to decreasing profitability of their output. This is the case even in the vegetable production sectors which are significant contributors to Kenya's economy and whose production is a major economic activity in Kiambu and Murang'a. Agroecological cropping systems which usually require knowledge intensive process have been identified to improve this situation. However, there are very few studies on the effect of these agroecological systems on the economic aspects of vegetable growers, who are often smallholder farmers that rely on rain-fed agriculture. This study therefore intended to fill this research gap by characterizing the smallholder farmers, identifying influencing factors, and assessing the effect of agroecological vegetable cropping systems on the performance of smallholder farmers.

1.3 General Objective

To assess the effects of agroecological cropping systems on the performance of smallholder vegetable farmers in Kiambu and Murang'a counties, with the aim of contributing to their increased utilization for improved income.

1.3.1 Specific Objectives

i. To characterize the smallholder farmers that are implementing agroecological vegetable cropping systems in Kiambu and Murang'a counties.
ii. To determine the factors which influence the use of agroecological vegetable cropping systems by smallholder farmers in Kiambu and Murang'a counties.
iii. To assess the effect of agroecological vegetable cropping systems on the performance of smallholder farmers in Kiambu and Murang'a counties.

1.4 Research Questions

i. What are the characteristics of smallholder farmers that are implementing agroecological vegetable cropping systems in Kiambu and Murang'a counties?
ii. What factors influence the use of agroecological vegetable cropping systems by smallholder farmers in Kiambu and Murang'a counties?
iii. What is the effect of agroecological vegetable cropping systems on the performance of smallholder farmers in Kiambu and Murang'a counties?

1.5 Justification of the Study

Vegetable production has great potential to increase income and enhance the livelihoods of smallholder farmers and therefore lead to poverty reduction as underscored in Kenya Vision

2030. In addition, the adoption of more sustainable production of these vegetables can contribute to enhanced food security and nutrition for current and future generations which has been the focus of policy recommendations from the Food and Agriculture Organization (FAO). Agroecological cropping systems are recognized as priority interventions for supporting sustainable agriculture, according to the Kenya Climate Smart Agriculture Strategy (KCSAS). Therefore, by exploring the effect of agroecological vegetable cropping systems on the performance of smallholder farmers, the findings of this study are anticipated to guide research and inform policy interventions in the vegetable production sector. These results will also be of benefit to smallholder vegetable farmers that aim at ensuring efficient production. These findings will contribute to the existing literature on smallholder farmers' preference for agroecological cropping systems which will enable the informed decision making of smallholder farmers on the best agroecological systems to adopt Overall, these results will lead to increased adoption of agroecological cropping systems for increased income and improved smallholder farmer livelihoods.

1.6 Scope and Limitation of the Study

This study targeted only the active smallholder brassica and traditional African vegetable producers within Kiambu and Murang'a counties, which are major brassica and traditional African vegetable growing regions in Kenya. These farmers were diverse in their characteristics thus enriching the needed information. The researcher issued detailed questionnaires to the smallholder farmers within these regions. Information available from the year starting January 2021 to the year ending December 2021 that relates to the research objectives was also obtained and analyzed. The targeted smallholder farmers were engaged in various other inter-dependent agricultural activities whose interactions may not be sufficiently understood but may influence the study.

1.7 Operational Definition of Terms

Agroecological cropping systems- this refers to cropping systems that simultaneously apply ecological, social, and cultural principles in their design and management. In relation to this study this included mixed cropping, strip cropping, row intercropping, border cropping, and crop rotation.

Conventional practices- within this study context these are vegetable farming practices that depend extensively on external inputs such as pesticides, genetically modified organisms, and fertilizers.

Cropping systems- this refers to the type and sequence of vegetables grown as well as the practices used to grow them in an area over a period. According to this study this included mixed cropping, strip cropping, row intercropping, border cropping, crop rotation as well as monocropping.

Net income- this refers to the total vegetable sales minus their production costs and vegetable production related expenses.

Performance- this refers to the level to which smallholder vegetable farmers are able to optimize the use of their limited resources to achieve desirable outcomes. According to this study, it was measured in terms of smallholder farmers' net income as well as their technical efficiency.

Smallholder farmers- this refers to individuals engaged in farming on small parcels of land, primarily cultivating food crops and, in some cases, limited cash crops. In relation to this study these are brassica and traditional African vegetable farmers that produced these vegetables on less than 10 acres of land.

Technical efficiency-this is the capacity of smallholder farmers to achieve the highest level of vegetable production using the least number of inputs such as labor, land, and capital. In this study it was quantified as a ratio of actual vegetable output to the maximum attainable output.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter comprises of the empirical review, theoretical review, and the conceptual framework. The conceptual framework indicates independent and dependent variables that are deemed to play a role in the economic effect of agroecological vegetable cropping systems.

2.2 Empirical Review

This section is a review of what other scholars have investigated on the effect of agroecological cropping systems on the performance of smallholder farmers.

2.2.1 Factors That Influence Smallholder Farmers' Preference for Agroecological Cropping Systems

According to Garini *et al*. (2017) farmer characteristics are likely influence the use of agroecological cropping systems. This study utilized the Cognitive Mapping Approach on the viticulture sector in the province of Trento in Italy in order to evaluate farmers' motivation to adopt agroecological practices (Garini *et al*., 2017). The study showed that farmers' intrinsic motivations positively influenced their adoption of agroecological systems of practices. Schoonhoven and Runhaar (2018) also studied the adoption of different agroecological farming practices through a case study of almond farming in Andalusia, Spain. The results showed some factors affect adoption depending on farmers' characteristics. The level of skill, understanding of the ecosystem and feeling for future generations positively influenced adoption, while lack of innovativeness negatively influenced adoption (Schoonhoven & Runhaar, 2018).

Several institutional and socio-economic factors may also influence the adoption of agroecological cropping systems by smallholder farmers (Hannah, 2021). Chichongue *et al*. (2020) conducted a study to assess the determinants influencing the decisions of smallholder farmers to adopt intercropping, crop rotation, minimum tillage and cover cropping in Mozambique. They used a descriptive logit model and found varying results. The size of the household, livestock ownership and group membership positively affected adoption while the gender of the household head and perception of decline in soil fertility affected negatively the adoption of these practices.

Farmers in the central highlands of Kenya were surveyed by Mwaura *et al*. (2021) on the extent of adoption of organic-based practices and the socioeconomic factors that influenced the extent of adoption. This study utilized a tobit regression model through which agroforestry, cover cropping, crop rotation, intercropping, mulching and manure application were analyzed. Mwaura *et al*. (2021) found that gender, household head's age, level of education, size of the household, reliance of hired labor, access to training, membership in agriculture group, availability of credit, cultivated land and the amount of experience in farming were factors that influenced the intensity of adoption of organic-based practices among the smallholder farmers. The findings revealed that age negatively influenced adoption for compost and crop rotation while the other institutional and socio-economic factors positively influenced adoption.

Rebecca *et al*. (2018) carried out a study on the factors that influence the probability and the level of use of different agricultural innovation on the production and marketing of underutilized cereals in Elgeyo-Marakwet county, Kenya (Gichungi, 2021). The agricultural innovations considered included improved varieties, conservation tillage as well as integrated weed and pest management. About 384 finger millet producers were selected using the multi-stage sampling technique to conduct the survey. The multivariate probit model was utilized to analyse adoption decisions that are interdependent. The ordered probit model was also used to assess the level of adoption. The results indicated that accessibility of credit, off/non-farm income and plot size as well as extension contract had positive and significant effects on adoption decision and extent of adoption. Although training increased the level of adoption, it was associated with lower likelihood of adoption of such innovation.

Kanyenji *et al*. (2020) conducted an examination of what determines the probability and intensity of adoption for mulching, farmyard manure, intercropping and inorganic fertilizer in Western Kenya. Kanyenji *et al*. (2020) studied socio-economic variables, plot-level data, and external support variables. They applied a multivariate probit model to ascertain the adoption of technology and a generalized ordered logit model to scrutinize adoption intensity (Kanyenji *et al.,* 2020). The study shows farmers' adoption decisions are linked to one another. The likelihood and extent of adoption are influenced by some plot-level factors, literacy level, access to credit, membership in group, market participation and gender of the household head (Kanyenji *et al.,* 2020).

This review reveals a range of factors influencing smallholder farmers' choice of agroecological cropping systems. Nonetheless, information regarding the factors influencing the preference for agroecological vegetable cropping systems is still limited (Njenga *et al*., 2017). This study seeks to contribute to existing literature by the use of Multivariate Probit model to determine the determinants of adoption of agroecological based brassica and traditional African vegetable cropping systems in Kiambu and Murang'a counties.

2.2.2 Understanding and Definition of Performance

According to Sonnentag & Frese (2002), performance consists of a person's actions during a work-related situation and the results of these actions. While smallholder farmers carry out many activities on their farms, their actual performance constitutes only those actions that are relevant to their production goals. Farms generally measure their performance by considering the relation of outputs like crop yields to inputs such as labor, fertilizer, and pesticides (Dimov *et al*., 2019). They also consider the how often the yields are harvested each year (Dimov *et al*., 2019). Essentially, measuring the performance of a farm entails quantifying the efficiency and effectiveness of farming efforts (Neely *et al*., 2005). Effectiveness refers to how well the farm is able to satisfy the needs of customers. On the other hand, efficiency refers to whether a farm can achieve desired results without wasting resources (Kumari, 2019).

Measuring the performance of agroecological production among smallholder farms is useful so that high yielding and sustainable production systems can be implemented (Meng *et al*., 2017). Zheng *et al*. (2021) suggests considering net income a meaningful way of measuring farm performance since it shows the actual gains. Several studies (Komarek & Msangi, 2019; Seo & Umeda, 2021) employed gross farm income, but this fails to account for production costs, a significant flaw. The estimation of technical efficiency is also a worthwhile tool to measure performance (Fare & Lovell, 1978). It can be used as a success indicator in performance appraisal, and it also allows for the exploration and elimination of sources of inefficiency (Kotosz, 2018). According to Mwangi *et al.* (2020), there are few studies that actually look into technical efficiency of farms. Therefore, this study sought to add to the body of by examining the net incomes as well as technical efficiency of smallholder vegetable farmers.

2.2.3 Estimation of Technical Efficiency

According to Farrell (1957) technical efficiency is the extent to which the maximum possible outputs can be produced from a limited level of inputs, or a certain level of output can be produced from the least possible amount of inputs, within a specific technology (Kotosz, 2018). Technical efficiency analysis is a key informant in agricultural policy decisions and thus, farmers' technical efficiency levels have significant implications for a country's development strategy (Abate *et al*., 2019). This is because government policies to introduce new technology will not yield the desired shift to production frontier if farmers' existing efficiency levels remain low (Degefa *et al*., 2020).

Smallholder brassica and traditional African vegetable farmers face production inefficiency due to suboptimal use of scarce resources such as water, plant and animal diversity, ecosystems services, land, skills, and education (Abate *et al*., 2019). Measuring efficiency in agricultural production is essential in providing useful information for elimination of inefficiencies and for relevant decision making in the reformulation of agricultural policies that are likely to improve farmers' technical efficiency and therefore contribute to agricultural development (Abate *et al*., 2019; Dessale, 2019). From the microeconomic perspective, measurement of technical efficiency is important since the use of insights from such studies may increase farm efficiency, leading to improved decision-making and higher incomes (Mwangi, 2020; Thomas *et al*., 2020). It also allows for the comparison of the performance of different farmers (Kassa &Demissie, 2019).

Studies on the assessment of technical efficiency have majorly used either non-parametric approach, such as data envelopment analysis (DEA) or parametric methods, such as the stochastic frontier analysis (SFA) (Mwangi, 2020; Ngango, 2019). The DEA approach was proposed by Charnes *et al*. (1978) to estimate production frontiers and assess the efficiency of decision-making units. It is often preferred as an substitute for other econometric approaches such as regression and ratio analysis (Mohd *et al*., 2020). This is because it does not require prior assumption about the functional relationship between inputs and outputs while also accomodating for the estimation of technical efficiency in systems with multiple input and output variables (Mohd *et al*., 2020).

However, according to Liu (2019), DEA and SFA produce different and uncorrelated results, but SFA produces a more precise estimate of efficiency. Aigner *et al*. (1977) proposed the

SFA model which accomodates the effects of measurement error and other statistical noise on the shape and positioning of the estimated production frontier (Ngango, 2019). Coelli *et al*. (1998) stated that SFA is the most suitable technical efficiency measurement model for studies involving the agricultural sector, especially within developing countries (Ngango, 2019). The SFA model assumes that the underlying mathematical function (frontier) represents the benchmark and therefore institutions that fall close to the frontier are considered efficient because they possess optimal input-output ratio while those that are far from the benchmark are inefficient. Each farm obtains an efficiency score ranging from zero to one depending on their proximity to the frontier, where values closer to one indicate a higher level of efficiency (Gralka, 2018). However, majority of the studies using SFA to estimate technical efficiency within the agricultural industry have been conducted on the production of other crops and vegetables with paucity of information in relation to brassicas and traditional African vegetables. Therefore, this study sought to address this gap by analyzing the effect of agroecological vegetable cropping systems on the technical efficiency of smallholder farmers in Kiambu and Murang'a counties, Kenya.

2.3 Theoretical Review

A Theoretical review consists of concepts and ideas that are developed to describe a set of facts or phenomena, particularly those that have been tested extensively or are well established, and which can serve as a basis for predicting natural occurrence (Kothari, 2004).

2.3.1 Economic Theory of Production

This research was grounded on the economic theory of production, which thoroughly examines the optimization of agricultural production systems. This theory looks into the association of inputs with their corresponding outputs in production (Mdoda *et al*., 2023; Rasmussen, 2012). Moreover, it does not disregard large social and environment components that are very important components of agroecological production and considers their impact on land, labor, and capital (Faye, 2022). It is an examination of how production activities impact not just natural resources but the environment, while focusing on long term sustainability (Krishnan *et al.,* 2020). This theory studies how a firm can reach its objectives, typically profit maximization, without wasting resources such as labor, land, and capital (Malinga *et al*., 2015). The approach thus forms a basis to study the effects of agroecological cropping systems on the net incomes and technical efficiencies of smallholder vegetable farmers. Other theories also can apply like profit maximization theory and theory of the firm which can explain agroecological cropping systems and the farmers' performance. However, these alternatives put their focus on profit maximization (Jafar *et al*., 2010). They neglect small holder farmers' resource limitation as well as their broader social and environmental objectives. In contrast, economic production theory provides a more comprehensive framework that is more compatible with agroecological farming..

2.4 Conceptual Framework

In this study, different variables were interacted to determine the influence of agroecological vegetable cropping systems on performance of smallholder farmers, as shown in Figure 2.1(Okello, 2021). The response variable in this study was performance of the smallholder farmers, measured by their net incomes as well as their technical efficiency. The independent variables were the agroecological vegetable cropping systems which included mixed cropping, strip cropping, row intercropping, border cropping as well as crop rotation. These independent variables are assumed to follow a pathway where they influence farmers' production costs as well as their yields which then influences their performance. Socioeconomic, institutional, transaction and market related factors played a moderating role in the relationship between the independent and dependent variables (Okello, 2021).

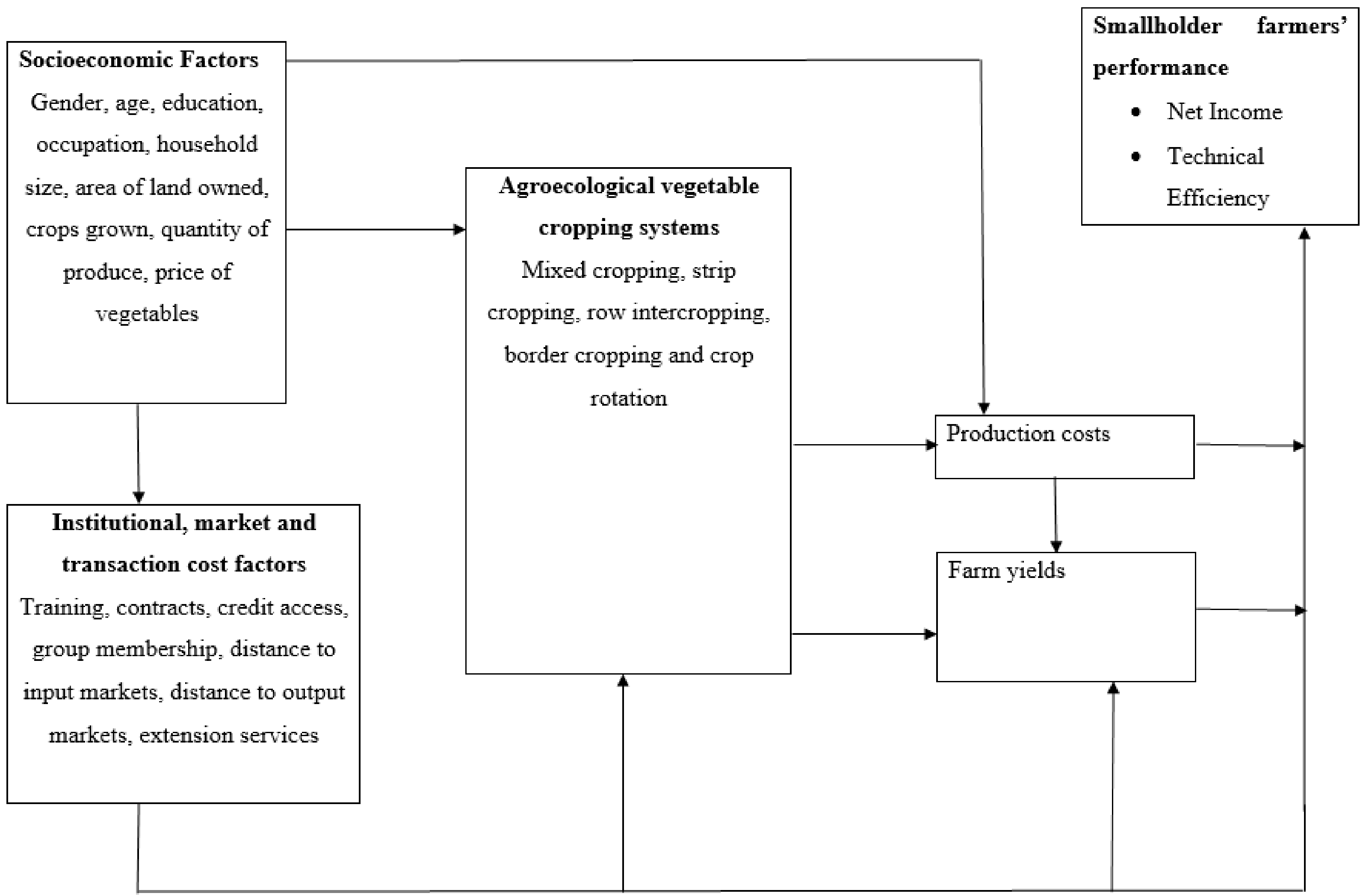

Figure 2.1: Conceptual framework

CHAPTER THREE
METHODOLOGY

3.1 Study Area

This study was conducted in Kiambu and Murang'a which are among the five counties located within Central Kenya. Kiambu county (1.1462 °S, 36.9665 °E) is made up of 12 constituencies and its size is approximately 2543.5 KM^2 with a population of about 2,032,464 people. Agriculture serves as the primary economic activity in this county, accounting for approximately 17.4% of the population's income with around 304,449 people being both directly and indirectly employed in the sector. The main cash crops grown include coffee and tea while food crops such as pineapples, maize, beans, and irish potatoes bananas and vegetables are widely cultivated on small scale, particularly in the upper highlands of Limuru, Kikuyu, Gatundu North and South Constituencies. The major vegetables grown include snow peas, kales, French beans, tomatoes, cabbage, spinach, garden peas, and carrot among others. Muranga county (0.7957 °S, 37.1322 °E) occupies a total area of 2,558.8KM^2 and has an estimated population of approximately 1,056,640 people. Agriculture also serves as the primary economic activity within this county with coffee being the major cash crop among various others such as tea, avocado, mangoes, macadamia, and horticultural crops. The acreage under food crops within the county is approximately twice that of cash crop. Food crops are grown in all parts of the county, but cash crops are mainly farmed within the upper zones and in some lower zones of the county.

Kiambu and Murang'a counties were purposely chosen for this study because of the vibrant small scale vegetable farming within these counties which has been generally increasing in acreage and production. Their county governments together with other non-profit and non-governmental organizations have also initiated various policies and initiatives to promote the use of agroecological cropping systems in the farming of brassicas and traditional African vegetables. These initiatives are aimed at empowering the smallholder vegetable farmers, increasing their productivity, and thus boosting their income (Okello, 2021). An assessment of the effect of these agroecological vegetable cropping systems on farmers' performance is therefore necessary. The study area map is shown in Figure 3.1.

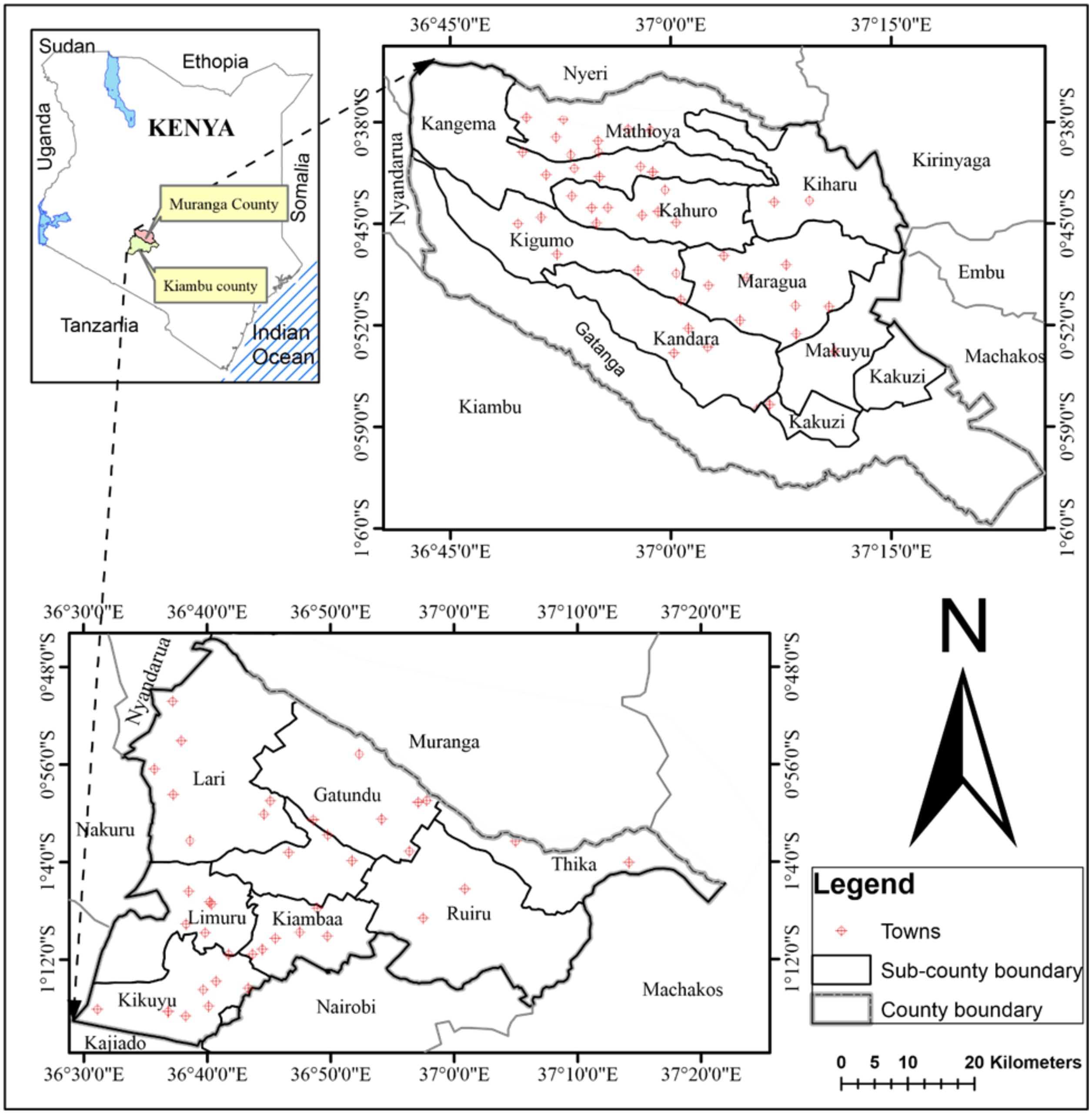

Figure 3.1: Map of Kiambu and Murang'a counties

Source: Egerton University, Geography Department (2022)

3.2 Research Design

This study employed a quantitative research design using a cross-sectional approach. A cross-sectional research design was applied in this study as it enables the collection of data at a single point in time, providing an overview of the situation as it exists (Adeyinka-Ojo, 2025). Cross-sectional studies offer broad coverage within a short period and are cost-effective, as they eliminate the need for repeated data collection. They also enable the analysis of naturally occurring variations across sub-groups, making it possible to examine associations such as those between adoption practices and income levels among smallholder farmers.

3.3 Data and Sampling Approach

3.3.1 Population of the Study

The target population for this study was smallholder farmers within Kiambu and Murang'a counties that were practicing brassica and traditional African vegetable farming (Okello, 2021).

3.3.2 Sample Size

The study determined the sample size using Cochran (1963) formula for representative sampling (Okello, 2021):

$$n_o = \frac{z^2pq}{e^2} \quad \text{...} (1)$$

Where:

n_o= initial sample size

z= z–score corresponding to the desired confidence level (α = 0.05)

p= assumed portion of the population with the characteristic of interest (maximum possible variance)

q= 1-p

e= margin of error

A 95% confidence interval with a margin of error of ±5% was applied in this study (Kirui, 2023). Given the large population of this study and lack of information on farmer variability, the study assumed a proportion of p=0.5, representing about 50% of all the smallholder brassica and traditional African vegetable farmers (Kirui, 2023). Substituting these values into the formula produced:

$$n = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 385 \text{ farmers} \text{...} (2)$$

To account for potential data collection errors or missing responses, the intended sample size was raised from 385 to 550 respondents (Kirui, 2023). Previous studies that were carried out in similar contexts (Kalele *et al*., 2021; Ogada *et al*., 2021) suggested that approximately 30% of the targeted respondents may fail to participate, largely because of the inaccessibility of certain rural areas such as Kigumo and Kangema. It was also anticipated that some respondents may not be available or willing to participate. Ultimately, a total of 546 respondents were successfully interviewed during the survey and this whole data was used (Okello, 2021).

3.4 Sampling Method

Farmers of brassica and traditional African vegetables from Kiambu and Murang'a counties were selected using non-probability multistage purposive sampling approach. Essentially, purposive sampling refers to a sampling technique where the research is conducted by selecting a sample based on the purpose of the study, strengthening the reliability and validity of the findings (Campbell *et al*., 2020). At the first stage, purposive sampling was used to pick the various sub-counties in Kiambu and Murang'a counties with significant outputs of brassicas and traditional African vegetables (Kirui, 2023). Key informant interviews with county agricultural officers informed this selection (Kirui, 2023). The Murang'a sub-counties that were chosen were Kigumo, Kangema, Kahuro, Murang'a South, Kiharu and Gatanga while the Kiambu sub-counties were Gatundu South, Lari, Juja and Githunguri. Using insights from sub-county agricultural officers and ward representatives, the wards were then purposely selected from each sub-county and respondents from these wards who were practicing brassicas and traditional African vegetable farming (Kirui, 2023), as shown in Table 3.1.

Table 3.1

Distribution of the Sample Among the Sub-Counties and Counties

County	Sub-Counties	Sample Per Sub-County	Sample Per County
Kiambu	Gatundu South	45	
	Lari	65	
	Juja	60	
	Githunguri	40	210
Murang'a	Gatanga	70	
	Kigumo	53	
	Kangema	60	
	Kahuro	40	
	Murang'a South	45	

	Kiharu	68	336
Total			546

3.5 Tools for Data Collection

Data collection was carried out using a structured questionnaire, developed in CSPro and implemented through computer assisted personal interviews (CAPI). These interviews were conducted by a team of 8 enumerators that had good experience in data collection, were proficient in the local language and were trained in the use of CS entry. These questionnaires were divided into eight modules where each module sought to obtain different information from the respondents. These include household demographics; brassica and TAV production and sales; pesticide use in vegetable production; training of brassica and TAV farmers; brassica and TAV value chain actors; household income; social capital, access to credit and other services; and household assets. The questions were simple and straightforward, requiring straightforward answers. The questions were presented using the exact same structure and wording to all the respondents to guarantee consistency of responses.

3.6 Data Types and Sources

This study used secondary data collected by the International Centre of Insect Physiology and Entomology (*icipe*). This is data that was collected by trained enumerators through household survey using the structured questionnaires. It also used other secondary sources of data from websites such as Elsevier, academia.edu and scienceopen; book publications; and relevant journals that were used in the literature review.

3.7 Data Analysis

The secondary data was modelled using descriptive statistics, the multivariate probit model and the multinomial endogenous switching regression model (Okello, 2021). STATA version 17 was employed to derive descriptive statistics and to carry out further analysis on regression and correlation of the data (Okello, 2021).

3.8 Analytical Framework

Objective 1: To characterize smallholder farmers that are implementing agroecological vegetable cropping systems in Kiambu and Murang'a counties.

This research objective was attained by employing descriptive statistics such as frequency distribution, percentages, and measures of central tendency (Jimenez, 2012; Morepje, 2024). Descriptive statistics were employed to characterize the smallholder vegetable farmers' sample without making any inference based on probability theory (Kaliyadan, 2019). The characteristics that were considered were household demographics; vegetable production and sales; value chain actors in vegetable production; other crops and livestock production; household income.

The characteristics of smallholder farmers that were considered were derived from previous studies (D'Annolfo *et al*., 2021; Ekhuya *et al*., 2018; Ochilo *et al*., 2019). This research provided summarized information on the variables from the data set as well as the correlation between them. This provided an overall understanding of the smallholder farmers that were under study (Kaur *et al*., 2018).

Objective 2: To determine the factors which influence the use of agroecological vegetable cropping systems by smallholder farmers in Kiambu and Murang'a counties.

Agroecological vegetable cropping systems in this study included mixed cropping, strip cropping, row intercropping, border cropping, and crop rotation. The utilization of these agroecological cropping systems was represented using a dummy variable (Okello, 2021). That is, 1 if the smallholder farmers applied the agroecological vegetable cropping system and 0, if otherwise. Either a univariate probit or logit model could be an appropriate model to use since these serve the same function when the outcome variable is binary in nature (Alsoruji *et al*., 2018). Carrying out analysis with these univariate models would however require the cropping systems to be separately analyzed. This overlooks the path-dependent nature of adopting cropping systems, where choosing one practice is partly influenced by previously adopted systems (Kanyenji, 2020). Since these systems can either complement or substitute one another, analyzing a single system in isolation, without considering the others, would lead to biased results and inefficiency of estimates (Kanyenji, 2020).

To account for these shortcomings, the study employed a Multivariate Probit (MVP) model since it accounts for the correlation among the error terms by simultaneously estimating the effects of independent variables on each of the cropping systems through a series of binary probit models (Azumah, 2019; Donkoh *et al*., 2019). This approach therefore accomodates more than two outcome variables by incorporating additional equations and makes it possible to assess the interdependence in the adoption of different cropping systems as well as the correlations among unobserved factors. (Ahmed, 2015). The empirical specification of the model is presented in equation 3 below.

$Y_{i1} = X'_{ij1}\beta_1 + \varepsilon_{i1}$

$Y_{i2} = X'_{ij2}\beta_2 + \varepsilon_{i2}$

$Y_{i3} = X'_{ij3}\beta_3 + \varepsilon_{i3}$

$Y_{i4} = X'_{ij4}\beta_4 + \varepsilon_{i4}$

$Y_{i5} = X'_{ij5}\beta_5 + \varepsilon_{i5}$ ………………………………………………………………………….. (3)

Where, i = identification of smallholder farmers; Y_{i1}= 1 if mixed cropping was adopted (0 = otherwise), Y_{i2}= 1, if strip cropping was adopted (0 = otherwise), Y_{i3} = 1, if row intercropping was adopted (0 = otherwise), Y_{i4} = 1, if border cropping was adopted (0 = otherwise), Y_{i5}= 1 if crop rotation as adopted (0 = otherwise); X′i = a set of independent variables influencing the adoption of cropping systems, β_j= a set of parameters to be estimated (j = 1, 2, 3, 4, 5); and ε = the error term (Mango, 2018; Okello 2021). A multivariate probit model, specified as follows, was employed to test the hypothesis on factors influencing the adoption of agroecological cropping practices (Okello, 2021):

$Y_{ij} = X'_{ij}\beta_j + \varepsilon_{ij}$ ……………………………………………………………….…… (4)

Where Y_{ij} (j =1…,5) denotes the five agroecological cropping systems adopted by the ith farmers; X'_{ij} is a 1 × k vector of explanatory variables influencing smallholder farmers' choices, β_j denotes a k × 1 set of parameters determined through simulated maximum likelihood, and ε_{ij} is the stochastic error term, which follows a multivariate normal distribution with a mean vector of zero (Okello, 2021; Wooldridge, 2003). The independent variables in this study were informed by past studies (Chichongue *et al.*, 2020; Kanyenji *et al.,* 2020; Mwaura *et al.*, 2021; Okello, 2021; Rebecca *et al.*, 2018) on the adoption of agroecological cropping systems, as shown in Table 3.2.

Table 3.2

Description of Variables That Were Used in the Multivariate Probit Model.

Variables	**Description of variables**	**Hypothesized sign**
	Dependent	
Adoption of agroecological cropping systems	Dummy=1 if smallholder farmer adopts the agroecological cropping systems and 0 if otherwise.	
	Independent	
Gender	Dummy= 1 if the household (HH) head is male and 0 if female	+
Age	Age of the HH head in years	+/-
Education	Highest education level of the HH head (0=None, 1=Primary, 2=Secondary, 3=Tertiary)	+/-
Occupation *	The main occupation(s) of the HH head	+/-
Household size	The total number of household members	+
Ownership of the land	Household member that owns the land (Male=1; Female=0)	+
Management of the land	Household member in charge of management (Male=1; Female=0)	+
Income	The gross income earned from brassica and traditional African vegetable farming in KES and USD	+
Training	Number of training sessions each household has attended	+/-

Contracts	Dummy =1 if the HH has any contract farming, 0 if otherwise	+
Market and Information platform	Dummy =1 if the HH used any market and information platform, 0 if otherwise	+
Other-farm income	Income earned from other activities on the farm except brassica and traditional African vegetable farming in KES and USD	+/-
Off-farm income	Income earned from HH activities beyond the farm in KES and USD	+/-
Credit access	Dummy =1 if the HH received vegetable production and marketing credit, 0 if otherwise	+/-
Group membership	Dummy =1 if the HH is a member of a production and marketing group, 0 if otherwise	+
Distance to input market	Distance to input market (walking minutes)	+/-
Distance to output market	Distance to output market (walking minutes)	+/-
Extension services	Dummy =1 if the HH has access to extension, 0 if otherwise	+
County	Dummy =1 if the HH is in Kiambu county and 0 if Murang'a county	+/-

Note. HH= Household; KES= Kenyan Shillings; USD = United States Dollar; *1= Vegetable production, 2= Other farming activities, 3= Off-farm employment, 4= Casual labor, 5= Own business off-farm, 6= Retired, 7= Unemployed, 8= In school.

Objective 3: To assess the effect of agroecological vegetable cropping systems on the production performance of smallholder farmers in Kiambu and Murang'a counties, Kenya.

The dependent variable under this objective was performance which was measured in terms of smallholder farmers' net income and technical efficiency. Net income was measured as gross income from sale of brassicas and traditional African vegetables in a year (total quantity sold in kilograms multiplied by the sale price) minus production costs and expenses. Farmers technical efficiency was measured using the stochastic frontier analysis (SFA) approach (Haryanto *et al*., 2023b). This parametric approach was employed because it provides a more accurate efficiency measure than non-parametric techniques such as the Data Envelopment Approach (DEA) (Haryanto *et al*., 2023a; Liu, 2019). The SFA also uses a production function for its estimation, therefore, it is the most appropriate for research on the production processes of the agricultural sector, especially in developing countries (Coelli *et al*., 1998; Ngo *et al*., 2019). The SFA function was formally introduced and characterized by Aigner *et al*. (1977) and Meeusen and Den Broeck (1977) as:

$$Y_i = f(X_i; \beta) \cdot \varepsilon_i \quad \text{……… (5)}$$

For $i = 1,2, \dots, N$

Where Y_i represents the quantity of output produced by the ith farmer in a specified period and $f(X_i; \beta)$ is the appropriate specified production function (Kirui, 2023). X_i is the input variable used by the ith farmer, and β is a vector of the unknown parameters that are to be estimated (Khan, 2020; Ngango, 2019). The stochastic error term, ε_i, has two uncorrelated components u_i and v_i such that ($\varepsilon_i = v_i - u_i$) (Khan 2020). The component v_i is an error term that has a symmetric distribution which accounts for random variation in output (Ngango, 2019). This can be because of measurement errors or other reasons which cannot be controlled by the producers such as natural disasters (Khan 2020).

This random error term v_i is assumed to have a mean of 0, constant variance, and an independent identical distribution and specified as $v_i \sim N(0, \sigma_v^2$ (Kirui, 2023; Ngango, 2019). On the contrary, the component u_i is a non-negative stochastic term ($u_i \geq 0$) which takes values between 0 and 1, and it reflects the level of technical inefficiency for the ith farmer (Kirui, 2023; Ngango, 2019). This inefficiency term u_i is assumed to follow a half normal distribution, expressed as $u_i \sim N^+(0, \sigma_v^2)$, and it captures deviations from the production frontier arising from inefficiency (Asfaw 2019; Bravo-Ureta *et al*., 2021; Kirui, 2023; Ngango, 2019).

The variance of ε is given by:

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \quad \text{……… (6)}$$

Where σ^2 is the variance variable that represents the deviation from the frontier (Asfaw 2019). σ_u^2 denotes deviation from the frontier due to inefficiency while σ_v^2 denotes deviation from the frontier due to stochastic noise (Endalew, 2022).

$$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2) \quad \text{.......} \quad (7)$$

Where γ indicates the relative variability of u_i and v_i which distinguishes the actual yield from the production frontier (Murali, 2017). As σ_v^2 approaches zero, u_i becomes the predominant error component and γ will tend to 1 (Murali, 2017). This means that the yield difference is majorly because of non-adoption of the best technique (Murali, 2017). When σ_u^2 tends to zero, it suggests that v_i is the major error term and so γ also approaches zero (Murali, 2017). Essentially, this shows that the variations in yield are mainly because of statistical noise or other external factors which the model does not account for (Murali, 2017).

The use of SFA requires the specification of an appropriate functional form (Ngango, 2019). This study employed the Cobb-Douglas (CD) functional form (Murali, 2017) specified as:

$$InY_i = \beta_0 + \sum_{j=1}^{4} \beta_j InX_{ij} + (v_i - u_i) \quad \text{.......} \quad (8)$$

Where In represents natural logarithm, Y_i shows the vegetable output of the i^{th} farmer and j shows the j^{th} production factor (Ngango, 2019). X_i denotes the four inputs: land, labor, capital, and pesticides (insecticides, fungicides, and herbicides) (Ngango, 2019). The maximum likelihood estimates of these variables were then derived and used to determine their frontier yield. The technical efficiency of each individual smallholder farmer was then worked out using the following formula Coelli *et al*. (1998):

$$TE = \frac{Y_i}{Y_i^*} \quad \text{.......} \quad (9)$$

Where Y_i^* is the frontier yield and Y_i is the actual yield. Since the observed output is lower than the frontier output, technical efficiency (TE) scores ranged between 0 and 1. The utilization of agroecological cropping systems was then modelled on the assumption that smallholder farmers decide either to adopt or not adopt the systems (Oparinde, 2021). The agroecological cropping systems under this study included mixed cropping, strip cropping, row intercropping, border cropping and crop rotation as shown in Table 3.3. It was assumed that the smallholder farmer i is risk neutral and seeks to maximize their expected utility T_{ij} from selecting option j $(j = 0,1, \dots N)$, whereby N represents the number of choices (Oparinde, 2021). The utility function can be presented as shown in equation 10 below (Oparinde, 2021):

$$T_{ij} = X_i\beta_j + \mu_{ij} \quad \ldots\ldots\ldots\ldots (10)$$

Where X denotes vector of explanatory variables; β is a vector of parameters to be estimated; μ is the error term assumed to follow an independent and identically distributed pattern (Ding, 2020). A smallholder farmer is assumed to select an option (j) provided that the expected utility from that choice is higher than that obtained from choosing any other alternative (k), that is $T_{ij} > T_{ik}$ (Ding, 2020).

Since the net expected benefit is unobserved, it was represented by a latent variable D_i, modelled as a function of observed characteristics of smallholder farmers and an idiosyncratic unobserved random disturbance term (ε) (Ding, 2020). The latent variable can then be specified as follows:

$$D_{ij} = Z_i\alpha_j + \varepsilon_{ij} \quad \ldots\ldots\ldots\ldots (11)$$

Where α is a set of parameters that are to be estimated; Z is a vector of factors that represent exogenous variables. D_i is the dummy variable that indicates that smallholder farmer i will select a certain agroecological cropping system given that it provides greater expected benefit than the other options (Ding, 2020).

$$D_i = \begin{Bmatrix} 1\ iff\ D_{i1} > max_{k\neq 1}\, D_{ik} \\ \vdots \quad\quad \ddots \quad\quad \vdots \\ N\ iff\ D_{iN} > max_{k\neq N}\, D_{ik} \end{Bmatrix} \quad \ldots\ldots\ldots\ldots (12)$$

This model basically assumes that the observed variable Z is independent of the stochastic error term ε so that $E(\varepsilon|Z) = 0$ (Ding, 2020). This implies that ε is follows an independent and identical distribution (Ding, 2020). In the first stage of estimation, the probability P_{ij} that a smallholder farmer i with Z_i characteristics will select system j was modelled using a standard multinomial logit model according to McFadden (1973) as shown in equation 13 below (Setsoafia, 2021):

$$P_{ij} = \frac{\exp(Z_i\alpha_j)}{\sum_{k=1}^{N}\exp\,(Z_i\alpha_k)} \quad \ldots\ldots\ldots\ldots (13)$$

The farmers' decision to adopt or not to adopt the cropping systems is usually influenced by some observable and unobservable factors (Okello, 2021; Wanyonyi *et al.*, 2021). However, selection bias may arise since the unobservable factors such as motivation, innate abilities and risk preference of the farmers may influence their terms of selection of the cropping systems as well as their outcomes (net income and technical efficiency). These unobservable factors may also lead to relationship between the error terms in the selection equation (ε) and in the outcome equation (μ)

which is likely to result in inconsistent outcome estimates (Ding, 2018; Ding, 2020; Kassie, 2018; Oparinde, 2021).

Propensity score matching (PSM) technique as well as endogenous switching regression (ESR) model could be used to deal with the issue of selection bias, but the major drawback of these approaches is that they can only handle two options such as users and non-users (Ji, 2023; Oparinde, 2021). To address possible selection bias arising from unobservable factors when more than two options exist, the multinomial endogenous switching regression model (MESRM) is most suitable (Ji, 2023; Ding, 2020). This model was therefore used in this study since it corrects for improper randomization of smallholder farmers into the adoption of agroecological cropping systems and thus yields consistent outcome estimates of the impact of agroecological cropping systems on smallholder farmers' net income and technical efficiency.

The MERSM was employed to compare the expected returns between adopters and non-adopters of agroecological cropping systems (Okello, 2021). According to the framework, the relationship between outcome variables (net income and technical efficiency) and the independent variables *X* were estimated for the selected agroecological cropping systems (Okello, 2021; Setsoafia, 2021). Two categories were defined where the base category comprised of smallholder vegetable farmers that did not adopt any agroecological cropping system (j=0) (Okello, 2021) while the other is where farmers adopted one of the alternative combinations of agroecological cropping systems, represented as j=1,2,3 (Okello, 2021; Wanyonyi *et al*., 2021). The outcome estimation model for each possible category (j) is as shown below:

$$\begin{cases} E(T_{i0}|D_i = 0) = X_i\beta_0 + \mu_{i0} \\ E(T_{i1}|D_i = 1 = X_i\beta_1 + \mu_{i1} \\ \vdots \\ E\left(T_{ij}|D_i = j\right) = X_i\beta_j + \mu_{ij} \end{cases} \quad \ldots\ldots\ldots\ldots (14)$$

Where T_{ij} denotes the outcome variable of household i in category j (j=0,1,2,3); X_i represents a set of household characteristics; D_i represents the adoption status with $D_i = 0$ for non-adopters (Ding, 2020; Oparinde, 2021). β is the set of parameters to be estimated using maximum likelihood method; μ is the unobserved disturbance assumed to satisfy $E\left(\mu_{ij}|X_iZ_i\right) = 0$ and $Var\left(\mu_{ij}|X_iZ_i\right) = \sigma_j^2$ (Ding, 2020; Oparinde, 2021). It is worth noting that X and Z may overlap since both signify vectors of household characteristics, but it is imperative that, for the purposes of identification, at least one variable in Z must not be included in X (Ding, 2018; Ding, 2020; Oparinde, 2021).

The multinomial endogenous switching regression model further assumed the normalized linearity assumption $\mu_{ij} = \sigma_j \sum_j \rho_j \varepsilon_j + \omega_{ij}$ (Oparinde, 2021). Given this assumption and following the Dubin and McFadden (1984) framework to address potential bias from the correlation of error terms ε and μ in equations 10 and 14, the outcome equations was specified as follows (Ding, 2020):

$$\begin{cases} T_{i0} = X_i\beta_{i0} + \sigma_0\lambda_0 + \omega_{i0} \; if \; D_i = 0 \\ T_{i1} = X_i\beta_{i1} + \sigma_1\lambda_1 + \omega_{i1} \; if \; D_i = 1 \\ T_{i2} = X_i\beta_{i2} + \sigma_2\lambda_2 + \omega_{i2} \; if \; D_i = 2 \\ T_{i3} = X_i\beta_{i3} + \sigma_3\lambda_3 + \omega_{i3} \; if \; D_i = 3 \end{cases} \quad \ldots\ldots (15)$$

Where ω_{ij} represents the residual term that is orthogonal to ε_{ij} due to the independence of irrelevant alternatives (IIA) assumption (Addai, 2023); σ_j is the covariance between μ and ε; and λ_j is the bias correlation coefficient, computed from the estimated probabilities in equation 13 which is specified as $\lambda_{ij} = \rho_{ij} n(P_{ij}) + \sum_J \rho_{ij} n(P_{ij}) \frac{P_{ij}}{P_{ij}-1}$ (Addai, 2023). In this equation, P_{ij} denotes the probability that a smallholder farmer i selects an option j as obtained from equation 13 (Oparinde, 2021); ρ_j is the correlation coefficient between μ_j and ε_j; $n(P_{ij})$ represents the conditional expectation applied to correct for selectivity bias and $n(P_{ij}) = \int J(v - logP_j) g(v) dv$ where J(.) is the inverse transformation for the normal distribution function and g(.) is the conditional density for the gumbel distribution, $v = \varepsilon_{ij} + logP_j$ (Oparinde, 2021). However, according to Bourguignon *et al*. (2007) this approach will be heteroskedastic which is usual with all two-step correction methods. To deal with this empirical estimation problem the bootstrap method was used (Parvathi & Waibel, 2016).

In order to address unobserved heterogeneity in the determination of equation 15, it is crucial to identify at least one selection instrument beyond those automatically provided by the nonlinearity of the adoption selection model (Kassie *et al*., 2015; Khonje *et al*., 2018; Msangi *et al*., 2022). These instrumental variables should be incorporated into the multinomial logit model (equation 13) but ommitted from the outcome equation (equation 15) (Khonje *et al*., 2018). Therefore, the following set of instruments were excluded from the outcome equation: distance to the input market, distance to the output market, and access to extension services (Gichungi, 2021). Many other empirical studies (Kassie *et al*., 2015; Khonje *et al*., 2018; Zegeye & Meshesha, 2022) have employed similar variables as selection instruments in the estimation of impact of adoption. The admissibility of these instruments was affirmed through falsification tests and correlation analysis, ensuring that they exert no direct influence on farmers' net incomes and technical efficiency, except through the adoption decision (Khonje *et al*., 2018).

To estimate the effect of using agroecological cropping systems, the outcome that the smallholder farmer would achieve if they used a different system from the one that they used was estimated. The average treatment effects (ATE) in the actual and counterfactual scenarios were computed (Di Falco & Veronesi, 2013). The specific outcome equations for the actual and counterfactual situations are presented in equations (16a) and (16b) for users of the cropping systems (Ding, 2020).

$$\begin{cases} E(T_{i1}|D_i = 1) = X_i\beta_{i1} + \sigma_1\lambda_1 \\ E(T_{i2}|D_i = 2) = X_i\beta_{i2} + \sigma_2\lambda_2 \\ E(T_{i3}|D_i = 3) = X_i\beta_{i3} + \sigma_3\lambda_3 \end{cases} \quad \text{......} (16a)$$

$$\begin{cases} E(T_{i0}|D_i = 1) = X_i\beta_{i0} + \sigma_0\lambda_1 \\ E(T_{i0}|D_i = 2) = X_i\beta_{i0} + \sigma_0\lambda_2 \\ E(T_{i0}|D_i = 3) = X_i\beta_{i0} + \sigma_0\lambda_3 \end{cases} \quad \text{......} (16b)$$

The average treatment effect on the treated (ATT) was computed from the difference between equations (16a) and (16b) as shown in equation 17 below (Oparinde, 2021).

$$ATT = E(T_{i1}|D_i = 1) - E(T_{i0}|D_i = 1) = X_i(\beta_{i1} - \beta_{i0}) + \lambda_1(\sigma_1 - \sigma_0) \quad \text{......} (17)$$

Table 3.3

Description of Variables and Expected Signs That Will Be Used in the Multinomial Endogenous Switching Regression Model

Variables	**Description of variables**	**Hypothesized sign**
	Dependent variables	
Vegetable Income	Net income from brassica and traditional African vegetables	
Farmers' technical efficiency	Technical efficiency value from stochastic frontier analysis	
	Treatment variables	

Mixed cropping	Dummy =1 if HH has adopted mixed cropping, otherwise=0	
Strip cropping	Dummy =1 if HH has adopted strip cropping, otherwise=0	
Row intercropping	Dummy =1 if HH has adopted row intercropping, otherwise=0	
Border cropping	Dummy =1 if HH has adopted border cropping, otherwise=0	
Crop rotation	Dummy =1 if HH has adopted crop rotation, otherwise=0	
	Independent	
Gender	Dummy= 1 if the household (HH) head is male and 0 if female	+
Age	Age of the HH head in years	+/-
Education	Highest education level of the HH head (1=None, 2=Primary, 3=Secondary, 4=Tertiary)	+/-
Occupation *	The main occupation(s) of the HH head	+/-
Household size	The total number of household members	+
Ownership of the land	Household member that owns the land (Male=1; Female=0)	+
Management of the land	Household member in charge of management (Male=1; Female=0)	+
Income	The gross income earned from brassica and traditional African vegetable farming in KES and USD	+
Training	Number of training sessions each household has attended	+/-

Contracts	Dummy =1 if the HH has any contract farming, 0 if otherwise	+
Market and Information platform	Dummy =1 if the HH used any market and information platform, 0 if otherwise	+
Other-farm income	Income earned from other activities on the farm except brassica and traditional African vegetable farming in KES and USD	+/-
Off-farm income	Income earned from HH activities beyond the farm in KES and USD	+/-
Credit access	Dummy =1 if the HH received vegetable production and marketing credit, 0 if otherwise	+/-
Group membership	Dummy =1 if the HH is a member of a production and marketing group, 0 if otherwise	+
County	Dummy =1 if the HH is in Kiambu county and 0 if Murang'a county	+/-
Instrumental Variables		
Distance to input market	Distance to input market (walking minutes)	
Distance to output market	Distance to output market (walking minutes)	
Extension services	Dummy =1 if the HH has access to extension services, 0 if otherwise	

Note. HH= Household; KES= Kenyan Shillings; USD = United States Dollar *1= Vegetable production, 2= Other farming activities, 3= Off-farm employment, 4= Casual labor, 5= Own business off-farm, 6= Retired, 7= Unemployed, 8= In school.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results and discussions on the effect of agroecological cropping systems on smallholder farmers' performance in Murang'a and Kiambu counties, Kenya. The study focused on several important agroecological cropping systems, including mixed cropping, strip cropping, row intercropping, border cropping and crop rotation. The results in this section have been delineated in accordance with the objectives, which included characterizing the smallholder farmers; determining the factors which influence their use of agroecological vegetable cropping systems; and assessing the effect of agroecological vegetable cropping systems on the performance of smallholder farmers in Kiambu and Murang'a counties. The analysis of the first objective was done using descriptive statistics and the second objective was analyzed using a multivariate probit model with the third objective analyzed using the multinomial endogenous switching regression model.

4.2 Characterization of Smallholder Farmers Implementing Agroecological Vegetable Cropping Systems

In total 546 households were involved in the study. The distribution of farmers surveyed in each region was 210 farmers (38%) in Kiambu and 336 farmers (62%) in Murang'a. Table 4.1 summarizes the descriptive statistics. On average 78%, 18.5%, 11.9%, 8%, and 7.9% of these smallholder farmers had adopted crop rotation, mixed cropping, strip cropping, row intercrop and border cropping farming systems respectively. This shows that most of the farmers had adopted crop rotation but the adoption rate for all the other cropping systems under study was low (Asfaw, 2019).

The study found that most of these households (82%) were male-headed. Many rural communities in Kenya have this social situation where females are only able to head household in an instance where the main male is not present (Onyalo, 2019). According to Musafiri *et al*. (2020), the gender of the leader of the household is very important in the explanation the adoption of agricultural technology (Zakaria *et al*., 2020). Most of the household heads grow other crops (except vegetables) and keep livestock as their main occupation. Therefore, women within these households are usually more involved in the farming of vegetables than men. As Kanyenji *et al*.

(2020) notes, the main occupation of the household head affects their likelihood of the household adopting some systems (such as intercropping) which may usually be time-consuming to implement (Apeh *et al*., 2024).

Most farmers in the area are relatively elderly, given that the average age of the household head was 54 years. The findings also showed that most had completed secondary school education and therefore were relatively educated. Household heads' higher age and education attainment may lead them to have more control over resources and to be more experienced than younger farmers *(*Ajambo *et al*., 2024; Kanyenji *et al*., 2020; Okello, 2021). The possibility of this happening can influence their adoption of agroecological cropping systems, which often require high initial capital outlay and require a blend of traditional and practical knowledge (Loconto & Fouilleux, 2019). In this study, the size of the household is an approximation of labor endowment, where households do not hire labor (Manda *et al*., 2016; Okello, 2021). On average, each household had four members. As stated by Jindo *et al*. (2020), easy access to family labor is important for smallholder farming systems. According to Debonne *et al*. (2021) it is the small farms that are most likely to depend on family labour (Muyanga & Jayne, 2019).

As regards ownership of land, 67% of the land was owned by male members of the household, 30% of the land was owned by female members of the household whereas only 3% of the land was jointly owned. The results suggest that women have less access to and control over land than their male counterparts and are therefore less economically empowered (International Fund for Agricultural Development, 2020). These findings on land ownership are in slight discordance with results from the study conducted by Ng'ang'a (2015) who reported that only 20.7% of women in Kenya own land. The higher number of women owning land in this study could be linked to the management of land where 57% of the land was managed by women, 36% was managed by men and 7% was jointly managed. According to Andersson (2020), a wife's involvement in productive work on her husband's land may influence her right to land. This postulation is further affirmed by the Land Registration Act of 2012 which stipulates under Section 93(2) that a spouse may obtain joint ownership of their partner's land if they contribute their labor or other resources towards its productivity, maintenance or improvement (Andersson, 2020).

The mean income that the farmers earned from other farm activities (except vegetable farming) was KES 117,234 (USD 1086.51); the mean income they earned from activities beyond the farm was KES 75,758 (USD 702.11); while the mean gross income that they earned from crucifer and traditional African vegetable farming was KES 58,138 (USD 538.81). This significantly showed that smallholder farmers have diversified their sources of income with crucifer and traditional African vegetable farming being the lowest contributor to their overall earnings. The higher incomes earned from other farm and non-farm activities imply that these farmers may be more experienced or prefer pursuits beyond vegetable farming (Ezeanyika, 2023). These findings are however different from those of Chepkoech *et al*. (2020) conducted on smallholder traditional African vegetable farmers in Kenya where the majority of the farmers surveyed had no access to off-farm income and relied solely on a single source of livelihood.

From Table 4.1, it can be observed that, on average, the smallholder vegetable farmers had been trained on fewer than one occasion on improved method of vegetable production and pest management. Most smallholder farmers are likely to face challenges in the effective adoption of the agroecological cropping systems due to limited exposure to such training (Kirui *et al*.,2023). Farmers with greater exposure to training on farming have higher potential to adopt (Chepkoech *et al*., 2020). Similarly, Karuga (2022) observed that the adoption of mixed and integrated cropping by farmers in Kiambu increased as a result of training provided by government and non-governmental agents. It is thus important to expand access to comprehensive training of smallholder vegetable farmers (Dabkiene *et al*., 2025).

Of the farmer respondents contacted for the study, 11.9% had received production and marketing credit. According to Musembi (2019), limited access to agricultural credit negatively affects the ability of the low-income farmers to adopt new technologies making them more vulnerable to climate change. Moreover, fewer than 3% of the smallholder farmers utilized market and information platforms. The result differs from Krell *et al*. (2021) who studied farming households in Central Kenya and found that 25% are using mobile phones to access agri and livestock-related information while 23% use mobile phones to obtain information on buying and selling products. Therefore, stakeholders engaged in the development of digital marketing platforms should focus on a sufficiently comprehensive training and knowledge sharing to improve the accessibility and usage of these platforms effectively (Maina *et al*., 2023).

Only 1.5% of the smallholder farmers studied had adopted contract farming. This indicates that very few of them reaped the benefits of contract farming such as higher incomes, productivity, and efficiency due to price incentives (Ogutu *et al*., 2020). Furthermore, only a small fraction, 5.7%, belonged to a production and marketing group. Membership in a production and marketing group helps to build farmers' social capital; increases information access; and allows farmers to learn from each other (Kanyenji *et al*., 2020). It is apparent that participation in these groups is low even though increased group membership could enhance the probability of farmers adopting agroecological cropping practices (Kanyenji *et al*., 2020).

Farmers were 58 and 65 walking minutes away from input and output markets, respectively. These distances reflect the transport and transaction costs associated with transporting vegetables as well as purchasing inputs from the markets (Kanyenji *et al*., 2020). Additionally, the findings showed that 35% of the farmers had the opportunity to access extension services. Availability of extension services increases awareness of agroecological practices and their efficiencies (Oyetunde-Usman *et al*., 2021). Furthermore, availability of extension services has widely been found to impact the adoption of agricultural technologies positively (Musafiri *et al*., 2022; Rebecca *et al*., 2018).

Table 4.1

Description and Descriptive Statistics of the Variables Used in This Study

Variable	Description of variables	Mean	Std. Dev.
	Dependent		
Mixed cropping	Dummy = 1 if HH has adopted mixed cropping, 0 if otherwise	0.185	0.389
Strip cropping	Dummy = 1 if HH has adopted strip cropping, 0 if otherwise	0.119	0.324
Row intercrop	Dummy = 1 if HH has adopted row cropping, 0 if otherwise	0.082	0.275
Border cropping	Dummy = 1 if HH has adopted border cropping, 0 if otherwise	0.079	0.270
Crop rotation	Dummy = 1 if HH has adopted crop rotation, 0 if otherwise	0.780	0.414
	Independent		
Gender	Dummy = 1 if the household (HH) head is male and 0 if female	0.817	0.387

Age	Age of the HH head in years	53.628	12.612
Education	The highest education level of the HH head (1=None, 2=Primary, 3=Secondary, 4=Tertiary)	1.678	0.756
Occupation*	The main occupation(s) of the HH head	2.423	1.364
Household size	The total number of household members	4.216	1.881
Female ownership	Dummy = 1 if any plot of land is owned by a female household member, 0 if otherwise	0.300	0.459
Male ownership	Dummy = 1 if any plot of land is owned by a male household member, 0 if otherwise	0.667	0.472
Female management	Dummy = 1 if any plot of land is managed by a female household member, 0 if otherwise	0.568	0.496
Male management	Dummy = 1 if any plot of land is managed by a male household member, 0 if otherwise	0.357	0.480
Gross Income	The gross income earned from crucifer and traditional African vegetable farming in KES (USD 538.81)	58,138.652	101,249.450
Training	Number of training sessions each household has attended	0.484	0.999
Contracts	Dummy = 1 if the HH has any contract farming, 0 if otherwise	0.015	0.120
Market and information platform	Dummy = 1 if the HH used any market and information platform, 0 if otherwise	0.029	0.169
Other farm income	Income earned from other activities on the farm except for crucifer and traditional African vegetable farming in KES (USD 1086.51)	117,234.070	185,225.340
Off-farm income	Income earned from HH activities beyond the farm in KES (USD 702.11)	75,758.007	180,424.800
Credit access	Dummy = 1 if the HH received vegetable production and marketing credit, 0 if otherwise	0.119	0.324
Group	Dummy =1 if the HH is a member of a production	0.057	0.232

membership	and marketing group, 0 if otherwise		
Distance to input market	Distance to input market (walking minutes)	57.493	74.233
Distance to output market	Distance to output market (walking minutes)	65.412	84.198
Extension services	Dummy=1 if the HH has access to extension services, 0 if otherwise	0.350	0.477
County	Dummy=1 if the HH was in Kiambu, 0 if the HH was in Murang'a	1.385	0.487

Note. HH refers to Household: KES refers to Kenyan Shillings; USD refers to United States Dollar; *1= Vegetable production, 2= Other farming activities, 3= Off-farm employment, 4= Casual labor, 5= Own business off-farm, 6= Retired, 7= Unemployed, 8= In school.

4.3 Determination of Factors Influencing the Adoption of Agroecological Cropping Systems

4.3.1 Complementarity and Tradeoff Among Agroecological Cropping Systems

Results of the complementarities and substitutability of the agroecological cropping systems are presented in Table 4.2. The likelihood ratio test [$\chi^2 = 28.8445$] showed significance at $p < 0.01$, therefore rejecting the null hypothesis of independence among the agroecological cropping systems under the study (Muriithi *et al*., 2018). The findings indicated a positive correlation between crop rotation and mixed cropping and between row intercropping and strip cropping which indicates that these cropping systems were adopted as complements. These findings are similar to those of Kemboi *et al*. (2020) who found that farmers in Kenya that diversify production often adopt both crop rotation and mixed cropping. Conversely, the results indicated that both row intercropping and border cropping were negatively correlated with mixed cropping. This suggests that smallholder households that have limited resources usually adopt these cropping systems as substitutes (Ochieng *et al*., 2022). The interdependence of these cropping system choices implies that if a univariate probit or logit regression were to be fitted, this would have yielded inefficient estimates (Kanyenji *et al*., 2020).

Table 4.2

Complementarity and Substitutability of Agroecological Cropping Systems: Correlation Coefficient of Error Term Matrix

	Mixed cropping	Strip cropping	Row intercropping	Border cropping	Crop rotation
Mixed cropping	1				
Strip cropping	-0.056	1			
	(0.099)				
Row intercropping	-0.445***	0.346***	1		
	(0.096)	(0.127)			
Border cropping	-0.192*	-0.176	0.024	1	
	(0.107)	(0.110)	(0.121)		
Crop rotation	0.212**	0.067	-0.093	0.008	1
	(0.083)	(0.085)	(0.090)	(0.101)	

Note. Robust standard errors are in parenthesis. The likelihood ratio test of regression interdependence χ^2 (10) = 28.8445***. The asterisks ***, **, and * represent 1%, 5%, and 10% significant levels respectively.

4.3.2 Factors Influencing the Adoption of Agroecological Cropping Systems

Findings from the multivariate probit model estimation are given in Table 4.3. A Wald Chi-square test [χ^2 (105) = 196.52] showed significance at $p < 0.01$, which indicates that the model is a good fit. The findings show that male headed households were 26.3% less likely to adopt a mixed cropping system compared to female headed households. In contrast, female-headed households had a 16.8% lower likelihood of adopting row intercropping than male-headed households. The associations were statistically significant at $p < 0.01$. Male household heads are stronger than female ones, therefore more likely to implement labor-intensive practices such as row intercropping (Adzawla *et al*., 2019; Kanyenji *et al*., 2020; Zeweld *et al*., 2018). Likewise, Mmbando *et al*. (2021), found that male-headed household in Tanzania were more likely to adopt row cropping over female-headed households (Meshesha, 2023). According to the findings of Teklewold *et al*. (2020) female farmers were also less likely to take risks compared to male farmers (Mwangi, 2021; Onyeneke et al., 2025). Kurgat *et al*. (2020) proved that mixed cropping is likely to take place in household farms where farm resources are under the control of the female head.

However, Oyetunde-Usman *et al*. (2021) found that mixed cropping system adoption was less likely among female headed households in Nigeria. The results indicate that the gender relationship with preferences for cropping systems is complex, which requires more insights into the context of these relationships.

The study found that if the main occupation of the head of the household has nothing to do with producing vegetables, there is a positive and significant effect ($p < 0.01$) on adopting row intercropping by 3 percent (Tesgera *et al*., 2024). The involvement of the household head in other occupations might limit their time and resources from managing a separate vegetable plots (Tesgera *et al*., 2024 As a result, they might go for row intercropping since they are able to put all their vegetable in one plot which is easy to observe and manage. Engaging in off-farm employment could also increase opportunities for the household to earn income from sources other than farming. Farmers can utilize the extra income to access essential resources such as hired labor and capital which facilitates the successful adoption of row-intercropping (Ndiritu *et al*., 2014; Odendo *et al*., 2010).

The chances of adopting mixed cropping significantly ($p < 0.1$) declined by 13.2% when the plot was owned by female household members. The bargaining power of women within the households has improved and enabled them to make decisions regarding the use of land (Osanya *et al*., 2020; Yokying & Lambrecht, 2020). Owning land enables women to explore additional plots instead of trying to fit more crops into a limited space, hence reducing their interest in mixed cropping. The finding aligns with the results of Ruzzante *et al*. (2021). It also suggests that when making decisions on the adoption of vegetable cropping systems, female landowners are not primarily concerned with mixed cropping objectives, such as crop diversification and risk reduction (Tüzel & Öztekin, 2018). On the other hand, when the land is owned by a male member, there is a significant ($p < 0.1$) 10.9% decrease in the chances of the household practicing row intercropping. Accordingly, it gives an indication that male landholders might have specific plans about their lands that might fit with the requirements of row intercropping, which involve elaborate processes in which planting, management and harvest are done (Himanen *et al*., 2016; Huss *et al*., 2022). Our results agree with other studies which found gender differences and different preferences in the uptake of agricultural technologies. This has been attributed to difference in ownership of land between male and female (Mairura *et al*., 2021; Theis *et al*., 2018; Yokying & Lambrecht, 2020).

Vegetable plots managed by female household members were significantly ($p < 0.05$) more likely to engage in border cropping than those managed by male household members. On the other hand, there was a significantly higher adoption of mixed cropping ($p < 0.01$) as well as crop rotation ($p < 0.05$), on plots managed by male household members. Women were significantly ($p < 0.01$) more likely to undertake strip cropping than men. Empowerment strongly influences plot managers' capacity to make decisions. The higher possibility of male family members using crop rotation, for example, may arise from the larger number of male landowners as compared to women ones. In Nigeria, male plot managers were more empowered and, thus, more likely to practice crop rotation than female plot mangers (Oyawole *et al*., 2021). The findings also resemble similar studies conducted in Kenya and Malawi whose plot manager gender affects the adoption of agroecological cropping systems (Ng'ang'a *et al*., 2019; Muriithi *et al*., 2018; Ngigi & Muange, 2022; Tufa *et al*., 2022).

Higher gross income from vegetable production was found to significantly and negatively ($p < 0.01$) affect mixed cropping and row intercropping adoption contrary to findings by Ooga and Gikunda (2021). In other words, mixed cropping and row intercropping are more common among vegetable farmers with lower vegetable income. Smallholder farmers producing lesser vegetables might be less economically dependent on it because vegetable farming does not constitute their primary economic activity (Benitez-Altuna *et al*., 2021). This may increase the likelihood of farmers testing out agroecological cropping techniques like mixed cropping and row intercropping. Accordingly, those farmers doing vegetable production regularly and earning higher incomes are less likely to adopt mixed cropping and row intercropping.

Farmers who attended more trainings were significantly ($p < 0.1$) more likely to adopt crop rotation compared to other farmers. This could be because crop rotation requires certain knowledge and skills during the implementation and continued management. Mairura *et al*. (2021) found that training farmers on agriculture enhanced their knowledge, skills and awareness, and so had a positive effect on adoption of crop rotation in the Central Highlands of Kenya. Our results are however contrary to those of Zeweld *et al*. (2018) in Ethiopia, who observed that technical training had no significant effect on farmers' adoption of crop rotation (Gichungi, 2021).

Access to market information platforms strongly ($p < 0.1$) and positively influenced strip cropping adoption but significantly ($p < 0.1$) and negatively influenced on the adoption of crop rotation (Mebrate *et al*., 2022). This implies that the decision to employ strip cropping was positively influenced by the market information, possibly due to its increased alignment with market demand (Muriithi *et al*., 2021). On the other hand, the market information might have indicated certain market conditions that would favor other cropping systems over crop rotation in vegetable farming (Selim, 2019). The results of Mwikamba *et al*. (2021) are however different from these findings as they indicated an increase in the use of cropping systems like agroforestry and crop rotation by horticulture farmers in Kenya, because of market information through mobile phones.

Income earned from other farm activities apart from vegetables had a strong positive correlation with adoption of strip cropping, crop rotation and row intercropping. The impact of this income was significant ($p < 0.1$) for strip cropping and crop rotation, and highly significant ($p < 0.01$) with row intercropping. Higher income from diverse farm enterprises for instance fruit cultivation, sale of livestock and livestock products, among others, plays an important role in the use of agroecological cropping systems. The extra income obtained from these farm activities enables farmers to afford the inputs required to implement the agroecological cropping systems (Ng'ang'a *et al*., 2019; Wairore *et al*., 2016). In addition, their greater income means more of their production takes place. Weeds, leaves, food waste, farm waste, and manure can be used as organic by-products for vegetable production systems (Zeweld *et al*., 2018). Organic inputs lessen the dependence on external inputs in vegetable cropping systems and promote the adoption of input-intensive practices such as row intercropping as reported by Kanyenji *et al*. (2019).

The amount of time spent walking from the farm to the input market positively and significantly ($p < 0.1$) influenced the practice of strip cropping. This indicates that smallholder farmers further from the input markets adopted strip cropping more than other farmers. This may be because it requires the transaction costs that are needed to obtain inputs (Kanyenji *et al*., 2020) for other cropping systems. Farmers may therefore use strip cropping as it uses less input. Alternatively, the minutes it takes to walk from the farm to the sales market may also represent an access to information and technology indicator (Kanyenji *et al*., 2020). In this study it negatively and significantly influenced ($p < 0.1$) the adoption of strip cropping. This means that smallholder farmers who are nearer to sales markets are more exposed to information hence, possess higher probability of adopting strip cropping. Farmers' choice to adopt strip cropping is influenced positively by market information, which is consistent with earlier findings. Similarly, Nyang'au *et* *al*. (2021) found that the information that farmers obtain from the markets encourages the use of agroecological cropping systems in Kisii, Kenya (Kirui *et al*., 2023).

Use of extension services positively and significantly affected adoption of mixed cropping ($p < 0.01$), border cropping ($p < 0.05$), and crop rotation ($p < 0.1$) (Mebrate *et al*., 2022). As noted by Oyetunde-Usman *et al*. (2021) extension services can help to enhance awareness of agricultural technologies and demonstrate their effect on improved production. A study conducted by Zeweld *et al*. (2018) in Ethiopia found access to extension services has a positive and significant impact on the adoption of crop rotation. On the other hand, extension services had negative impacts on the adoption of strip cropping and row intercropping that were statistically significant at probability levels of ($p < 0.01$) and ($p < 0.05$) respectively (Kule *et al*., 2025). This could be due to the fact that many households in the study area have been implementing these cropping systems for a long time (Ngaiwi, 2023). As extension workers give more education on these cropping systems, some farmers may perceive them as old farming methods and so stop using them (Kanyenji *et al*., 2020). Likewise, Kanyenji *et al*. (2020) found that extension services negatively affect intercropping adoption in Kenya (Mdoda *et al*., 2023). For this reason, even though extension services may have a positive effect on the adoption of agroecological cropping systems, extension officers should fully understand the context and needs of farmers(Mugambi *et al*., 2021).

According to the findings, households located in Kiambu were 9.5% and 8.7% more likely to adopt row intercropping and crop rotation, respectively, but they were 6.8% less likely to adopt border cropping than those located in Murang'a. The higher adoption rates of row intercropping and crop rotation in Kiambu suggest greater emphasis on sustainable and diversified farming techniques in the region. Factors such as access to markets, information availability, and robustness of social networks may enhance the adoption of agricultural technologies by farmers in Kiambu County (Gikunda *et al*., 2020). These studies revealed that strategies to enhance any adoption of technology must take into account the regional requirements and constrains of the intended target sector (Khan & Xiangyu, 2020; Khan *et al*., 2025).

Table 4.3

Adoption of Agroecological Cropping Systems: Multivariate Probit Model Results (MVP) results

	Mixed cropping		**Strip cropping**		**Row intercropping**		**Border cropping**		**Crop rotation**	
	Coefficient	Std. Err	Coefficient	Std. Err	Coefficient	Std. Err	Coefficient	Std. Err	Coefficient	Std. Err
Gender	-1.053***	0.311	-0.367	0.287	1.131***	0.329	-0.060	0.305	-0.131	0.233
(Male=1; Female=0)	(-0.263)		(-0.064)		(0.168)		(-0.001)		(-0.036)	
Age (Years)	0.002	0.006	-0.008	0.007	-0.000	0.008	-0.002	0.008	0.000	0.005
	(0.001)		(-0.001)		(0.000)		(-0.000)		(-0.000)	
Education	-0.003	0.100	-0.028	0.117	0.116	0.142	0.136	0.131	0.104	0.095
(1=None, 2=Primary, 3=Secondary, 4=Tertiary)	(-0.000)		(-0.004)		(0.020)		(0.019)		(0.027)	
Occupation ✖	0.061	0.054	0.060	0.060	0.220***	0.072	-0.036	0.065	-0.072	0.049
	(0.014)		(0.012)		(0.030)		(-0.006)		(-0.018)	
Household size	-0.009	0.038	-0.064	0.044	-0.080	0.057	0.009	0.049	0.009	0.036
	(-0.002)		(-0.010)		(-0.009)		(0.000)		(0.003)	
Female ownership	-0.535*	0.299	-0.064	0.362	0.210	0.383	0.048	0.311	0.103	0.259
(1= Yes; 0=No)	(-0.132)		(-0.011)		(0.022)		(0.003)		(0.033)	
Male ownership	0.319	0.317	0.324	0.365	-0.668*	0.382	0.108	0.312	0.060	0.256
(1= Yes; 0=No)	(0.080)		(0.051)		(-0.109)		(0.011)		(0.019)	
Female manager	0.188	0.211	-0.173	0.217	-0.059	0.288	0.568**	0.271	0.157	0.191
(1= Yes; 0=No)	(0.044)		(-0.032)		(-0.005)		(0.074)		(0.043)	
Male manager	0.716***	0.222	-0.789***	0.239	-0.001	0.298	-0.214	0.284	0.477**	0.200

(1= Yes; 0=No)	(0.173)		(-0.138)		(0.007)		(-0.023)		(0.124)	
Gross income (KES)	-0.000***	0.000	0.000	0.000	-0.000***	0.000	0.000	0.000	0.000	0.000
	(-0.000)		(0.000)		(-0.000)		(-0.000)		(0.000)	
Training	-0.006	0.071	-0.039	0.089	-0.050	0.115	0.092	0.082	0.139*	0.079
	(-0.002)		(-0.005)		(-0.006)		(0.012)		(0.038)	
Contracts	-0.065	0.606	-0.024	0.576	-4.977	320.426	0.069	0.710	-0.453	0.498
(1= Yes; 0=No)	(-0.020)		(-0.001)		-		(0.016)		(-0.128)	
Market information	-0.398	0.444	0.792*	0.408	-4.785	276.023	0.401	0.479	-0.722*	0.399
(1= Yes; 0=No)	(-0.094)		(0.139)		-		(0.049)		(-0.180)	
Other farm income	0.000	0.000	0.000*	0.000	0.000***	0.000	0.000	0.000	0.000*	0.000
(KES)	(0.000)		(0.000)		(0.000)		(0.000)		(0.000)	
Off-farm income	-0.000	0.000	0.000	0.000	-0.000	0.000	0.000	0.000	-0.000	0.000
(KES)	(-0.000)		(0.000)		(-0.000)		(0.000)		(-0.000)	
Credit access	-0.123	0.225	-0.106	0.240	-4.567	127.586	-0.088	0.256	0.044	0.204
(1= Yes; 0=No)	(-0.033)		(-0.016)		-		(-0.009)		(0.010)	
Group membership	0.358	0.289	-0.000	0.350	-4.972	180.368	-0.668	0.462	0.004	0.302
(1= Yes; 0=No)	(0.085)		(0.001)		-		(-0.082)		(-0.012)	
Distance to input	0.003	0.002	0.010*	0.006	0.001	0.002	-0.002	0.003	0.003	0.002
market (minutes)	(0.001)		(0.002)		(0.000)		(-0.000)		(0.001)	
Distance to sales	-0.002	0.002	-0.010*	0.006	-0.000	0.002	0.000	0.003	0.001	0.002
market (minutes)	(-0.001)		(-0.002)		(-0.000)		(0.000)		(0.000)	
Extension services	0.443***	0.149	-0.567***	0.198	-0.481**	0.226	0.464**	0.191	0.284*	0.152
(1= Yes; 0=No)	(0.104)		(-0.102)		(-0.066)		(0.061)		(0.075)	
County (1=Kiambu;	0.085	0.144	-0.010	0.160	0.770***	0.205	-0.517**	0.205	0.306**	0.142

0=Murang'a)	(0.021)		(-0.001)		(0.095)		(-0.068)		(0.087)	
Constant	-0.905*	0.528	-0.184	0.618	-3.147***	0.749	-1.432**	0.663	-0.335	0.499

Note. Number of observations = 546; Log likelihood = -907.67674; Wald $\chi^2(105)$ = 196.52; Prob > χ^2 = 0.0000; : The asterisks ***, **, and * represent 1%, 5%, and 10% significant levels respectively (Figures in parentheses are average marginal effects); KES=Kenyan Shillings; ×1= Vegetable production, 2= Other farming activities, 3= Off-farm employment, 4= Casual labor, 5= Own business off-farm, 6= Retired, 7= Unemployed, 8= In school.

4.4 Effect of Agroecological Cropping Systems on the Performance of Smallholder Farmers

4.4.1 Technical Efficiency of Smallholder Farmers

The maximum-likelihood estimation result of the stochastic frontier analysis is presented in Table 4.4. This analysis was conducted to obtain the value of the technical efficiency of smallholder brassica and traditional African vegetable farmers. The Wald Chi-square statistic [χ^2 (4) =225.73] was significant at $p<0.01$, which stipulates the rejection of the null hypothesis that all the parameters included in the model are simultaneously equal to zero, suggesting that the model is a good fit (Belete, 2020). However, before conceding the results of the stochastic frontier model, there is need to test the null hypothesis that there is no inefficiency in brassica and traditional African vegetable production (Eshetu *et al*., 2022). The test results as presented in Table 4.4 show that this null hypothesis of no inefficiency is rejected because the value of lambda (λ) is 1.413, therefore greater than 1, and this value is also statistically significant at $p<0.01$.

The results presented in Table 4.4 show that labor was positively and significantly correlated with vegetable production at $p<0.01$. Labor had the highest positive elasticity of 0.588 which indicates that a 1% increase in the number of people working on a farm increases the vegetable output by 0.588%. This suggests that higher availability of labor allows for improved care and maintenance as well as for better utilization of the available land. This may be because vegetable farming is usually labor intensive, requiring significant manual input for land preparation, weeding, irrigation, pest management, and harvesting (Alulu *et al*., 2020; Kotir *et al*., 2020). Canwat *et al*. (2021) similarly found that vegetable output from farming in Kenya was positively influenced by increased labor. Nevertheless, the high labor elasticity shows that demand for labor is the most limiting factor for smallholder vegetable producers, and has the potential to hinder them from maximizing their output (Makena *et al*., 2023).

Farmers' application of pesticides (insecticides, fungicides, and herbicides) was also positively and significantly correlated with vegetable production at $p<0.01$. Every 1% increase in pesticides application on the farm increased vegetable output by 0.158%. Essentially, controlling pests and diseases through the application of pesticides led to improved crop health and therefore increased vegetable production. These results concur with those of Wamuyu *et al*. (2022). They further showed that the proportion of land used in production is positively and significantly correlated with vegetable production at $p<0.1$ and a 1% increase in the total area of land cultivated increases vegetable output by 0.147%. This echoes the work by Thomas *et al*. (2020) who established that increasing the acreage of land under tomato cultivation increased its output.

Table 4.4

Estimation Results of the Stochastic Frontier Model for Vegetable Production

Log of Covariates	Coefficient	Std.Err	z	P>z
Labor	0.588***	0.070	8.440	0.000
Area of land	0.147*	0.080	1.840	0.066
Total value of assets	0.053	0.037	1.420	0.156
Total amount of pesticides	0.158***	0.024	6.670	0.000
Constant	6.553***	0.393	16.650	0.000
		Variance Parameters		
Sigma u (σ_u)	1.429***	0.158	9.040	0.000
Sigma v (σ_v)	1.011***	0.075	13.550	0.000
Lambda (λ)	1.413***	0.220	6.420	0.000

Note. *$p < 0.1$; ***$p < 0.01$; Dependent variable is log of vegetable produced; Number of observations= 546; Wald chi2(4) = 225.73; Prob > chi2 = 0.0000; Log likelihood = -925.4058.

4.4.2 Alternative Combination of Agroecological Cropping Systems

This research considered five agroecological cropping systems used by smallholder farmers: mixed cropping, strip cropping, row intercropping, border cropping and crop rotation. Among these, mixed cropping, strip cropping, row intercropping, and border cropping were considered multiple cropping systems which is the practice of planting and harvesting single crop species more than once in a year (Blanco-Canqui & Lal, 2010; Waha *et al*., 2020). These cropping systems were analyzed together due to their similarities and common goala of diversifying agricultural production (Waha *et al*., 2020). The research was thus carried out on two cropping systems: multiple cropping and crop rotation. A binary variable was used to show the adoption of these cropping systems: 1 was recorded if they adopted and 0 if they did not adopt.

However, farmers often use cropping systems combinations in sequence over time rather than relying solely on a single cropping system (Khonje *et al*., 2018). It is important for studies assessing the adoption of cropping systems and their impacts to consider a dynamic approach (Khonje *et al*., 2018). Thus, the analysis of the choices of alternative combinations of agroecological cropping systems (including monocropping "M_0C_0" where none of the cropping systems were adopted either singly or in combination) by smallholder farmers is presented in Table 4.5. The finding indicated that the majority of smallholder farmers (45.05%) adopted only crop rotation (M_0C_1). According to Autio *et al*. (2021) these smallholder farmers may have secure land tenure rights that afforded them the freedom to adopt this cropping system. Other studies carried out by Chepchirchir *et al*. (2021) and Nyang'au *et al*. (2021) support the finding that smallholder farmers in Kenya extensively practice crop rotation.

A combination of crop rotation and multiple cropping (M_1C_1) was adopted by 32.97% of the farmers. Small scale farmers in Kenya often use multiple technologies at the same time and manage them simultaneously across different plots of land. (Mairura *et al*., 2022). In the same vein, Otieno *et al*. (2021) found that a good number of farmers sampled in the central highlands of Kenya combine crop rotation and intercropping. Moreover, 13.19% of the farmers had not adopted any of the cropping systems and thus adopted monocropping (M_0C_0) while 8.79% had adopted multiple cropping only (M_1C_0). This shows there are diverse objectives among the smallholder farmers as well as differences in the kinds of crops planted (Kemboi *et al*., 2020). However, Owade *et al*. (2020) report that, on average, smallholder farmers growing cowpea leaves in Kenya, have adopted both monocropping and intercropping in equal measure.

Table 4.5

Alternative Combinations of Agroecological Cropping Systems

		Multiple Cropping (M)		Crop Rotation (C)			
Choice (j)	Combination	M_1	M_0	C_1	C_0	Frequency	Percentage (%)
1	M_0C_0		✓		✓	72	13.19
2	M_0C_1		✓	✓		246	45.05
3	M_1C_0	✓			✓	48	8.79
4	M_1C_1	✓		✓		180	32.97

Note. n = 546 households; Subscript 1= adoption, and 0 = non-adoption

4.4.3 Multicollinearity Diagnosis

Regression analysis commonly suffers from multicollinearity. A variance inflation factor (VIF) was employed to evaluate its presence by determining whether there is any misspecification problem among the independent variables used in the objective three analysis (Sarma & Rahman, 2020). The test results from VIF analysis, as presented in Table 4.6 below, show that for all the independent variables the VIF was lower than 3.500 and that the overall mean VIF was 1.580. These values are lower than the threshold mean of 10 that is typically used as a rule of thumb to indicate multicollinearity (Sarma & Rahman, 2020). Therefore, in the case of approximate models using these independent variables, multicollinearity is not a concern.

Table 4.6

Multicollinearity Test Results

Variable	VIF	1/VIF
Female ownership	3.500	0.286
Male ownership	3.500	0.286
Male manager	2.320	0.431
Female manager	2.270	0.441
Gender (HHH)	2.200	0.455
Occupation (HHH)	1.330	0.750
Education (HHH)	1.220	0.817
Trainings	1.170	0.856
Off-farm income	1.150	0.873
Gross income	1.120	0.893
Market Information	1.110	0.899
Age (HHH)	1.110	0.903
Group membership	1.090	0.919
Credit access	1.090	0.921
Household size	1.080	0.923
Other farm income	1.080	0.925

County	1.070	0.938
Contracts	1.040	0.960
Mean VIF	1.580	

Note. HHH=Household head

4.4.4 Determinants of Adoption of the Different Alternatives of Agroecological Cropping Systems

The results of the multinomial logit regression are presented in Table 4.7. The test of the goodness of fit of the model (Wald Chi-square statistic [χ^2 (63) =200.274]) is significant at p<0.01, therefore rejecting the null hypothesis that all the regression coefficients are jointly equal to zero, implying that the model is a good fit (Ngango *et al*., 2021). The results confirm that the instrumental variables used in the analysis are valid as they jointly significantly influence adoption but do not influence the outcome variables such as net income and technical efficiency (see Tables 4.9 and 4.10). The estimated coefficients of the multinomial logit model correspond to the effects of the independent variables on the log-odds of choosing a particular agroecological cropping system relative to the reference category of non-adoption (M_0C_0) (Nguyen-Van *et al*., 2017). However, for clarity and convenience, this study primarily focuses on interpreting the average marginal effects on the individual probabilities (Khonje *et al*., 2018; Nguyen-Van *et al*., 2017). These results are outlined in Table 4.8 and reveal notable disparities in the average marginal effects across various choices of agroecological cropping systems.

The gender of the household head negatively and significantly influenced the adoption of crop rotation and multiple cropping (M_1C_1). It shows that male household members were less likely than females to adopt this cropping system combination. This may be because of the perceived risks associated with crop rotation and multiple cropping systems, such as the uncertain crop yields, uncertain markets, and uncertain returns (Benitez-Altuna *et al*., 2021; Kyire *et al*., 2023). Men who head households are often mostly responsible for the economic welfare of the household. They are therefore likely to be more risk averse and prefer the perceived stability of monoculture farming (Osanya *et al*., 2020; Reynolds *et al*., 2020). These findings are consistent with other researchers (Gikonyo *et al*., 2022; Kanyenji *et al*., 2020; Nyarindo *et al*., 2024) which found that a male headed household in Kenya is less likely to adopt sustainable agricultural technologies and their combinations.

Well-educated smallholder farmers were more likely to adopt crop rotation combined with multiple cropping (M_1C_1). Conversely, they were less likely to adopt only multiple cropping. Educated smallholder farmers are informed on problems and solutions of vegetable cropping and, therefore, able to appreciate the merits of adopting this cropping systems combination (Khonje *et al*., 2018; Zerssa *et al*., 2021). They may recognize that crop rotations help to spread the risk of losses, over different crops and seasons, that multiple cropping alone may not adequately address (Yu *et al*., 2022). A mix of crop rotation plus multiple cropping may be seen as a more diversified risk management strategy, likely performing better than multiple cropping only (Lv *et al*., 2023). Mwaura *et al*. (2021) also surveyed smallholder farmers in central Kenya and reported that the education level of household head positively and significantly affected the adoption of a combination of organic-based technologies.

The occupation of the household head had a positive influence on the adoption of multiple cropping (M_1C_0). Multiple cropping was adopted more in households where the main occupation of the household head was non-agricultural production activities. Households participating in non-agricultural production activities tend to have a number of income sources and may be able to afford the adoption of agricultural practices such as multiple cropping (Danso-Abbeam *et al*., 2020; Kundu & Das, 2022). Similarly, Danso-Abbeam *et al*. (2020) reported that the adoption of farm technologies by smallholder farmers was positively influenced by income derived from non-farm activities.

Household size had a negative and significant effect on the adoption of multiple cropping systems (M_1C_0). This shows that, with growing household size, the chances of adopting multiple cropping systems reduces. As the number of people in the household increases, the financial burden of providing for the additional family members similarly increases (Peng *et al*., 2022). The resources may be low for investing in the effective adoption and management of multiple cropping systems, which may impede their adoption. Studies by Ehiakpor *et al*. (2021) and Musafiri *et al*. (2022) found that the household size negatively affected the agricultural technologies adopted by farmers. However, Muriithi *et al*. (2021) however, obtained varying findings that household size has a positive influence on adoption of crop diversification practices of small-scale farmers in lower Eastern Kenya.

Gross income earned from vegetable farming has positive and significant impact on adoption of crop rotation (M_0C_1) while it has negative and significant impact on adoption of multiple cropping (M_1C_0). The difference might arise due to differing risk perception and time horizons of the two cropping systems. When vegetable farmers' gross income gets high, they are likely to invest in crop rotation. This is because the benefit of this practice covers different seasons and risks are perceived to be low over time (Waaswa *et al*., 2022; Yu *et al*., 2022). On the other hand, there may be less likelihood for vegetable farmers to opt for multiple cropping systems as their gross income increases because multiple cropping systems refer to growing several crops simultaneously in the same growing season (Blanco-Canqui & Lal, 2010). These farmers may consider the risks and costs associated with the implementation of multiple cropping systems as more immediate than the benefits, probably because they lay greater emphasis on short-term profits (Benitez-Altuna *et al*., 2021; Huss *et al*., 2022; Khanal *et al*., 2021). As a result, they might not want to go for these cropping systems. This supports the findings by Waaswa *et al*. (2021) regarding the adoption of crop rotation by smallholder potato farmers in Gilgil, Kenya who found that as farm income grows, the adoption of this practice also grows..

Access to contracts positively and significantly affected the adoption of multiple cropping systems (M_1C_0). Farmers who had access to contracts were more willing to adopt multiple cropping systems than monocropping. It is probably because contracting companies supply farmers with production inputs as well as guaranteed markets for growing specific crops (Dedehouanou *et al*., 2013; Dubbert *et al*., 2023). Under such circumstances, smallholder farmers may be encouraged to invest in multiple cropping systems as they are equipped with the correct inputs for cultivation and support (Dubbert *et al*., 2023; Mulwa *et al*., 2021).According to the research by Gikunda and Lawver (2020) the contracts between farmers and exporter companies in central Kenya contributed to increased adoption of organic farming practices. However, Dubbert *et al*. (2023) found that the participation of households in Ghana in contract farming inhibited the uptake of sustainable farming practices.

Using a market information platform positively and significantly influenced the adoption of multiple cropping systems (M_1C_0). This means that farmers who were aware of markets adopted multiple cropping over monocropping. This may be because consumers may prefer products that are environmentally friendly to signal a greater social status (Constantino *et al*., 2022; Griskevicius *et al*., 2010). Therefore, farmers might adopt more sustainable practices based on evidence from their market information platforms in order to reflect consumer and other market preferences (Dessart *et al*., 2019). Similarly, horticultural farmers in Taita-Taveta, Kenya, increasingly adopted climate-smart practices due to their use of mobile phones to access market information (Mwikamba *et al*., 2021).

Higher income earned from other farm activities (except vegetable production) made smallholder farmers more willing to adopt a combination of multiple cropping and crop rotation (M_1C_1) than monocropping. This shows that as a result of farming practices such as livestock keeping, farmers are able to acquire inputs and resources for the adoption of crop rotation and multiple cropping (Ng'ang'a *et al*., 2019). Likewise, Ooga and Gikunda (2021) established that farm income had a positive influence on the adoption of indigenous agricultural practices such as crop rotation and intercropping by the Chuka farmers, Kenya.

Farmers who earned higher income off farm were more likely to adopt a combination of multiple cropping and crop rotation (M_1C_1) but less likely to adopt crop rotation only (M_0C_1). This implies that as smallholder farmers earn more from off-farm activities, they also perceive more risks associated with relying solely on crop rotation. Subsequently, they are willing to invest more in multiple cropping along with crop rotation. This allows them to take advantage of the stability of off-farm income while diversifying their on-farm activities in order to enhance their resilience to uncertain agricultural conditions (Lv *et al*., 2023; Sapbamrer & Thammachai, 2021). However, Otieno *et al*. (2021) found that as off-farm income increased the adoption of a combination of soil fertility management practices that included both crop rotation and intercropping among farmers in Tharaka-Nithi county reduced.

Table 4.7

Multinomial Logit Model Estimates of Agroecological Cropping Systems

Variables	**M0C1** n= 246		**M1C0** n=48		**M1C1** n=180	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Gender (HHH)	0.479	0.543	0.645	0.808	-0.264	0.581
Age (HHH)	-0.005	0.012	-0.002	0.017	0.000	0.013
Education (HHH)	-0.109	0.206	-0.499	0.313	0.138	0.220
Occupation (HHH)	-0.104	0.117	0.151	0.157	-0.055	0.123
Household size	-0.037	0.078	-0.261**	0.132	-0.073	0.083
Female ownership	0.530	0.565	-0.056	0.954	0.407	0.610

Male ownership	0.277	0.555	0.154	0.934	0.456	0.607
Female manager	-0.109	0.409	-0.566	0.636	0.031	0.452
Male manager	0.338	0.435	-0.285	0.678	0.730	0.481
Gross income	0.024	0.053	-0.261***	0.059	-0.060	0.055
Training	0.178	0.177	0.059	0.310	0.291	0.182
Contracts	-0.115	1.200	1.802	1.392	-0.670	1.317
Market information	-0.468	0.933	2.354*	1.297	-0.314	0.995
Other farm income	0.103***	0.027	0.080*	0.043	0.194***	0.032
Off-farm income	-0.001	0.027	0.066*	0.040	0.056*	0.029
Credit access	-0.245	0.402	-1.702*	0.998	-0.287	0.444
Group membership	-0.064	0.648	-0.243	1.029	-0.145	0.694
County	0.534*	0.318	-0.065	0.484	0.660*	0.342
Constant	0.209	1.410	2.725	2.053	-2.682*	1.535
Joint significance of instrumental variables: χ^2 (9)				25.04***		
Wald χ^2(63)				200.274***		
Number of observations				546		

Note. M0C0 is the reference category; *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$; HHH = Household head

Table 4.8

Average Marginal Effect Estimates from Multinational Logit

Variables	**M_0C_1** n= 246		**M_1C_0** n=48		**M_1C_1** n=180	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Gender (HHH)	0.124	0.079	0.032	0.041	-0.129*	0.072
Age (HHH)	-0.001	0.002	0.000	0.001	0.001	0.002
Education (HHH)	-0.029	0.030	-0.031*	0.016	0.052*	0.027
Occupation (HHH)	-0.020	0.018	0.013*	0.008	0.000	0.017
Household size	0.009	0.011	-0.013*	0.007	-0.003	0.010
Female ownership	0.065	0.083	-0.027	0.051	0.007	0.077
Male ownership	-0.004	0.084	-0.009	0.050	0.046	0.078

Female manager	-0.013	0.062	-0.032	0.034	0.033	0.059
Male manager	-0.015	0.064	-0.043	0.035	0.099	0.061
Gross income	0.021***	0.007	-0.015***	0.002	-0.009	0.006
Training	-0.001	0.023	-0.008	0.016	0.030	0.019
Contracts	0.014	0.181	0.128**	0.063	-0.152	0.172
Market information	-0.128	0.130	0.164**	0.065	-0.050	0.119
Other farm income	-0.005	0.004	-0.002	0.002	0.021***	0.004
Off-farm income	-0.010**	0.004	0.003	0.002	0.009***	0.004
Credit access	0.032	0.066	-0.091	0.058	0.017	0.062
Group membership	0.012	0.095	-0.010	0.055	-0.013	0.086
County	0.032	0.044	-0.034	0.024	0.055	0.040

Note. M_0C_0 is the reference category; Number of observations = 546; **p* < 0.1; ***p* < 0.05; ****p* < 0.01; HHH = Household head

4.4.5 Effect of Explanatory Variables and Selection Correction Terms on Farmers' Performance Across the Alternatives of Agroecological Cropping Systems

The results from the second stage of multinomial endogenous switching regression model estimations are presented in Table 4.9 and Table 4.10. This estimation considered the effect of a set of explanatory variables and the selection correction terms derived from the multinomial logit regression on the net incomes and technical efficiency of smallholder farmers across alternative combinations of agroecological cropping systems (Zeweld *et al*., 2020). Generally, the estimates show that the economic effects on net income and technical efficiency differ from the observable characteristics and are related to specific agroecological cropping systems (Oparinde, 2021).

Based on the results, income earned from other farming activities (except vegetable farming) significantly and positively influence the net income and technical efficiency of farmers who adopted both crop rotation only (M_0C_1) and the combination of crop rotation and multiple cropping (M_1C_1). These results indicate as income form from other farming activities increases so do the net income and technical efficiencies of the farmers who adopted these two alternatives of cropping systems. The place where the farm was located was found to have a positive and significant effect on the net income and technical efficiency of farmers who adopted only crop rotation (M_0C_1). Farmers who adopted crop rotation in Murang'a county had greater net incomes and technical efficiencies than farmers located in Kiambu county. The location of the farm significantly affects income from farming activities due to variations in farm sizes, crop diversity and fertilizer use owing to different locations (Okoth *et al*., 2022).

The technical efficiency of farmers who adopted a combination of crop rotation and multiple cropping (M_1C_1) was negatively and significantly influenced by household size. Households with more members face competition over limited family resources, which can lead to inefficiencies in the management of agricultural activities. However, these findings are different from those of Eshetu *et al*. (2022) who found that the household size had positively and significantly influenced farmers' technical efficiency. On the other hand, income earned off-farm was found to positively and significantly inlfuence the technical efficiency of farmers who adopted both crop rotation only (M_0C_1) and the combination of crop rotation and multiple cropping (M_1C_1). These findings are similar to those of Iticha (2020) who showed that income from off-farm activities usually has spillover effects that increase the technical efficiencies of farmers.

A number of the selectivity correction terms (λ_1 to λ_4) were statistically significant in both tables, suggesting that the adoption of various alternatives of the agroecological cropping systems will not have the same effect on non-adopters, if they had chosen to adopt, as it would on adopters (Ding & Abdulai, 2020; Zeweld *et al*., 2020). For instance, in Table 4.9, the significant selectivity correction term λ_1 indicates that for smallholder farmers who adopted crop rotation only (M_0C_1), switching to the non-adoption of any of the cropping systems will have a significantly negative effect on their net income (Oparinde, 2021). On the other hand, in Table 4.10, the term λ_4 indicates that for smallholder farmers that adopted crop rotation only (M_0C_1), switching to the adoption of a combination of crop rotation and multiple cropping (M_1C_1) will lead to a positive and significant increase in their technical efficiency. It is however important to note that these uncorrected significant selectivity correction terms can lead to an overestimation or underestimation of the results of the outcome variables (Zeweld *et al*., 2020).

Table 4.9

Estimation of the Main Equation for Net Income from Vegetable Production

Variables	Net Income from vegetable production							
	M_0C_0 (1)		**M_0C_1** (2)		**M_1C_0** (3)		**M_1C_1** (4)	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Gender	-7854.367	49076.070	29443.610	29012.830	-10100.000	30281.830	-2355.934	29656.870
Age	87.371	897.777	-204.109	470.681	260.645	626.220	255.709	494.702
Education	13782.660	19118.390	5152.993	9869.124	1067.376	18551.390	7564.762	11818.270
Occupation	940.283	10007.740	-5731.063	4643.006	-449.635	6263.527	-130.085	5856.226
Household size	-2105.744	6308.988	-1305.334	2899.783	977.721	4941.748	-2978.639	4052.274
Female ownership	1692.882	52101.940	-3819.422	20817.280	10431.310	42810.010	-12000.000	39932.670
Male ownership	8370.982	43643.420	-10300.000	24574.900	24876.040	38187.860	-11300.000	40070.510
Female manager	-36000.000	29038.670	-5102.390	16754.200	-23800.000	29032.890	-3478.093	21293.070
Male manager	15320.630	58240.490	13800.010	17368.030	-32400.000	34026.780	6237.892	23388.890
Training	-3474.933	14271.810	4835.545	6084.430	-10000.000	8870.776	1617.175	6275.616
Contracts	-40900.000	82967.140	28910.170	66488.550	-3364.990	53465.100	27758.900	52728.560
Market information	39520.810	58862.410	43939.500	50499.920	47055.620	50965.170	23497.430	45644.330
Other farm income	6630.728	6470.119	3898.304*	3304.979	1267.166	3468.793	6292.646*	3695.340
Off-farm income	1029.322	3211.338	1852.529	1512.665	303.741	2026.279	1633.862	2185.621
Credit access	-43900.000	33021.250	-17200.000	18118.920	36799.760	42898.830	-7199.501	28034.170
Group membership	6423.454	61770.900	20805.430	27442.860	-17900.000	40445.960	-19300.000	22611.050
County	62930.850	40207.080	32547.240**	14683.810	-9110.557	17827.590	-2005.115	14561.160
Constant	-10400.000	109104.000	-27200.000	58897.150	-8246.189	86114.730	-122745.000	125000.000
Ancillary								

σ^2	1.12e+10	4.00e+10	1.94e+10	1.98e+10	2.88e+09	3.89e+10	1.29e+10	2.57e+10
λ_1			-1.173*	0.611	-0.339	0.880	-0.725	0.836
λ_2	-0.906	0.680			-0.820	0.759	-0.793	0.603
λ_3	0.998*	0.594	0.662	0.469			1.101***	0.408
λ_4	0.502	0.859	0.653	0.600	1.002	0.702		
Joint significance of instrumentals	F (2, 50) = 1.06		F (2, 224) = 0.57		F (2, 26) = 0.11		F (2, 158) = 0.79	

Note. M_0C_0 is the reference category. Standard errors were bootstrapped with 100 replications. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table 4.10

Estimation of the Main Equation for Technical Efficiency of Vegetable Production

Variables	**Technical efficiency of vegetable production**							
	M_0C_0 (1)		**M_0C_1** (2)		**M_1C_0** (3)		**M_1C_1** (4)	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Gender	-0.043	0.182	-0.032	0.073	-0.188	0.153	-0.032	0.095
Age	-0.002	0.005	-0.001	0.001	0.002	0.004	-0.001	0.002
Education	0.018	0.047	0.021	0.026	-0.032	0.077	0.014	0.031
Occupation	-0.009	0.031	-0.019	0.013	0.023	0.034	0.004	0.018
Household size	-0.021	0.019	-0.011	0.009	0.021	0.028	-0.019*	0.011
Female ownership	0.059	0.134	-0.047	0.058	-0.326	0.208	-0.025	0.107
Male ownership	0.102	0.149	-0.017	0.070	-0.046	0.203	0.053	0.118
Female manager	-0.157	0.100	0.029	0.045	0.010	0.123	-0.001	0.060
Male manager	-0.066	0.128	0.083	0.052	-0.121	0.187	-0.018	0.074
Training	0.018	0.048	0.020	0.018	-0.056	0.092	0.024	0.021

Contracts	-0.263	0.287	-0.018	0.120	-0.173	0.242	-0.119	0.184
Market information	0.249	0.228	0.084	0.104	0.142	0.223	0.166	0.123
Other farm income	0.026	0.019	0.016***	0.006	0.016	0.024	0.020**	0.009
Off-farm income	0.003	0.009	0.010**	0.004	-0.002	0.015	0.007*	0.004
Credit access	-0.172	0.105	-0.004	0.043	0.177	0.222	-0.061	0.062
Group membership	0.028	0.211	-0.051	0.060	-0.068	0.221	0.021	0.057
County	0.173	0.123	0.088**	0.037	-0.118	0.123	0.024	0.045
Constant	0.603	0.369	0.434***	0.133	0.374	0.521	-0.080	0.270
Ancillary								
σ^2	0.276	0.538	0.169	0.128	0.237	1.366	0.289	0.241
λ_1			-0.869**	0.437	-0.406	0.866	-1.126*	0.652
λ_2	-0.945*	0.492			-0.826	0.607	-0.460	0.396
λ_3	1.209**	0.515	0.176	0.481			1.234***	0.347
λ_4	0.273	0.705	1.094***	0.336	1.060	0.684		
Joint significance of instruments	$F(2, 50) = 0.64$		$F(2, 224) = 0.75$		$F(2, 26) = 0.67$		$F(2, 158) = 1.28$	

Note. M_0C_0 is the reference category. Standard errors were bootstrapped with 100 replications; *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

4.4.6 Effect of Adoption of Alternatives of Agroecological Cropping Systems on Net Income and Technical Efficiency

The unconditional average effects of adoption of the alternatives of agroecological cropping systems on the net incomes and technical efficiencies of smallholder farmers are presented in Table 4.11. The results show that, on average, smallholder farmers who adopt these cropping systems either in isolation or in combination, have significantly higher technical efficiencies than non-adopters. On the other hand, the results show that smallholder farmers who adopt these alternatives of cropping systems generally realize lower net incomes compared to nonadopters. This implies that, while smallholder farmers who adopt agroecological cropping systems may achieve higher efficiencies in terms of resource use, they often face high initial investment costs, high labor costs as well as challenges accessing markets which can contribute to low net incomes (Karuga, 2022; Nijenhuis, 2022). However, these results may not be robust because they do not adjust for both observed and unobserved selection bias which may affect net incomes and technical efficiency (Khonje *et al*., 2018; Tran *et al*., 2020).

Thus, the conditional average treatment effects (ATT) calculated to show the true average adoption effects on net income and technical efficiencies after selection bias is considered (Zeweld *et al*., 2020). Table 4.12 summarizes the findings relating to the actual and counterfactual performance of adopters in reference to adoption of different types of agroecological cropping systems. To ascertain farmer performance net income and technical efficiency of farmers were measured. Given the backdrop of the research, the study found out that the adoption of crop rotation only (M_0C_1) translates into reduction in net incomes of the smallholder farmers by about KES 4182.081. In contrast, the adoption of only multiple cropping (M_1C_0) was highly associated with an increase of KES 17,441.617 net income from vegetable production. The implication is that crop rotation could be linked to more expensive input costs like extra labor, fertilizers or pesticides which may counterpoise income (Kotir *et al*., 2020). On the other hand, farmers who considered multiple cropping have, in all likelihood, been more efficient in their input usage or required fewer inputs. Likewise, Mogaka *et al*. (2022) found that Western Kenyan farmers that had adopted multiple cropping practices such as intercropping were more profitable than farmers that did not adopt.

According to the results, the ATT value of crop rotation only (M_0C_1) was negative and significant at $p<0.01$. This indicates that smallholder vegetable farmers who adopted crop rotation are expected to experience a reduction in technical efficiency by 0.025 units. Similarly, in Ethiopia, crop rotation had a negative effect on the technical efficiency of small holder farmers (Zewdie *et al*., 2021). The study's findings show that adopting multiple cropping only (M_1C_0) and combining multiple cropping with crop rotation (M_1C_1) positively and significantly contributed to the farmers' technical efficiencies at $p<0.01$ and $p<0.1$ respectively. The adoption of multiple cropping only was found to increase farmers' technical efficiency by 0.146 units whereas the adoption of the combination of multiple cropping and crop rotation would increase technical efficiency by 0.013 units. Similarly, Lanamana and Supardi (2020) found that farmers who adopted multiple cropping were more technically efficient than those that did not adopt.

Average treatment effects for adopters were also estimated. Table 4.13 presents result on the adoption heterogeneity effects. Specifically, smallholder farmers who adopted the combination of multiple cropping and crop rotation (M_1C_1) would generally have significantly more net income but significantly lower technical efficiency than those who adopted multiple cropping only (M_1C_0) if they both chose to adopt crop rotation only (M_0C_1).Conversely, farmers that adopted multiple cropping only (M_1C_0) would generally have lowr income than those that adopted crop rotation (M_1C_0), if they both adopted the combination (M_1C_1). The results also showed that farmers that adopted the combination (M_1C_1) were likely to have lower technical efficiency than those that adopted crop rotation (M_0C_1) if they both chose to adopt multiple cropping only (M_1C_0).

Table 4.11

MESR Based Treatment Effects of Adoption of Agroecological Cropping Systems on Performance: Unconditional Average Effects

Outcome variables	**Technology choice (j)**	**Adoption status**		**Average treatment effects**
		Adopting (j=2,3,4)	Nonadopting (j=1)	
		(1)	(2)	(3) = (1)-(2)
Net Income	M_0C_1	34701.504	37027.454	-2325.950**
		(1315.100)	(1939.229)	(1288.186)
	M_1C_0	22536.016	37027.454	-14491.438***
		(1159.505)	(1939.229)	(2021.291)

	M_1C_1	35690.505	37027.454	-1336.949
		(1179.212)	(1939.229)	(1631.737)
Technical Efficiency	M_0C_1	0.416	0.421	-0.005
		(0.004)	(0.009)	(0.007)
	M_1C_0	0.460	0.421	0.039***
		(0.009)	(0.009)	(0.011)
	M_1C_1	0.437	0.421	0.016***
		(0.005)	(0.009)	(0.006)

Note. j represents adoption of combination of technologies defined in Table 4.5. Standard errors in parenthesis; $^{**}p < 0.05$; $^{***}p < 0.01$

Table 4.12

MESR Based Treatment Effects of Adoption of Agroecological Cropping Systems on Performance

Outcome variables	Technology choice (j)	Adoption status		Average treatment effects
		Adopting (j=2,3,4)	Nonadopting (j=1)	
		(1)	(2)	(3) = (1)-(2)
Net Income	M_0C_1	40858.496	45040.577	-4182.081**
		(1808.664)	(2760.323)	(2039.848)
	M_1C_0	11528.854	-5912.762	17441.617**
		(3593.469)	(7960.692)	(7869.43)
	M_1C_1	36299.545	36636.073	-336.529
		(1867.021)	(3103.766)	(2800.941)
Technical Efficiency	M_0C_1	0.436	0.462	-0.025***
		(0.005)	(0.012)	(0.009)
	M_1C_0	0.338	0.193	0.146 ***
		(0.022)	(0.039)	(0.031)
	M_1C_1	0.425	0.413	0.013*
		(0.008)	(0.014)	(0.008)

Note. j represents adoption of combination of technologies defined in Table 4.5. Standard errors in parenthesis. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table 4.13

MESR Based Treatment Effects of Adoption of Agroecological Cropping Systems on Performance: Heterogeneity Effects

Outcome variables	**Technology combination**	**Within adoption status**		**Heterogeneity effects**
		Adopting (j=2,3,4)	Adopting (j=2,3,4)	
		(1)	(2)	(3) = (1)-(2)
Net Income	E (4|2) vs E (3|2)	40908.516	26778.308	14130.208***
		(1560.859)	(1773.007)	(1896.834)
	E (4|3) vs E (2|3)	7124.774	6697.077	427.698
		(5434.688)	(5058.808)	(3462.505)
	E (3|4) vs E (2|4)	17095.449	32535.645	-15440.196***
		(1953.882)	(2178.279)	(2501.39)
Technical Efficiency	E (4|2) vs E (3|2)	0.463	0.501	-0.038***
		(0.006)	(0.014)	(0.013)
	E (4|3) vs E (2|3)	0.297	0.341	-0.044***
		(0.023)	(0.015)	(0.017)
	E (3|4) vs E (2|4)	0.418	0.409	0.009
		(0.017)	(0.007)	(0.016)

Note. j represents adoption of combination of technologies defined in Table 4.5. Standard errors in parenthesis; ***$p < 0.01$

CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This study examined the smallholder vegetable farmers, identified the factors that influence their adoption of agroecological cropping systems and evaluated their impact on the farmers' performance. The results showed that smallholder vegetable farming households face gendered land dynamics and limited access to key agricultural resources. Adoption was shaped by gender roles, extension access, occupation, and income sources. Crop rotation alone decreased income and efficiency, whereas multiple cropping, independently or combined with rotation, enhanced technical efficiency.

5.2 Conclusions

The following are the key conclusions from the study according to the objectives;

i. Smallholder vegetable farming households are predominantly led by males, often headed by individuals of advanced age and with higher levels of education. Within these households, intricate gender dynamics shape the ownership and management of land. These smallholder farming households also face notable constraints, such as limited access to training opportunities, contracts, market and information platforms, credit facilities, group membership, and extension services.

ii. Agroecological cropping systems studied were interdependent. The gender of the household head and the plot manager affected positively and negatively the adoption of agroecological cropping systems. Similarly, access to extension services affected positively and negatively the adoption of cropping systems. In addition, the head of household's occupation and the income from non-vegetable farming was significantly and positively influencing adoption whereas gross income from vegetable production was negatively influencing adoption.

iii. The net incomes and technical efficiencies of smallholder farmers decreased when crop rotation only (M_0C_1) was adopted. In contrast, only using multiple cropping (M_1C_0) could enhance net income and technical efficiency. Farmers' technical efficiency improved positively and significantly due to the joint adoption of multiple cropping and crop rotation (M_1C_1).

5.3 Recommendations

Recommendations include the following, based on the findings of this study.;

i. To enhance access to training programs, market information systems, credit facilities and opportunities for group membership of smallholder farmers. Farmers can use these initiatives to access information, inputs and networks that improve agricultural productivity, increase farmer-market participation, and sustain their livelihoods.

ii. Awareness campaigns, policies, and programs should be developed to induce the smallholder farmers to adopt agroecological cropping systems. It is critical that access gender-sensitive and correct up to date information is prioritized. Farmers ought to be incentivized to belong to groups associated with agriculture, as they are platforms for sharing information.

iii. Cropping systems that enhance farmers' incomes and efficiency should be promoted. Extension service providers should also be supported to help them provide tailored advice and assistance to farmers in implementing effective cropping systems.

5.4 Further Research

This study did provide insights on how the adoption of agroecological cropping systems impacts the performance of smallholder vegetable farmers in Kiambu and Murang'a counties, Kenya. However, the findings may have limited generalizability. Future research should therefore replicate similar studies in diverse regions or countries to compare the effects of such systems on farmers' net incomes and technical efficiency across various agricultural contexts. Moreover, this study did not thoroughly examine the role of policy interventions in promoting agroecological cropping systems among farmers. Subsequent research should evaluate the effectiveness of policy interventions and assess their influence on farmers' net incomes and technical efficiency, potentially through policy analysis and evaluation studies aimed at identifying successful strategies and areas for enhancement.

Additionally, we acknowledge that there may be other factors beyond the scope of this study that affect adoption. Hence, we recommend that future research explore behavioral factors, such as risk attitudes and attitudes toward cropping systems, which were not addressed in our analysis. Furthermore, investigating how farmers acquire knowledge about agroecological cropping systems would be beneficial. Delving into these aspects will yield a more comprehensive understanding of adoption dynamics, facilitating the development of targeted interventions and policies to encourage the adoption of agroecological cropping systems.

REFERENCES

Abate, T. M., Dessie, A. B., & Mekie, T. M. (2019). Technical efficiency of smallholder farmers in red pepper production in North Gondar zone Amhara regional state, Ethiopia. *Journal of Economic Structures, 8*(1), 1-18. https://doi.org/10.1186/s40008-019-0150-6

Addai, K. N., Ng'ombe, J. N., & Lu, W. (2023). Disaggregated impacts of off-farm work participation on household vulnerability to food poverty in Ghana. *The Journal of Economic Inequality*, *21*(1), 83-104. https://doi.org/10.1007/s10888-022-09543-9

Adeyinka-Ojo, S., Ying, N. I., Schellini, M., Amatya, D. G., & Imam, A. M. (2025). *Developing joyful learning pedagogy to cultivate students' leadership skills*. Research Square. https://doi.org/10.21203/rs.3.rs-6652888/v1

Adzawla, W., Azumah, S. B., Anani, P. Y., & Donkoh, S. A. (2019). Gender perspectives of climate change adaptation in two selected districts of Ghana. *Heliyon*, *5*(11). https://doi.org/10.1016/j.heliyon.2019.e02854

Ahmed, M. H. (2015). Adoption of multiple agricultural technologies in maize production of the Central Rift Valley of Ethiopia. *Studies in Agricultural Economics, 117* (3), 162–168. https://doi.org/10.7896/j.1521

Aigner, D., Lovell, C., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*,*6*(1), 21-37. https://doi.org/10.1016/j.jeconom.2023.01.023

Ajambo, S., Enoch, K., Birachi, E., & Ogutu, S. (2024). *How inclusive are smallholder farmers' access to Digital Agricultural Platforms? Lessons from the EzyAgric Digital Platform in Uganda*. Alliance of Bioversity and CIAT.

Alsoruji, A. H., Binhimd, S., & Elaal, M. K. (2018). A comparison of univariate probit and logit models using simulation. *Applied Mathematical Sciences, 12*(4), 185–204. https://doi.org/10.12988/ams.2018.818

Altieri, M. A., & Nicholls, C. I. (2020). Agroecology and the reconstruction of a post-COVID-19 agriculture. *Journal of Peasant Studies*, 881–898. https://doi.org/10.1080/03066150.2020.1782891

Alulu, J., Oluoch-kosura, W., & Justus, O. (2020). Drivers of transformations in smallholder indigenous vegetable value chains in western Kenya: Evolution of contract farming. *Journal of Applied Business and Economics*, *22*(6). https://doi.org/10.33423/jabe.v22i6.3082

Andersson Djurfeldt, A. (2020). Gendered land rights, legal reform and social norms in the context of land fragmentation - A review of the literature for Kenya, Rwanda and Uganda. *Land Use Policy*, *90*. https://doi.org/10.1016/j.landusepol.2019.104305

Apeh, C. C., Chukwuone, N. A., Onyekuru, A. N., & Apeh, A. C. (2024). Gendered analysis of the economic impact of adoption of multiple climate-smart agriculture practices in Nigeria. *Journal of Agricultural Extension*, *28*(4), 131-143. https://dx.doi.org/10.4314/jae.v28i4.13

Asfaw, M., Geta, E., & Mitiku, F. (2019). Economic efficiency of smallholder farmers in wheat production: The case of abuna Gindeberet district, Oromia national regional state, Ethiopia. *International Journal of Environmental Sciences & Natural Resources*, *16*(2), 41-51. https://doi.org/ 10.19080/IJESNR.2019.16.555932

Autio, A., Johansson, T., Motaroki, L., Minoia, P., & Pellikka, P. (2021). Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya. *Agricultural Systems*, *194*, 103284. https://doi.org/https://doi.org/10.1016/j.agsy.2021.103284

Azumah, S. B. (2019). *Agricultural technology transfer, adoption and technical efficiency of rice farmers in Northern Ghana* (Doctoral dissertation, University for Development Studies, Ghana). https://www.udsspace.uds.edu.gh

Belete, A. S. (2020). Analysis of technical efficiency in maize production in Guji Zone: Stochastic frontier model. *Agriculture and Food Security*, *9*(1). https://doi.org/10.1186/s40066-020-00270-w

Benitez-Altuna, F., Trienekens, J., Materia, V. C., & Bijman, J. (2021). Factors affecting the adoption of ecological intensification practices: A case study in vegetable production in Chile. *Agricultural Systems*, *194*. https://doi.org/10.1016/j.agsy.2021.103283

Blanco-Canqui, H., & Lal, R. (2010). Cropping Systems. *Principles of Soil Conservation and Management*, 165–193. https://doi.org/10.1007/978-1-4020-8709-7_7

Boeraeve, F., Dendoncker, N., Cornélis, J. T., Degrune, F., & Dufrêne, M. (2020). Contribution of agroecological farming systems to the delivery of ecosystem services. *Journal of Environmental Management, 260*, 109576. https://doi.org/10.1016/j.jenvman.2019.109576

Bokelmann, W., Huyskens-Keil, S., Ferenczi, Z., & Stöber, S. (2022). The role of indigenous vegetables to improve food and nutrition security: Experiences from the project HORTINLEA in Kenya (2014–2018). *Frontiers in Sustainable Food Systems*, *6*, 806420. https://doi.org/10.3389/fsufs.2022.806420

Bourguignon, F., Fournier, M., & Gurgand, M. (2007). Selection bias corrections based on the multinomial logit model: Monte Carlo comparisons. *Journal of Economic Surveys*, *21*(1), 174–205. https://doi.org/10.1111/j.1467-6419.2007.00503.x

Bravo-Ureta, B. E., González-Flores, M., Greene, W., & Solís, D. (2021). Technology and technical efficiency change: Evidence from a difference in differences selectivity corrected stochastic production frontier model. *American Journal of Agricultural Economics*, *103*(1), 362-385.

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples. *Journal of Research in Nursing, 25*(8), 652. https://doi.org/10.1177/1744987120927206

Canwat, V., Oelofse, M., Onakuse, S., & de Neergaard, A. (2021). Agroecological intensification: Can organic conversion improve the production efficiency? A perspective from smallholder kale production systems Kenya. *Cleaner Environmental Systems*, *3*. https://doi.org/10.1016/j.cesys.2021.100048

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429-444. https://doi.org/10.1016/0377-2217(78)90138-8

Chepchirchir, F., Muriithi, B. W., Langat, J., Mohamed, S. A., Ndlela, S., & Khamis, F. M. (2021). Knowledge, attitude, and practices on tomato leaf miner, *Tuta absoluta* on tomato and potential demand for integrated pest management among smallholder farmers in Kenya and Uganda. *Agriculture*, *11*(12), 1242. https://doi.org/10.3390/agriculture11121242

Chepkoech, W., Mungai, N. W., Stöber, S., Bett, H. K., & Lotze-Campen, H. (2018). Farmers' perspectives: Impact of climate change on African indigenous vegetable production in Kenya. *International Journal of Climate Change Strategies and Management, 10*(4), 551-579. https://doi.org/10.1108/ijccsm-07-2017-0160/full/html

Chepkoech, W., Mungai, N., Stöber, S., & Lotze-Campen, H. (2020). Understanding adaptive capacity of smallholder African indigenous vegetable farmers to climate change in Kenya. *Climate Risk Management*, *27*, 100204. https://doi.org/10.1016/j.crm.2019.100204

Chichongue, O., Pelser, A., Tol, J. V., Du Preez, C., & Ceronio, G. (2020). Factors influencing the adoption of conservation agriculture practices among smallholder farmers in Mozambique. *International Journal of Agricultural Extension*, *7*(3), 277-290. https://doi.org/10.33687/ijae.007.03.3049

Cochran, W. G. (1963). *Sampling Techniques* (2nd ed.). John Wiley and Sons, Inc.

Coelli, T., Rao, P. D.& Battese, G. E. (1998). *An introduction to efficiency and productivity analysis*. Kluwer Academic Publishers.

Constantino, S. M., Sparkman, G., Kraft-Todd, G. T., Bicchieri, C., Centola, D., Shell-Duncan, B., Vogt, S., & Weber, E. U. (2022). Scaling up change: A critical review and practical guide to harnessing social norms for climate action. *Psychological Science in the Public Interest*, *23*(2), 50–97. https://doi.org/10.1177/15291006221105279

Côte, F. X., Poirier-Magona, E., Perret, S., Roudier, P., Rapidel, B., & Thirion, M. C. (2019). *The agroecological transition of agricultural systems in the Global South.* Quae, Versailles. https://doi.org/10.35690/978-2-7592-3057-0

Dabkiene, V., Siksnelyte-Butkiene, I., Streimikiene, D., Sapolaite, V., & Balezentis, T. (2025). From glass to grass ceiling: Addressing gender barriers in agricultural innovation. *Technological Forecasting and Social Change*, *212*, 123957. https://doi.org/10.1016/j.techfore.2024.123957

D'Annolfo, R., Gemmill-Herren, B., Amudavi, D., Shiraku, H. W., Piva, M., & Garibaldi, L. A. (2021). The effects of agroecological farming systems on smallholder livelihoods: A case study on push–pull system from Western Kenya. *International Journal of Agricultural Sustainability*, *19*(1), 56-70. https://doi.org/10.1080/14735903.2020.1822639

D'Annolfo, R., Gemmill-Herren, B., Graeub, B., & Garibaldi, L.A. (2017). A review of social and economic performance of agroecology. *International Journal of Agricultural Sustainability, 15*(6), 632-644. https://doi.org/10.1080/14735903.2017.1398123

Daniel, K. A., Mwende Muindi, E., & Mbuvi Muti, S. (2023). Cabbage (*Brassica oleracea*) Production in Kenya: A review of its economic importance, ecological requirement and production constraints. *International Journal of Plant & Soil Science*, *2023*(18), 245–254. https://doi.org/10.9734/IJPSS/2023/v35i183287ï

Danso-Abbeam, G., Dagunga, G., & Ehiakpor, D. S. (2020). Rural non-farm income diversification: Implications on smallholder farmers' welfare and agricultural technology adoption in Ghana. *Heliyon*, *6*(11). https://doi.org/10.1016/j.heliyon.2020.e05393

Debonne, N., van Vliet, J., Ramkat, R., Snelder, D., & Verburg, P. (2021). Farm scale as a driver of agricultural development in the Kenyan Rift Valley. *Agricultural Systems*, *186*. https://doi.org/10.1016/j.agsy.2020.102943

Dedehouanou, S. F. A., Swinnen, J., & Maertens, M. (2013). Does contracting make farmers happy? Evidence from Senegal. *Review of Income and Wealth*, *59*, S138-S160. https://doi.org/10.1111/roiw.12041

Degefa, K., Biru, G., & Abebe, G. (2020). Economic efficiency of smallholder farmers in tomato production in BakoTibe district, Oromia region, Ethiopia. *Journal of Agricultural Science and Food Research*, *11*(3), 1–8. https://doi.org/10.35248/2593-9173.20.11.273

Dessale, M. (2019). Analysis of technical efficiency of smallholder wheat-growing farmers of Jamma district, Ethiopia. *Agriculture & Food Security*, *8*(1), 1-8. https://doi.org/10.1186/s40066-018-0250-9

Dessart, F. J., Barreiro-Hurlé, J., & Van Bavel, R. (2019). Behavioural factors affecting the adoption of sustainable farming practices: A policy-oriented review. *European Review of Agricultural Economics*, *46*(3), 417–471. https://doi.org/10.1093/erae/jbz019

Di Falco, S., & Veronesi, M. (2013). How can African agriculture adapt to climate change? A counterfactual analysis from Ethiopia. *Land Economics, 89*(4), 743-766. https://doi.org/10.3368/le.89.4.743

Dimov, D., Löw, F., Uhl, J. H., Kenjabaev, S., Dubovyk, O., Ibrakhimov, M., & Biradar, C. (2019). Framework for agricultural performance assessment based on MODIS multitemporal data. *Journal of Applied Remote Sensing, 13*(2), 025501. https://doi.org/10.1117/1.jrs.13.025501

Ding, Z. (2018). *Rural Households' Preferences for Microfinance and Its Impact of Participation on Households' Welfare in China* (Doctoral dissertation, Christian-Albrechts Universität Kiel).

Ding, Z., & Abdulai, A. (2020). An analysis of the factors influencing choice of microcredit sources and impact of participation on household income. *Journal of International Development, 32*(4), 505-525. https://doi.org/10.1002/jid.3466

Donkoh, S. A., Azumah, S. B., & Awuni, J. A. (2019). Adoption of improved agricultural technologies among rice farmers in Ghana: A multivariate probit approach. *Ghana Journal of Development Studies, 16*(1), 46. https://doi.org/10.4314/gjds.v16i1.3

Dubbert, C., Abdulai, A., & Mohammed, S. (2023). Contract farming and the adoption of sustainable farm practices: Empirical evidence from cashew farmers in Ghana. *Applied Economic Perspectives and Policy*, *45*(1), 487–509. https://doi.org/10.1002/aepp.13212

Dubin, J. A., & McFadden, D. L. (1984). An econometric analysis of residential electric appliance holdings and consumption. *Econometrica: Journal of the Econometric Society*, *52* (2), 345-362. https://doi.org/10.2307/1911493

Duchene, O., Vian, J. F., & Celette, F. (2017). Intercropping with legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. *Agriculture, Ecosystems & Environment*, *240*, 148-161. https://doi.org/10.1016/j.agee.2017.02.019ï

Ehiakpor, D., Danso-Abbeam, G., & Mubashiru, Y. (2021). Adoption of interrelated sustainable agricultural practices among smallholder farmers in Ghana. *Land Use Policy*, *101*, 105142. https://www.sciencedirect.com/science/article/pii/s026483772031526x

Ekhuya, N. A., Wesonga, J. M., & Abukutsa–Onyango, M. O. (2018). Production, processing, and storage techniques of African nightshade (*Solanum* spp.) seeds and their correlations with farmers' characteristics in western Kenya. *African Journal of Food, Agriculture, Nutrition, and Development*, *18*(2), 13338-13351. https://doi.org/10.18697/ajfand.82.17445

Endalew, B., Anteneh, A., & Tasie, K. (2022). Technical efficiency of teff production among smallholder farmers: beta regression approach. *The European Journal of Development Research*, *34*(2), 1076-1096. https://doi.org/10.1057/s41287-021-00417-w

Eshetu, F., Haji, J., Ketema, M., & Mehare, A. (2022). *Impact of rural out-migration on technical efficiency of wheat and teff producers in southern Ethiopia*. The African Economic Research Consortium (AERC). https://doi.org/10.21203/rs.3.rs-1870409/v1

Ezeanyika, S. (2023). Managing the features and dynamics of a rural non-farm economy in a globalizing Africa: Challenges and prospects. *Administratio Publica*, *31*(1), 174-191

Fare, R., & Lovell, C. K (1978): Measuring the technical efficiency of production. *Journal of Economic Theory*, *19*(1), 150–162. http://dx.doi.org/10.1016/0022-0531(78)90060-1

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General)*, *120*(3), 253-281. https://doi.org/10.2307/2343100

Favela-González, K. M., Hernández-Almanza, A. Y., & De la Fuente-Salcido, N. M. (2020). The value of bioactive compounds of cruciferous vegetables (*Brassica*) as antimicrobials and antioxidants: A review. *Journal of Food Biochemistry*, *44*(10), e13414. https://doi.org/10.1111/jfbc.13414

Faye, A. (2022). *Agro-ecology and agricultural transformation: Conceptual analysis and theoretical considerations* [Paper presentation]. 96th Annual Conference KU Leuven, Belgium. https://doi.org/10.22004/ag.econ.321227

Food and Agriculture Organization of the United Nations (FAO). (2018). FAO's work on agroecology: A pathway to achieving the SDGs. FAO. http://www.fao.org/3/i9021en/i9021en.pdf

Garini, C. S., Vanwindekens, F., Scholberg, J. M. S., Wezel, A., & Groot, J. C. (2017). Drivers of adoption of agroecological practices for winegrowers and influence from policies in the province of Trento, Italy. *Land Use Policy*, *68*, 200-211. https://doi.org/10.1016/j.landusepol.2017.07.048

Gichungi, H. M. (2021). *Impact Assessment of Integrated Pest Management Strategy for Control of Mango Fruit Fly on Women Decision Making Among Smallholder Mango Producers in Machakos County, Kenya* (Doctoral dissertation, University of Nairobi).

Gikonyo, N. W., Busienei, J. R., Gathiaka, J. K., & Karuku, G. N. (2022). Analysis of household savings and adoption of climate smart agricultural technologies. Evidence from smallholder farmers in Nyando Basin, Kenya. *Heliyon*, *8*(6). https://doi.org/10.1016/j.heliyon.2022.e09692

Gikunda, R. M., Lawver, D., Baker, M., Boren Alpizar, A., Lawver, D. E., & Boren-Alpizar, A. E. (2020). Spatial trends and distribution patterns of organic crop production in central Kenya. *American Journal of Geographic Information System*, *9*(1), 23–32. https://doi.org/10.5923/j.ajgis.20200901.03

Gikunda, R., & Lawver, D. (2020). Effect of certification on adoption and sustainability of organic agricultural practices. *Journal of International Agricultural and Extension Education*, *27*(1), 64–78. https://doi.org/10.5191/jiaee.2020.27105

Gliessman, S. (2016). Transforming food systems with agroecology. *Agroecology and Sustainable Food Systems*, *40*(3), 187-189. https://doi.org/10.1080/21683565.2015.1130765

Gliessman, S. R. (2004). Integrating agroecological processes into cropping systems research. *Journal of Crop improvement*, *11*(1-2), 61-80. https://doi.org/10.1300/J411v11n01_04

Gori Maia, A., Silveira, R. L. F. da, Veneo Campos Fonseca, C., Burney, J., & Cesano, D. (2022). Climate resilience programmes and technical efficiency: Evidence from the smallholder dairy farmers in the Brazilian semi-arid region. *Taylor & Francis*, *14*(3), 197–207. https://doi.org/10.1080/17565529.2021.1904812

Gralka, S. (2018). *Stochastic frontier analysis in higher education: A systematic review*. (CEPIE Working Paper, No. 05/18). http://hdl.handle.net/10419/189968

Griskevicius, V., Tybur, J. M., & Van den Bergh, B. (2010). Going green to be seen: Status, reputation, and conspicuous conservation. *Journal of Personality and Social Psychology*, *98*(3), 392–404. https://doi.org/10.1037/a0017346

Guenat, S., Kaartinen, R., & Jonsson, M. (2019). Shade trees decrease pest abundances on brassica crops in Kenya. *Agroforestry Systems*, *93*(2), 641–652. https://doi.org/10.1007/S10457-017-0159-5

Hannah, M. G. (2021). *Impact Assessment of Integrated Pest Management Strategy for control of Mango Fruit fly on Women decision making among Smallholder Mango producers in Machakos County, Kenya* (Doctoral dissertation, University of Nairobi).

Haryanto, T., Wardana, W. W., & Basconcillo, J. A. Q. (2023a). Does sending farmers back to school increase technical efficiency of maize production? Impact assessment of a farmer field school programme in Indonesia. *Economic Research-Ekonomska Istraživanja*, *36*(3). https://doi.org/10.1080/1331677X.2023.2218469

Haryanto, T., Wardana, W. W., Jamil, I. R., Brintanti, A. R. D., & Ibrahim, K. H. (2023b). Impact of credit access on farm performance: Does source of credit matter?. *Heliyon*, *9*(9), e19720. https://doi.org/10.1016/j.heliyon.2023.e19720

Himanen, S. J., Mäkinen, H., Rimhanen, K., & Savikko, R. (2016). Engaging farmers in climate change adaptation planning: Assessing intercropping as a means to support farm adaptive capacity. *Agriculture (Switzerland)*, *6*(3). https://doi.org/10.3390/agriculture6030034

Huss, C. P., Holmes, K. D., & Blubaugh, C. K. (2022). Benefits and risks of intercropping for crop resilience and pest management. *Journal of Economic Entomology*, *115*(5), 1350–1362. https://doi.org/10.1093/jee/toac045

International Fund for Agricultural Development. (2020). *Transforming food systems for rural prosperity*. Rural development report. https://www.ifad.org/documents/38714170/43704363/rdr2021_overview_e.pdf/503cf76b-2a61-1d7e-44bd-7b4bf3739b85?t=1631621451944

Iticha, M. (2020). Review on determinants of economic efficiency of smallholder maize production in Ethiopia. *International Journal of Agricultural Economics*, *5*(4), 123–132. https://doi.org/10.11648/j.ijae.20200504.15

Jacobi, J., Mukhovi, S., Llanque, A., Augstburger, H., Käser, F., Pozo, C., Peter, M. N., Delgado, J. M. F., Kiteme, B. P., Rist S,& Speranza, C. I. (2018). Operationalizing food system resilience: An indicator-based assessment in agro-industrial, smallholder farming, and agroecological contexts in Bolivia and Kenya. *Land use policy, 79*, 433-446. https://doi.org/10.1016/j.landusepol.2018.08.044

Jacquet, F., Jeuffroy, M. H., Jouan, J., Le Cadre, E., Litrico, I., Malausa, T., Reboud, X., & Huyghe, C. (2022). Pesticide-free agriculture as a new paradigm for research. *Agronomy for Sustainable Development, 42*(1), 8. https://doi.org/10.1007/s13593-021-00742-8

Jafar, H., Muda, I., Zainal, A., & Yasin, W. (2010). Profit maximization theory, survival-based theory and contingency theory: A review on several underlying research theories of corporate turnaround. *Jurnal Ekonomi*, *13*(4), 8-16.

Ji, C., Zhuo, N., & Jin, S. (2023). Does cooperative membership stabilize farm income volatility? Evidence from the pig sector in China. *China Agricultural Economic Review*, *15*(3), 623-641.

Jimenez, N. (2012). *Higher education: Understanding the identity and retention of Latino(a) students* (Master's thesis, Rowan University). https://rdw.rowan.edu/etd/223

Jindo, K., Schut, A. G. T., & Langeveld, J. W. A. (2020). Sustainable intensification in Western Kenya: Who will benefit? *Agricultural Systems*, *182*. https://doi.org/10.1016/j.agsy.2020.102831

Joseph, A., Otieno, D. J., Oluoch-Kosura, W., & Justus, O. (2020). Drivers of transformations in smallholder indigenous vegetable value chains in Western Kenya: Evolution of contract farming. *Journal of Applied Business & Economics*, *22*(6). https://doi.org/10.33423/jabe.v22i6.3082

Juma, W. S., Waceke, J. W., & Nchore, S. B. (2020). Diversity of plant parasitic nematodes of tree tomato (*Solanum betaceum* Cav.) in Kiambu and Embu Counties, Kenya. *Middle East Journal of Agriculture Research, 9*(3), 605-616. https://doi.org/10.36632/mejar/2020.9.3.47

Kalele, D., Ogara, W., Oludhe, C., & Onono, J. (2021). Climate change impacts and relevance of smallholder farmers' response in arid and semi-arid lands in Kenya. *Scientific African*, *12*, e00814. https://www.sciencedirect.com/science/article/pii/S2468227621001186

Kaliyadan, F., & Kulkarni, V. (2019). Types of variables, descriptive statistics, and sample size. *Indian Dermatology Online Journal, 10*(1), 82. https://doi.org/10.4103%2Fidoj.IDOJ_468_18

Kanyenji, G. M., Oluoch-Kosura, W., Onyango, C. M., & Karanja Ng'ang'a, S. (2020). Prospects and constraints in smallholder farmers' adoption of multiple soil carbon enhancing practices in Western Kenya. *Heliyon*, *6*(3), e03226. https://doi.org/10.1016/j.heliyon.2020.e03226

Kanyenji, G. M., Oluoch-Kosura, W., Onyango, C. M., & Ng'ang'a, S. K. (2019). *Does the adoption of soil carbon enhancing practices pay off? Evidence on maize yields from Western Kenya* [Paper presentation]. The 6th African Conference of Agricultural Economists, September 23-26, 2019, Abuja, Nigeria. https://cgspace.cgiar.org/handle/10568/105884

Karuga, J. G. (2022). *Agroecological farming impacts on livelihoods improvement to inform county government on enactment of agroecology policy: Case study of Kiambu County, Central Kenya* (Master's thesis, Norwegian University of Life Sciences). https://hdl.handle.net/11250/2995687

Kassa, M. D, Demissie, W. M., & Batu, M. M. (2019). Smallholders' technical efficiency of teff production in Ethiopia. *African Journal of Agricultural Research, 14*(33),1641-1648. https://doi.org/10.5897/ajar2017.12790

Kassie, M., Stage, J., Diiro, G., Muriithi, B., Muricho, G., Ledermann, S. T., Pittchara, J., Midegaa, C., & Khan, Z. (2018). Push–pull farming system in Kenya: Implications for economic and social welfare. *Land use policy, 77,* 186-198. https://doi.org/10.1016/j.landusepol.2018.05.041

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., & Erenstein, O. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, *66*(3), 640–659. https://doi.org/10.1111/1477-9552.12099

Kaur, P., Stoltzfus, J., & Yellapu, V. (2018). Descriptive statistics. *International Journal of Academic Medicine, 4*(1), 60-63. https://doi.org/10.4103/ijam.ijam_7_18

Kemboi, E., Muendo, K., & Kiprotich, C. (2020). Crop diversification analysis amongst smallholder farmers in Kenya (empirical evidence from Kamariny ward, Elgeyo Marakwet County). *Cogent Food and Agriculture*, *6*(1). https://doi.org/10.1080/23311932.2020.1834669

Khan, K., & Xiangyu, G. (2020). Determinants of rice technical efficiency in District Nasirabad, Balochistan. *Journal of Innovative Sciences*, *6*(1), 12-16. http://dx.doi.org/10.17582/journal.jis/2020/6.1.12.16

Khan, S. A., Narula, S., Naim, A., & Srivastava, M. (Eds.). (2025). *Handbook of human factors and ergonomics in contemporary business: Strategic orientation, corporate success and innovation* (1st ed.). CRC Press. https://doi.org/10.1201/9781003532293

Khanal, U., Stott, K. J., Armstrong, R., Nuttall, J. G., Henry, F., Christy, B. P., Mitchell, M., Riffkin, P. A., Wallace, A. J., McCaskill, M., Thayalakumaran, T., & O'leary, G. J. (2021). Intercropping—evaluating the advantages to broadacre systems. *Agriculture (Switzerland) 11*(5). https://doi.org/10.3390/agriculture11050453

Khonje, M. G., Manda, J., Mkandawire, P., Tufa, A. H., & Alene, A. D. (2018). Adoption and welfare impacts of multiple agricultural technologies: Evidence from eastern Zambia. *Agricultural Economics*, *49*(5), 599–609. https://doi.org/10.1111/agec.12445

Kirui, E. C., Kidoido, M. M., Mutyambai, D. M., Okello, D. O., & Akutse, K. S. (2023). Farmers' knowledge, attitude, and practices regarding the use of agroecological-based pest management practices in crucifers and traditional African vegetable (TAV) production in Kenya and Tanzania. *Sustainability*, *15*(23), 16491. https://doi.org/10.3390/su152316491

Komarek, A. M., & Msangi, S. (2019). Effect of changes in population density and crop productivity on farm households in Malawi. *Agricultural Economics, 50*(5), 615-628. https://doi.org/10.1111/agec.12513

Kothari, C. R. (2004). *Research methodology: Methods and techniques* (2nd ed). New Age International (P) Ltd.

Kotir, J. H., Bell, L. W., Kirkegaard, J. A., Whish, J., & Aikins, K. A. (2020). Labour and machinery requirements: Implications of different crop sequences. *Grains Research Update, 54.*

Kotosz, M. J. K. B. (2018). Technical efficiency estimation in the livestock industry: Case study of the southern rangelands of Kenya. *Challenges in National and International Economic Policies*, 97-114.

Krell, N. T., Giroux, S. A., Guido, Z., Hannah, C., Lopus, S. E., Caylor, K. K., & Evans, T. P. (2021). Smallholder farmers' use of mobile phone services in central Kenya. *Climate and Development*, *13*(3), 215–227. https://doi.org/10.1080/17565529.2020.1748847

Krishnan, R., Agarwal, R., Bajada, C., & Arshinder, K. (2020). Redesigning a food supply chain for environmental sustainability–An analysis of resource use and recovery. *Journal of Cleaner Production*, *242*, 118374. https://doi.org/10.1016/j.jclepro.2019.118374

Kule, E. K., Obia, A., Agole, D., Okello, D. M., & Odongo, W. (2025). Farmer perceptions and their implications for adoption of sustainable agricultural intensification practices. *Discover Sustainability*, *6*(1), 210. https://doi.org/10.1007/s43621-025-00929-z

Kumari, R. (2019). Data envelopment analysis recent applications in banking sector: A survey. *International Journal for Research in Applied Science & Engineering Technology, 7*(11), 449-456. http://dx.doi.org/10.22214/ijraset.2019.11073

Kundu, A., & Das, S. (2022). Occupational diversification as livelihood strategy among the agricultural labour households of west Bengal, India. *Management and Labour Studies*, *47*(1), 40–58. https://doi.org/10.1177/0258042x211026149

Kurgat, B. K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., & Rosenstock, T. S. (2020). Adoption of climate-smart agriculture technologies in Tanzania. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.00055/full

Kyire, S., Kuwornu, J., Bannor, R., & Apiors, E. (2023). Perceived risk and risk management strategies under irrigated rice farming: Evidence from Tono and Vea irrigation schemes-Northern Ghana. *Journal of Agriculture and Food Research*, *12*, 100593. https://doi.org/10.1016/j.jafr.2023.100593

Lanamana, W., & Supardi, P. N. (2020). A comparison of economic efficiency of monoculture and multiple cropping patterns: The case of cassava farming in Ende, Indonesia. *Caraka Tani: Journal of Sustainable Agriculture*, *36*(1), 69. https://doi.org/10.20961/carakatani.v36i1.41784

Liu, R. (2019). Comparison of bank efficiencies between the US and Canada: Evidence based on SFA and DEA. *Journal of Competitiveness*, *11*(2), 113-129. https://doi.org/10.7441/joc.2019.02.08

Loconto, A., & Fouilleux, E. (2019). Defining agroecology: Exploring the circulation of knowledge in FAO's Global Dialogue. *The International Journal of Sociology of Agriculture and Food*, *25*(2), 116-137. https://doi.org/10.48416/ijsaf.v25i2.27

Lv, Q., Chi, B., He, N., Zhang, D., Dai, J., Zhang, Y., & Dong, H. (2023). Cotton-based rotation, intercropping, and alternate intercropping increase yields by improving root–shoot relations. *Agronomy*, *13*(2). https://doi.org/10.3390/agronomy13020413

Maina, F., Mburu, J., & Nyang'anga, H. (2023). Access to and utilization of local digital marketing platforms in potato marketing in Kenya. *Heliyon*, *9*(8). https://doi.org/10.1016/j.heliyon.2023.e19320

Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., Okeyo, J. M., Mugendi, D. N., Okwuosa, E. A., & Ngetich, F. K. (2021). Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the central highlands of Kenya. *Weather and Climate Extremes*, *34*, 100374. https://doi.org/10.1016/j.wace.2021.100374

Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., Okeyo, J. M., Okwuosa, E. A., & Ngetich, F. K. (2022). Farm factors influencing soil fertility management patterns in Upper Eastern Kenya. *Environmental Challenges*, *6*. https://doi.org/10.1016/j.envc.2021.100409

Makena, N. S., Mwenjeri, G., & Ngare, L. (2023). Technical efficiency analysis of pigeon pea production in Machakos county, Kenya. *East African Agricultural and Forestry Journal*, *87*(3 & 4), 10–10.

Malinga, N. G., Masuku, M. B., & Raufu, M. O. (2015). Comparative analysis of technical efficiencies of smallholder vegetable farmers with and without credit access in swazil and the case of the Hhohho region. *International Journal of Sustainable Agricultural Research*, *2*(4), 133-145. https://doi.org/10.18488/journal.70/2015.2.4/70.4.133.145

Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics*, *67*(1), 130–153. https://doi.org/10.1111/1477-9552.12127

Mango, N., Makate, C., Tamene, L., Mponela, P., & Ndengu, G. (2018). Adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on household income in the Chinyanja Triangle, Southern Africa. *Land*, *7*(2), 49. https://doi.org/10.3390/land7020049

McFadden, D. (1973). Conditional logit analysis of qualitative choice behavior. In P. Zarembka (Ed.) *Frontiers in econometrics* (pp. 105–142). Academic Press.

Mdoda, L., Obi, A., Tamako, N., Naidoo, D., & Baloyi, R. (2023). Resource use efficiency of potato production among smallholder irrigated farmers in the Eastern Cape Province of South Africa. *Sustainability*, *15*(19), 14457. https://doi.org/10.3390/su151914457

Mebrate, A., Zeray, N., Kippie, T., & Haile, G. (2022). Determinants of soil fertility management practices in Gedeo Zone, Southern Ethiopia: logistic regression approach. *Heliyon*, *8*(1). https://doi.org/10.1016/j.heliyon.2022.e08820

Meeusen, W.& Van Den Broeck, J. (1977) Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review*, *18* (2), 435–444. https://doi.org/105.161.238.100

Meng, F., Qiao, Y., Wu, W., Smith, P., & Scott, S. (2017). Environmental impacts and production performances of organic agriculture in China: A monetary valuation. *Journal of Environmental Management*, *188*, 49-57. https://doi.org/10.1016/j.jenvman.2016.11.080

Meshesha, A. T. (2023). *Climate-smart agriculture: Building resilience in the Upper Blue Nile highlands of Ethiopia* (Doctoral dissertation, Addis Ababa University).

Mmbando, F., Mbeyagala, E., Binagwa, P., Karimi, R., Opie, H., Ochieng, J., Mutuoki, T., & Nair, R. M. (2021). Adoption of improved mungbean production technologies in selected east African countries. *Agriculture (Switzerland)*, *11*(6). https://doi.org/10.3390/agriculture11060528

Mogaka, B., Ng'ang'a, S. K., & Bett, H. (2022). Comparative profitability and relative risk of adopting climate-smart soil practices among farmers. A cost-benefit analysis of six agricultural practices. *Climate Services*, *26*, 100287

Mohd Chachuli, F. S., Ahmad Ludin, N., Mat, S., & Sopian, K. (2020). Renewable energy performance evaluation studies using the data envelopment analysis (DEA): A systematic review. *Journal of Renewable and Sustainable Energy, 12*(6), 062701. https://doi.org/10.1063/5.0024750

Morepje, M. T. (2024). *Redesigning production systems for water-use efficiency amongst smallholder farmers at Numbi, South Africa* (Master's thesis, University of Mpumalanga).

Mottet, A., Bicksler, A., Lucantoni, D., De Rosa, F., Scherf, B., Scopel E, López-Ridaura, S., GemmilHerren, B., Bezner Kerr, R., Sourisseau, J. M., Petersen, P., Chotte, J. L., Loconto, A., & Tittonell, P. (2020). Assessing transitions to sustainable agricultural and food systems: A Tool for Agroecology Performance Evaluation (TAPE). *Frontiers in Sustainable Food Systems 4*, 579154. https://doi.org/10.3389/fsufs.2020.579154

Msangi, H. A., Waized, B., Löhr, K., Sieber, S., & Ndyetabula, D. W. (2022). Development outcomes of land tenure formalization under customary and statutory land tenure systems in Tanzania: A multinomial endogenous switching regression approach. *Agriculture and Food Security*, *11*(1). https://doi.org/10.1186/s40066-022-00403-3

Mugambi, I., Karanja, L., Macharia, I., Kaguongo, W., Ngundo, G., Amata, R., Makale, F., Wanjiku, J., Chacha, D., Nyongesa, M., Kimenju, J. W., Ochilo, W., & Mulema, J. (2021). What influences uptake of alternative pest management practices by potato farmers? Evidence from six counties in Kenya. *Journal of Development and Agricultural Economics*, *13*(3), 205–214. https://doi.org/10.5897/jdae2021.1278

Mukiri, M. J., Nyasani, J., Muya, S. M., Nyanjom, S. G., Khamis, F. M., Ombura, F. L., Subramanian, S., Nyambo, B., Ekesi, S., & Niassy, S. (2020). Establishment of an exotic parasitoid *Cotesia vestalis* in coastal areas of Kenya as biological control agent of *Plutella xylostella.* In Niassy, S., Ekesi, S., Migiro, L., Otieno, W. (eds) *Sustainable Management of Invasive Pests in Africa* (pp 107–124). https://doi.org/10.1007/978-3-030-41083-4_10

Mulwa, C. K., Muyanga, M., & Visser, M. (2021). The role of large traders in driving sustainable agricultural intensification in smallholder farms: Evidence from Kenya. *Agricultural Economics (United Kingdom)*, *52*(2), 329–341. https://doi.org/10.1111/agec.12621

Murali, P., & Puthira Prathap, D. (2017). Technical efficiency of sugarcane farms: An econometric analysis. *Sugar tech*, *19*(2), 109-116. https://doi.org/10.1007/s12355-016-0456-8

Muriithi, B., Diiro, G., Berresaw, M. K., & Muricho, G. (2018). Does gender matter in the adoption of sustainable agricultural technologies? A case of push-pull technology in Kenya. *Food Security*, *10*(2), 253–272

Muriithi, L. N., Onyari, C. N., Mogaka, H. R., & Gichimu, B. M. (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 D, 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). https://doi.org/10.1016/j.heliyon.2021.e08677

Musafiri, C. M., Macharia, J. M., Ng'etich, O. K., Kiboi, M. N., Okeyo, J., Shisanya, C. A., Okwuosa, E. A., Mugendi, D. N., & Ngetich, F. K. (2020). Farming systems' typologies analysis to inform agricultural greenhouse gas emissions potential from smallholder rain-fed farms in Kenya. *Scientific African*, *8*. https://doi.org/10.1016/j.sciaf.2020.e00458

Musembi, E. (2019). *Demand for agricultural credit by rural smallholder farmers: A case of climate smart agriculture villages in Nyando basin, Kenya* (Doctoral dissertation, University of Nairobi)

Mutoro, K. (2022). Pricing of spider plant (*Cleome gynandra*) quality attributes in Kiambu county, Kenya. *Quantum Journal of Engineering, Science, and Technology*, *3*(1), 40-49. https://www.qjoest.com/index.php/qjoest/article/view/59

Muyanga, M., & Jayne, T. (2019). Revisiting the farm size-productivity relationship based on a relatively wide range of farm sizes: Evidence from Kenya. *American Journal of Agricultural Economics*, *101*(4), 1140–1163. https://doi.org/10.1093/ajae/aaz003

Mvungi, H., Laizer, A., Lukumay, P. J., Ochieng, J., Ngoteya, G., Dinssa, F., Simon, J. E., Govindasamy, R., Ndinya, C., & Odendo, M. (2020). Profitability analysis of traditional African vegetable seeds production in Kenya. *Journal of Medicinally Active Plants*, *9*(4), 281-288. https://doi.org/10.7275/08eb-nv32

Mwangi, B. M. (2021) *Impact of improved sorghum varieties on poverty reduction among rural farming households in Tharaka Nithi county, Kenya* (Doctoral dissertation, Kenyatta University).

Mwangi, T. M., Ndirangu, S. N., & Isaboke, H. N. (2020). Technical efficiency in tomato production among smallholder farmers in Kirinyaga County, Kenya. *African Journal of Agricultural Research 16*(5), 667-677. https://doi.org/10.5897/ajar2020.14727

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. *Sustainable Food Systems*, *4*, 570190. https://doi.org/10.3389/fsufs.2020.570190

Mwikamba, J. N., Otieno, D. J., & Kosura, W. O. (2021). Adoption of climate-smart horticulture practices and use of mobile phones in Taita-Taveta county, Kenya. *East African Agricultural and Forestry Journal*, *85*(1 & 2), 13–13

Mwikamba, J. N., Otieno, D. J., & Oluoch-Kosura, W. (2024). Effect of using a mobile phone on technical efficiency and productivity of climate-smart horticulture farmers in Taita-Taveta county, Kenya. *Heliyon*, *10*(17). https://doi.org/10.1016/j.heliyon.2024.e36917

Ndiritu, S., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, *49*, 117–127. https://doi.org/10.1016/j.foodpol.2014.06.010

Neely, A., Gregory, M., & Platts, K. (2005). Performance measurement system design: A literature review and research agenda. *International Journal of Operations & Production Management*, *25*(12), 1228-1263. https://doi.org/10.1108/01443570510633639

Ngaiwi, M. E. (2023). *Modelling farm-household livelihoods for estimating the adoption impacts of selected policy instruments on agriculture and climate change in south-eastern Cameroon* (Doctoral thesis, University of Buea).

Ng'ang'a, S., Anyango Jalang'o, D., & Girvetz, E. H. (2019). Adoption of soil carbon enhancing practices and their impact on farm output in Western Kenya. *Springer Nature: Applied Sciences, 1*, 1726. https://doi.org/10.1007/s42452-019-1747-y

Ng'ang'a, T. (2015). Women's experiences on food security in Kenya: Major challenges that they face. *Pathways to African Feminism and Development, Journal of African Women's Studies Centre*, *1*(2). http://journals.uonbi.ac.ke/index.php/aws/article/view/1314

Ngango, J., & Kim, S. G. (2019). Assessment of technical efficiency and its potential determinants among small-scale coffee farmers in Rwanda. *Agriculture*, *9*(7), 161. https://doi.org/10.3390/agriculture9070161

Ngango, J., & Nkurunziza, F (2021). *Estimating the impact of sustainable agricultural intensification practices on household productivity and consumption in Rwanda: A multinomial endogenous switching regression* [Paper presentation]. International Association of Agricultural Economists (IAAE) 2021 Conference. https://doi.org/10.22004/ag.econ.315060

Ngigi, M. W., & Muange, E. N. (2022). Access to climate information services and climate-smart agriculture in Kenya: A gender-based analysis. *Climatic Change*, *174*(3–4). https://doi.org/10.1007/s10584-022-03445-5

Ngo, T., Le, T., Tran, S. H., Nguyen, A., & Nguyen, C. (2019). Sources of the performance of manufacturing firms: Evidence from Vietnam. *Post-Communist Economies*, *31*(6), 790-804. https://doi.org/10.1080/14631377.2019.1607129

Ngowi, B. V. (2019). *Potential effects of climate change on tritrophic interactions in crucifer farming systems of Mount Kilimanjaro and Taita Hills* (Doctoral dissertation, University of Nairobi). http://erepository.uonbi.ac.ke/handle/11295/152831

Nguyen, T. T. N. (2021). *How to develop agriculture and protect the environment around protected areas: A case analysis of Xuan Thuy National Park, Vietnam*. Universite de Liege (Belgium).

Nguyen-Van, P., Poiraud, C., & To-The, N. (2017). Modeling farmers' decisions on tea varieties in Vietnam: A multinomial logit analysis. *Agricultural Economics (United Kingdom)*, *48*(3), 291–299. https://doi.org/10.1111/agec.12334

Nijenhuis, V. H. (2022). *Agroecology as a solution for sustainable agriculture on industrialized farms:A stakeholder research on possibilities and challenges for agricultural alternatives* (Doctoral dissertation, University of Groningen)

Njenga, M. W., Mugwe, J. N., Mogaka, H., Nyabuga, G., Kiboi, M., Ngetich, F., Mucheru-Muna, M., Sijali, I., & Mugendi, D. (2017). Communication factors influencing adoption of soil and water conservation technologies in the dry zones of Tharaka-Nithi County, Kenya. *Heliyon*, *7*(10), e08236. https://doi.org/10.1016/j.heliyon.2021.e08236

Ntawuruhunga, D., Affognon, H. D., Fiaboe, K. K., Abukutsa-Onyango, M. O., Turoop, L., & Muriithi, B. W. (2020). Farmers' knowledge, attitudes, and practices (KAP) on production of African indigenous vegetables in Kenya. *International Journal of Tropical Insect Science*, *40*(2), 337-349. https://doi.org/10.1007/s42690-019-00085-8

Nyang'au, J. O., Mohamed, J. H., Mango, N., Makate, C., & Wangeci, A. N. (2021). Smallholder farmers' perception of climate change and adoption of climate smart agriculture practices in Masaba South Sub- County, Kisii, Kenya. *Heliyon*, *7*(4). https://doi.org/10.1016/j.heliyon.2021.e06789

Nyangau, P., Muriithi, B., Diiro, G., Akutse, K. S., & Subramanian, S. (2022). Farmers' knowledge and management practices of cereal, legume and vegetable insect pests, and willingness to pay for biopesticides. *International Journal of Pest Management*, *68*(3), 204–216. https://doi.org/10.1080/09670874.2020.1817621

Nyarindo, W. N., Mugera, A., Hailu, A., & Obare, G. A. (2024). Do combined sustainable agricultural intensification practices improve smallholder farmers welfare? Evidence from eastern and western Kenya. *Agricultural Economics*. https://doi.org/10.1111/agec.12816

Ochieng, J., Afari-Sefa, V., Muthoni, F., Kansiime, M., Hoeschle-Zeledon, I., Bekunda, M., & Thomas, D. (2022). Adoption of sustainable agricultural technologies for vegetable production in rural Tanzania: Trade-offs, complementarities, and diffusion. *International Journal of Agricultural Sustainability*, *20*(4), 478-496.

Ochilo, W. N., Nyamasyo, G. N., Kilalo, D., Otieno, W., Otipa, M., Chege, F., Karanja, T., & Lingeera, E. K. (2019). Characteristics and production constraints of smallholder tomato production in Kenya. *Scientific African*, *2*, e00014. https://doi.org/10.1016/j.sciaf.2018.e00014

Odendo, M., Obare, G., & Salasya, B. (2010). *Determinants of the speed of adoption of soil fertility-enhancing technologies in Western Kenya* [Paper presentation]. The Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa. http://dx.doi.org/10.22004/ag.econ.96192

Ogutu, S. O., Ochieng, D. O., & Qaim, M. (2020). Supermarket contracts and smallholder farmers: Implications for income and multidimensional poverty. *Food Policy*, *95*, 101940. https://doi.org/10.1016/j.foodpol.2020.101940

Okello, D. O. (2021). *Impact of agripreneurial orientations on resilience and performance of dairy agripreneurs in Murang'a County, Kenya: The mediating effect agribusiness support services* (Doctoral dissertation, Egerton University). http://dx.doi.org/10.22004/ag.econ.311314

Okoth, P. F., Stoorvogel, J. J., Heesmans, H. I. M., Besufkad, A., Tolla, M., Mamuye, M., Gebremeskel, Y., Elias, E., van Beek, C. L., & Smaling, E. M. A. (2022). An analysis of net farm income to guide agricultural policies in the Ethiopian highlands. *Agriculture and Food Security*, *11*(1). https://doi.org/10.1186/s40066-022-00404-2

Onyalo, P. O. (2019). Women and agriculture in rural Kenya: Role in agricultural production. *International Journal of Humanities, Art and Social Studies*, *4*(4), 1–10.

Onyeneke, R. U., Emenekwe, C. C., & Nwajiuba, C. U. (Eds.). (2025). *Energy transition, climate action and sustainable agriculture: Perspectives and strategies for Africa*. Springer Nature.

Ooga, D., & Gikunda, R. M. (2021). Influence of land tenure and farmer income on adoption of indigenous agricultural practices in Chuka sub-county, Kenya. *Journal of Environmental Sustainability Advancement Research*, *7*, 73-79. http://repository.chuka.ac.ke/handle/chuka/15468

Oparinde, L. O. (2021). Fish farmers' welfare and climate change adaptation strategies in southwest, Nigeria: Application of multinomial endogenous switching regression model. *Aquaculture Economics and Management*, *25*(4), 450–471. https://doi.org/10.1080/13657305.2021.1893863

Osanya, J., Adam, R., Otieno, D., Nyikal, R., & Jaleta, M. (2020). An analysis of the respective contributions of husband and wife in farming households in Kenya to decisions regarding the use of income: A multinomial logit approach. *Women's Studies International Forum*, *83*, 102419. https://doi.org/10.1016/j.wsif.2020.102419

Otieno, E. O., Kiboi, M. N., Gian, N., Muriuki, A., Musafiri, C. M., & Ngetich, F. K. (2021). Uptake of integrated soil fertility management technologies in heterogeneous smallholder farms in sub-humid tropics. *Environmental Challenges*, *5*, 100394. https://doi.org/10.1016/j.envc.2021.100394

Owade, J. O., Abong', G. O., Okoth, M. W., & Mwang'ombe, A. W. (2020). Trends and constraints in the production and utilization of cowpea leaves in the arid and semi-arid lands of Kenya. *Open Agriculture*, *5*(1), 325–334. https://doi.org/10.1515/opag-2020-0038

Oyawole, F. P., Shittu, A., Kehinde, M., Ogunnaike, G., & Akinjobi, L. T. (2021). Women empowerment and adoption of climate-smart agricultural practices in Nigeria. *African Journal of Economic and Management Studies*, *12*(1), 105–119. https://doi.org/10.1108/ajems-04-2020-0137

Oyetunde-Usman, Z., Olagunju, K. O., & Ogunpaimo, O. R. (2021). Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria. *International Soil and Water Conservation Research*, *9*(2), 241–248. https://doi.org/10.1016/j.iswcr.2020.10.007

Paracchini, M. L., Justes, E., Wezel, A., Zingari, P. C., Kahane, R., Madsen, S., Scopel, E., Héraut, A., Bhérer-Breton, P., Buckley, R., Colbert, E., Kapalla, D., Sorge, M., Adu Asieduwaa, G., Bezner Kerr, R., Maes, O., & Nègre, T. (2020). *Agroecological practices supporting food production and reducing food insecurity in developing countries. A study on scientific literature in 17 countries.* Publications Office of the European Union. https://doi.org/10.2760/82475

Parvathi, P., & Waibel, H. (2016). Organic agriculture and fair trade: A happy marriage? A case study of certified smallholder black pepper farmers in India. *World Development*, *77*, 206-220. https://doi.org/10.1016/j.worlddev.2015.08.027

Peng, J., Chen, L., Yu, B., Zhang, X., & Huo, Z. (2022). Effects of multiple cropping of farmland on the welfare level of farmers: Based on the perspective of poverty vulnerability. *Frontiers in Ecology and Evolution*, *10*. https://doi.org/10.3389/fevo.2022.988757

Rasmussen, S. (2012). *Production economics: the basic theory of production optimisation*. Springer Science & Business Media.

Rebecca, J., Peter, D., George, O., Patience, M., Paul, K., Maximilian, W., & Gideon, H. (2018). Factors affecting the adoption of agricultural innovations on underutilized cereals: The case of finger millet among smallholder farmers in Kenya. *African Journal of Agricultural Research*, *13*(36), 1888–1900. https://doi.org/10.5897/ajar2018.13357

Republic of Kenya. (2019). *Gross county product: Report*. Kenya National Bureau of Statistics. https://new.knbs.or.ke/reports/kenya-gross-county-product-2019/

Reynolds, T., Tobin, D., Otieno, G., & McCracken, A. (2020). Differences in crop selection, resource constraints, and crop use values among female- and male-headed smallholder households in Kenya, Tanzania, and Uganda. *Journal of Agriculture, Food Systems, and Community Development*, 1–24. https://doi.org/10.5304/jafscd.2020.094.011

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. https://doi.org/10.1016/j.worlddev.2021.105599

Sahu, M., Devi, S., Mishra, P., & Gupta, E. (2020). Mustard is a miracle seed to human health. In *Ethnopharmacological Investigation of Indian Spices* (pp. 154-162). IGI Global. https://doi.org/10.4018/978-1-7998-2524-1.ch012

Sapbamrer, R., & Thammachai, A. (2021). A systematic review of factors influencing farmers' adoption of organic farming. *Sustainability (Switzerland)*, *13*(7). https://doi.org/10.3390/su13073842

Sarma, P. K., & Rahman, M. M. (2020). Impact of government agricultural input subsidy card on rice productivity in Rajbari District of Bangladesh: Application of endogenous switching regression model. *Universal Journal of Agricultural Research*, *8*(5), 131–145. https://doi.org/10.13189/ujar.2020.080501

Scherf, B. (2018). Agroecology–A pathway to achieving the SDGs. *International Journal for Rural Development, 2*, 14–16.

Schoonhoven, Y., & Runhaar, H. (2018). Conditions for the adoption of agro-ecological farming practices: A holistic framework illustrated with the case of almond farming in

Andalusia. *International Journal of Agricultural Sustainability, 16*(6), 442-454. https://doi.org/10.1080/14735903.2018.1537664

Selim, M. (2019). A review of advantages, disadvantages and challenges of crop rotations. *Egyptian Journal of Agronomy*, *41*(1), 1–10. https://doi.org/10.21608/agro.2019.6606.1139

Seo, Y., & Umeda, S. (2021). Evaluating farm management performance by the choice of pest-control sprayers in rice farming in Japan. *Sustainability*, *13*(5), 2618. https://doi.org/10.3390/su13052618

Setsoafia, E. D. (2021). *The impact of the adoption of sustainable agricultural practices on farm income and household food security in Northern Ghana* (Doctoral dissertation, Lincoln University).

Sonnentag, S., & Frese, M. (2002). Performance concepts and performance theory. *Psychological Management of Individual Performance, 23*(1), 3-25.

Stassart, P.M., Crivits, M., Hermesse, J., Tessier, L., Van Damme, J., & Dessein, J., (2018). The generative potential of tensions within Belgian agroecology. *Sustainability*, *10*(6), 2094. https://doi.org/10.3390/su10062094

Teklewold, H., Adam, R., & Marenya, P. (2020). What explains the gender differences in the adoption of multiple maize varieties? Empirical evidence from Uganda and Tanzania. *World Development Perspectives*, *18*, 100206. https://doi.org/10.1016/j.wdp.2020.100206

Tesgera, W. D., Beyene, A. B., & Wakjira, T. K. (2024). Does non-farm employment increase rural households' consumption in western Ethiopia? Empirical evidence from the horo guduru wollega zone. *Heliyon*, *10*(7). https://doi.org/10.1016/j.heliyon.2024.e26449

Theis, S., Lefore, N., Meinzen-Dick, R., & Bryan, E. (2018). What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. *Agriculture and Human Values*, *35*(3), 671–684. https://doi.org/10.1007/s10460-018-9862-8

Thomas, M. M., Samuel, N. N., & Hezron, N. I. (2020). Technical efficiency in tomato production among smallholder farmers in Kirinyaga County, Kenya. *African Journal of Agricultural Research*, *16*(5), 667–677. https://doi.org/10.5897/ajar2020.14727

Tran, N. L. D., Rañola, R. F., Ole Sander, B., Reiner, W., Nguyen, D. T., & Nong, N. K. N. (2020). Determinants of adoption of climate-smart agriculture technologies in rice production in Vietnam. *International Journal of Climate Change Strategies and Management*, *12*(2), 238–256. https://doi.org/10.1108/ijccsm-01-2019-0003/full/html

Tufa, A., Alene, A., Cole, S., Manda, J., & Feleke, S. (2022). Gender differences in technology adoption and agricultural productivity: Evidence from Malawi. *World Development*, *159*, 106027. https://doi.org/10.1016/j.worlddev.2022.106027

Tüzel, Y., & Öztekin, G. (2018). Crop diversification, management and practical uses. In *Good agricultural practices for greenhouse vegetable production in the South East European countries* (pp. 105–120). Food and Agriculture Organization of the United Nations: Rome, Italy

Van der Ploeg, J. D., Barjolle, D., Bruil, J., Brunori, G., Madureira, L. M. C., Dessein, J., Drąg, Z., Fink-Kessler, A., Gasselin, P., Gonzalez de Molina, M., Gorlach, K., Jürgens, K., Kinsella, J., Kirwan, J., Knickel, K., Lucas, V., Marsden, T., Maye, D. Migliorini, P., … & Wezel, A. (2019). The economic potential of agroecology: Empirical evidence from Europe. *Journal of Rural Studies, 71*, 46-61. https://doi.org/10.1016/j.jrurstud.2019.09.003

Waaswa, A., Nkurumwa, A. O., Kibe, A. M., & Ng'eno, J. K. (2021). Understanding the socioeconomic determinants of adoption of climate-smart agricultural practices among smallholder potato farmers in Gilgil Sub-County, Kenya. *Discover Sustainability*, *2*(1). https://doi.org/10.1007/s43621-021-00050-x

Waaswa, A., Oywaya Nkurumwa, A., Mwangi Kibe, A., & Ngeno Kipkemoi, J. (2022). Climate-Smart agriculture and potato production in Kenya: Review of the determinants of practice. *Climate and Development*, *4*(1), 75-90. https://doi.org/10.1080/17565529.2021.1885336

Waha, K., Dietrich, J. P., Portmann, F. T., Siebert, S., Thornton, P. K., Bondeau, A., & Herrero, M. (2020). Multiple cropping systems of the world and the potential for increasing cropping intensity. *Global Environmental Change*, *64*, 102131. https://doi.org/10.1016/j.gloenvcha.2020.102131

Wairore, J. N., Mureithi, S. M., Wasonga, O. V., & Nyberg, G. (2016). Benefits derived from rehabilitating a degraded semi-arid rangeland in private enclosures in West Pokot County, Kenya. *Land Degradation and Development*, *27*(3), 532–541. https://doi.org/10.1002/ldr.2420

Wamuyu, S. N., Bett, H. K., Kariuki, I. M., & Cadot, J. (2022). Socio-economic factors influencing technical efficiency among smallholder potato farmers in Kenya. *East African Agricultural and Forestry Journal, 86*(1-2), 12–12

Wanyonyi, E. I., Gathungu, E. W., Bett, H. K., & Okello, D. O. (2021). Determinants of Porter's competitive strategy utilization among agro-dealers in Kenya. *Cogent Food & Agriculture*, *7*(1), 1865595. https://doi.org/10.1080/23311932.2020.1865595

Wezel, A., Casagrande, M., Celette, F., Vian, J. F., Ferrer, A., & Peigné, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development 34*(1), 1–20. https://doi.org/10.1007/s13593-013-0180-7

Wezel, A., Goris, M., Bruil, J., Félix, G. F., Peeters, A., Bàrberi, P., Bellon, S., & Migliorini, P. (2018). Challenges and action points to amplify agroecology in Europe. *Sustainability, 10*(5), 1598. http://dx.doi.org/10.3390/su10051598

Wezel, A., Soboksa, G., McClelland, S., Delespesse, F., & Boissau, A. (2015). The blurred boundaries of ecological, sustainable, and agroecological intensification: A review. *Agronomy for Sustainable Development, 35*(4), 1283–1295. https://doi.org/10.1007/s13593-015-0333-y

Wooldridge, J. M. (2013). *Introductory Econometrics* (5th ed). Cengage learning.

Yokying, P., & Lambrecht, I. (2020). Landownership and the gender gap in agriculture: Insights from northern Ghana. *Land Use Policy*, *99*. https://doi.org/10.1016/j.landusepol.2020.105012

Yu, T., Mahe, L., Li, Y., Wei, X., Deng, X., & Zhang, D. (2022). Benefits of crop rotation on climate resilience and its prospects in China. *Agronomy*, *12*(2). https://doi.org/10.3390/agronomy12020436

Zakaria, A., Alhassan, S. I., Kuwornu, J. K., Azumah, S. B., & Derkyi, M. A. (2020). Factors influencing the adoption of climate-smart agricultural technologies among rice farmers in northern Ghana. *Earth Systems and Environment*, *4*(1), 257-271. https://doi.org/10.1007/s41748-020-00146-w

Zegeye, M. B., & Meshesha, G. B. (2022). Estimating the impact of fertilizer adoption on poverty in rural Ethiopia: An endogenous switching regression approach. *Asia-Pacific Journal of Regional Science*, *6*(2), 713–733. https://doi.org/10.1007/s41685-022-00234-x

Zerssa, G., Feyssa, D., Kim, D. G., & Eichler-Löbermann, B. (2021). Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture (Switzerland)*, *11*(3), 1-26. https://doi.org/10.3390/agriculture11030192

Zewdie, M. C., Moretti, M., Tenessa, D. B., Ayele, Z. A., Nyssen, J., Tsegaye, E. A., Minale, A. S., & Van Passel, S. (2021). Agricultural technical efficiency of smallholder farmers in Ethiopia: A stochastic frontier approach. *Land*, *10*(3), 1–17. https://doi.org/10.3390/land10030246

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., & Speelman, S. (2018). Impacts of socio-psychological factors on actual adoption of sustainable land management practices in dryland and water stressed areas. *Sustainability (Switzerland)*, *10*(9). https://doi.org/10.3390/su10092963

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., & Speelman, S. (2020). Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: Empirical evidence from Northern Ethiopia. *Land Use Policy*, *95*. https://doi.org/10.1016/j.landusepol.2019.01.002

Zheng, H., Ma, W., & Li, G. (2021). Adoption of organic soil amendments and its impact on farm performance: Evidence from wheat farmers in China. *Australian Journal of Agricultural and Resource Economics*, *65*(2), 367-390. https://doi.org/10.1111/1467-8489.12406

APPENDICES

Appendix A: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **526109** Date of Issue: **02/August/2023**

RESEARCH LICENSE

This is to Certify that Miss.. Essy Chemutai Kirui of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Kiambu, Muranga on the topic: Effects of Agroecological Vegetable Cropping Systems on Smallholder Farmers' Performance in Kiambu and Murang'a Counties, Kenya for the period ending : 02/August/2024.

License No: **NACOSTI/P/23/28124**

526109

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See overleaf for conditions

Appendix B: Ethical Approval

EGERTON UNIVERSITY

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FAX: 051-2217942

P. O. BOX 536
EGERTON

EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW COMMITTEE

EU/RE/DIR/009
Approval No. EUISERC/APP/260/2023 ***29th June*** **2023**

Essy Chemutai Kirui
P.O Box 3561, 20100
Telephone: 0701890809
E-mail: kiruiessy01@gmail.com.

Dear Essy,

RE: ETHICAL APPROVAL: EFFECTS OF AGROECOLOGICAL VEGETABLE CROPPING SYSTEMS ON SMALLHOLDER FARMERS' PERFORMANCE IN KIAMBU AND MURANG'A COUNTIES, KENYA

This is to inform you that ***Egerton University Institutional Scientific and Ethics Review Committee*** has reviewed and approved your above research proposal. Your application approval number is ***EUISERC/APP/260/2023.*** The approval period is ***29th June, 2023 –30th June, 2024***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***Egerton University Institutional Scientific and Ethics Review Committee***.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours.
v. Clearance for Material Transfer of biological specimens must be obtained from relevant

institutions.

vi. Submission of a request for renewal of approval at least 60 days prior to expiry of theapproval period. Attach a comprehensive progress report to support the renewal.

vii. Submission of an executive summary report within 90 days upon completion of the studyto ***Egerton University Institutional Scientific and Ethics Review Committee***.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely.

EGERTON UNIVERSITY
Date. 29/06/2023
RESEARCH ETHICS

Prof. Raphael M. Ngure

CHAIRMAN, EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICSREVIEW CTTEE

RMN/BK/

Appendix C: Questionnaire

THE IMPACT OF AGROECOLOGICAL BASED CRUCIFER AND TRADITIONAL AFRICAN VEGETABLE CROPPING SYSTEMS ON PERFORMANCE OF SMALLHOLDER FARMERS IN CENTRAL KENYA

BASELINE QUESTIONNAIRE

Introductory and consent statement:
"Dear Sir/Madam, I work for the International Center of Insect Physiology and Ecology (*icipe*). We are conducting a survey to assess the impact of agroecological based crucifer and traditional African vegetable cropping systems on the performance of smallholder producers. Your household response to these questions would remain **anonymous**. Taking part in this study is voluntary. If you choose not to take part, at any point of the interview, you have the right not to participate and there will be no consequences.
Do you and your family consent to provide information? 1=Yes, **0**=No (*if NO, skip to end*) ………………………….
"Thank you for your kind co-operation".

MODULE A. HOUSEHOLD DEMOGRAPHICS

No.	**Question**	**Response**	**Code**
A.1	Name of enumerator		
A.2	a) Date (dd/mm/yyyy) b) Start time	a) ____________________ b) ____________________	
A.3	Household ID		
A.4	Name of respondent (*max. of three names*)		
A.5	Gender of respondent	Male	0
	(Circle the appropriate response code)	Female	1
A.6	Age of respondent (*Year of birth*)		
A.7	Relationship of respondent to the household head	Household head	1
	(Circle the appropriate response code)	Husband	2
		Wife	3
		Other(specify) _______	4
A.8	Main occupation of respondent (*select multiple*)	Vegetable production	1
		Other farming (crop + livestock)	2
		Off-farm salaried employment	3
		Casual labor	4
		Own business off-farm	5
		Retired	6
		Unemployed	7
		In school	8
		Other(specify) _________	9
A.9	Respondent's level of education completed	None	0
		Primary	1
		Secondary	2
		Tertiary	3
A.10	Respondent's phone number		
A.11	Name of household head (*max. of three names*) (*skip if respondent is household head*)		

No.	Question	Response	Code
A.12	Gender of household head (*skip if respondent is household head*)	Male	0
		Female	1
A.13	Age of household head (*skip if respondent is household head*) (*Year of birth*)		
A.14	Main occupation of household head (*skip if respondent is household head*)	Vegetable production	1
		Other farming (crop + livestock)	2
		Off-farm salaried employment	3
		Casual labor	4
		Own business off-farm	5
		Retired	6
		Unemployed	7
		In school	8
		Other(specify) __________	9
A.15	Level of education household head completed. (*Skip if respondent is household head*)	None	0
		Primary	1
		Secondary	2
		Tertiary	3
A.16	Household head's phone number (*skip if respondent is household head*)		
A.17	Spouse's name (Maximum *of three names*)		
A.18	Age of Spouse (*skip if respondent is Spouse*) (*Year of birth*)		
A.19	Main occupation of Spouse (*skip if respondent is Spouse*)	Vegetable production	1
		Other farming (crop + livestock)	2
		Off-farm salaried employment	3
		Casual labor	4
		Own business off-farm	5
		Retired	6
		Unemployed	7
		In school	8
		Other(specify) __________	9
A.20	Level of education Spouse completed. (*Skip if respondent is Spouse)*	None	0
		Primary	1
		Secondary	2
		Tertiary	3
A.21	Spouse's phone number (*skip if respondent is Spouse*)		
A.22	What is your household size? (Total number of household members)		
A.23	How many children below 5 years?		
A.24	How many female household members above 18 years?		
A.25	How many male household members above 18 years?		
A.26	District/County	Kenya	
		Murang'a	1

No.	Question	Response	Code
		Kiambu	2
A.27	Village		

MODULE B: BRASSICAS AND TRADITIONAL AFRICAN VEGETABLES PRODUCTION AND SALES

Please provide the following information about the land used by the household in the last 12 months (also include rented land, and fallow/ grazing land)

	B.1. Total agricultural cultivated land			B.2. Own land left fallow	B.3. Land given to other family members		B.4. Grazing land	B.5. Home stead land
	B.1.1. Own land	B.1.2. Gift land	B.1.3. Rented-in		B.3.1. Rented out	B.3.2. Gift		
Acres								
If you rented out/in land, what is the cost of renting land per acre?________________								

Give details about the plots of land cultivated (including the rented in land) for the last 12 months 2021 in Short rains, long rains and dry season, for brassicas and Traditional African Vegetables (TAVs) (*Enumerators show farmers TAVs photos for accurate identification*)

B.6 Season (Code **A**)	B.7 Plot No	B.8. Sub plot No.	B.9 Area (Acres)	B.10. Brassicas /TAV (Code **B**)	B.11. Who owns the plot (Code **C**)	B.12. Who manages the plot (Code **C**)	B.13.Vegetable output		B.14.Vegetable sales		B.15. Where did you sell [vegetables]? Code D	B.16. Who sold the [vegetables] (Code **C**)	B.17. Who decides how the proceeds will be allocated in the household? (Code **C**)
							(1)Quantity [vegetables] produced (Kgs)	(2)Quantity [vegetables] lost due to pests/diseases (Kgs)	Quantity[vegetables] (Kgs)	Price per Kg of vegetable (Kshs)			

Code (A)	**Code (B)**	**Code (B)**	**Code (B)**	**Code (C)**	**Code (D)**
Long rain=1 Short rain=2 Dry season=3	Kale=1 Cabbage=2 Beetroots=3 Cauliflower=4 Carrots=5 Eggplant=6 Onions=7 Tomatoes=8	Amaranth (terere) (Specify variety) =9 _____________ Cowpeas (Kunde mboga)=10 Pumpkin leaves=11) African nightshade (specify variety) =12 _________ Sunnhemp=13 Jute plant=14	Pig weed =15 cassava leaves=16 Sweet potato leaves=17 Spider plant (sagaa, Saget)=18 Jew's Mallow (Mrenda/Murere)=19 Stinging nettle (thatha) =20 Crotalaria (Mito, Miro) =21 Other (Specify) =19___________	Household head =1 Spouse=2 Jointly=3 Other(specify)=4 __________	Farm gate=1 Village market=2 District market=3 Broker=4 Exported=5

B.18. Cost of Fertilizer (Kshs)	B.19. Cost of hired labor (Kshs)	B.20. Other costs (e.g seeds, transport) (Kshs)	B. 21. What is the production system ? (Code **E)**	B.22. What is the cropping system used on this plot? (Code **F**)
			Code E	**Code F**
			Rain-fed=1, irrigation=2, Both=3	Row intercrop=1 Mixed/ broadcast cropping (no *specific pattern in polyculuture*)=2 Border cropping=3 Strip cropping =4 Monoculture=5

MODULE C: CHEMICAL USE IN VEGETABLE PRODUCTION

Indicate the cost and area (acres) that the insecticide/fungicide/herbicide was applied

Season (Code A)	Plot No	Subplot No.	Did this plot receive insecticide? Yes=1, No=0	Amount of insecticide used? used(Kgs/liters) (*Convert to Kgs/liters*)	Total cost of insecticide used? (Kshs)	Was fungicide applied on this plot? Yes=1, No=0	Amount of fungicide used? (Kgs/Liters)	Total cost of fungicide used? (Kshs)	Was herbicide applied on this plot? Yes=1, No=0	Amount of herbicide used? (Kgs/Liters)	Total cost of herbicide used? (Kshs)

MODULE D: TRAINING OF BRASSICAS AND TAV FARMERS

(*Please indicate all the trainings the farmers have attended on crucifer and TAVs production***)**

D.0. Serial no.	D.1. Training	D.2. Have you received training on [name]? Yes=1 , No=0	D.3. From whom did you receive the training? (Code **A**)	D.4. Which year was the training?	D.5. Have you ever applied [name] in your TAV farm? Yes=1 , No=0	D.6. Are you currently using [name] in your TAV farm? (in the last 12 months) Yes=1 , No=0
1	Improved vegetable production methods					
2	Vegetable pest and diseases management (Conventional and IPM)					
3	Biological control of pests					
4	Agro-ecological based approaches on pest control					
5	Push- pull technology in controlling pest and diseases					
6.	Other training (specify)__________					

Code A: *Icipe*=1 , Ministry of agriculture=2, TARI=3, KALRO=4, Other farmers=5, Tropical Pesticides Research Institute(TPRI)=6, National Biological Control Centre (NBCC)=7, WorldVeg=8, Other (specify)=9________

MODULE E: TAVs & BRASSICAS VALUE CHAIN ACTORS

E.1	Do you have any contract farming?			Yes	1	No	0
E.2	If YES, for which crop(s)? (*select multiple*)			(Use vegetables listed in Module B)			
E.3	If YES, what is the name of organization (s) that gave the contract?	Farm Africa	1		4		7
			2		5		8
			3		6	Other(specify)	9
E.4	What challenges do face in selling Vegetables? (Rank challenges in order of importance)	Market is not easily available	1	Low selling prices	2	Lack of market information	3
		Distance to market	4	Transport cost	5	Lack of proper means of transportation	6
		High perishability of vegetables	7	Lack of storage facility	8	High post-harvest losses	9
		Lack of advertising platform	10	Lack of proper packaging materials	11	Other(specify)	12
E.5	Are you aware of any marketing and information platform?			Yes	1	No	0
E.6	If YES, which platform(s) do you know?						
E.7	Did you use the marketing and information platform in the last 12 months?			Yes	1	No	0
E.8	If YES, name which platform(s) you have used:						

MODULE F: HOUSEHOLD INCOME

(Please list all the sources and amount of income earned in the last 12 months)

Serial No.	F.1. Source of income	Did you earn from [name]? [yes=1, no=0]	Annual estimate (Tshs.)
1	Income from horticultural crops (fruits & vegetables)		
2	Income from other farm crops		
3	Income from livestock sales and livestock products (e.g. milk)		
4	Income from other farm activities (e.g. brew making, charcoal burning etc), other specify……………		
5	Income from wages/ salaries/ non-farm, pension and (specify profession)_____		
6	Income from business activities		
7	Income from remittances/ gifts from absent family members and other external income		
8	Income from rental houses		
9	Income from other sources, specify:______________		

MODULE G: SOCIAL CAPITAL, ACCESS TO CREDIT AND OTHER SERVICES

H.1. Did you receive any vegetable production and marketing credit? [Yes=1, no=0] ________

H.2. How much did you receive? ____________________________

H.3. Where did you obtain the credit from? ______________________ (Bank (specify)=1, SACCO=2, Microfinance institution=3, Mobile phone application (e.g Mshwari, Tala)=4, Merry go-round=5, Other(specify)=6)

H.4. Did you need the credit? ______________________ [Yes=1, no=0]

H.5. constraints to receiving credit? (Rank the constraints) ______________________

Lack of institutions giving credit for vegetable production=1 Lack of collateral=2 High interest rates=3 No means of paying back=4 Low returns from vegetables=5	Long distance to credit facility=6		

H.6. Belong to any vegetable production and marketing group? ______________[Yes=1, no=0]

H.6.a) Name of group? __________________________

H.7. How many members does the group have? ______How many are women? _______ How many are youth? _____

H.8. Other group(s) ______________________________

H.9. Distance to input market _________________ (walking minutes)

H.10. Distance to sales market_____________ (walking minutes)

H.11. Distance to savings services bank/sacco ________________ (walking minutes)

1.12. Distance to credit services _______________________(walking minutes)

H.13. Do you have access to extension services? _________________[Yes=1, no=0]

H.14. Distance to extension services? _______________________

H.15. How timely is the extension service available? ……………………………. (On time = 1, Late = 0)

MODULE H: HOUSEHOLD ASSETS

At present, do you own the following assets?

Assets	Number of currently owned	Current Total Value (Kshs/Tshs.)	Who owns (ownership codes)
Farm assets			
1= spray pump			
2= water pump			
3= Sprinkler			
4= water tanks			
5= stores (chemical/grain store etc)			
6= grinder			
7= weighing machine			
8= power saw			
9= wheelbarrow			
10= animal traction plough			
11= zero-grazing units			
12= milking equipment/shed			
13= Motorized/ hand thresher			
14= chaff cutter			
15= cattle dip			
16= water trough			
17= pigsties			

18= poultry houses			
19= borehole or well			
20= dam			
21= pestle and mortar			
22= cart			
23= ploughs for tractor/animal			
24= tractor/power-tiller			
25= harrow/tiller			
26= combine harvesters			
27= planter			
28= generator			
29= green house			

END
(Please remember to thank the farmer genuinely)

1. Household location GPS coordinates
   longitude________________________________
   Latitude________________________________
   Altitude________________________________

The enumerator to answer the section below privately immediately after the interview

2. In your opinion, how did you establish rapport with this respondent /_________/

1=with ease	**2**=with some persuasion	**3**=with difficulty	**4**=it was impossible

3. Overall, how did the respondent give answers to the questions /_________/

1=willingly	**2**=reluctantly	**3**=with persuasion	**4**=it was hard to get answers

4. How often do you think the respondent was telling the truth/_________/?

1=rarely	**2**=sometimes	**3**=most of the times	**4**=all the time

I (the enumerator) certify that I have checked the questionnaire two times to be sure that all the questions have been answered, and that the answers are legible.

Signed: __________________Date/____________/End time:

Appendix D: Results of the Multivariate Probit Analysis of the Factors Influencing Adoption of Agroecological Cropping Systems

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  Multivariate probit (MSL, # draws = 5)          Number of obs   =        546
                                                   Wald chi2(105)  =     196.52
Log likelihood = -907.67674                       Prob > chi2     =     0.0000
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	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
mixed_cropping						
hhh_gender1	-1.05264	.3114468	-3.38	0.001	-1.663064	-.4422153
Age hhh_education	.0022715	.0055268	0.41	0.681	-.0085608	.0131038
hhh_occupation	-.0026048	.1003523	-0.03	0.979	-.1992918	.1940821
hh_size	.0609658	.0535628	1.14	0.255	-.0440154	.165947
Owner_female	-.0085368	.0380817	-0.22	0.823	-.0831756	.0661021
Owner_male	-.5353346	.2985127	-1.79	0.073	-1.120409	.0497394
Manager_female	.3192187	.3165982	1.01	0.313	-.3013025	.9397398
Manager_male	.1876437	.210832	0.89	0.373	-.2255794	.6008667
Income_Gross	.7164359	.2221601	3.22	0.001	.2810101	1.151862
TRAINING	-3.15e-06	1.16e-06	-2.71	0.007	-5.43e-06	-8.77e-07
contracts	-.0056705	.0711365	-0.08	0.936	-.1450955	.1337544
market_info	-.0650567	.6062095	-0.11	0.915	-1.253205	1.123092
other_farm_income	-.3978519	.4435387	-0.90	0.370	-1.267172	.471468
off_farm_income	3.14e-07	3.93e-07	0.80	0.424	-4.56e-07	1.08e-06
credit_access	-4.45e-07	4.94e-07	-0.90	0.368	-1.41e-06	5.23e-07
h_6_group	-.1230251	.2246497	-0.55	0.584	-.5633304	.3172802
h_9_market	.3580335	.288821	1.24	0.215	-.2080452	.9241122
h_10_salemarket	.0029315	.0023748	1.23	0.217	-.0017231	.0075861
h13_extension	-.0024822	.0022549	-1.10	0.271	-.0069017	.0019374
a27_district_county	.4434663	.1489547	2.98	0.003	.1515205	.735412
_cons	.0847966	.1435671	0.59	0.555	-.1965897	.3661829
	-.9051817	.5276417	-1.72	0.086	-1.93934	.128977
strip_cropping						
hhh_gender1	-.36719	.2867219	-1.28	0.200	-.9291545	.1947745
Age	-.0078858	.006693	-1.18	0.239	-.0210039	.0052323
hhh_education	-.0284865	.1167732	-0.24	0.807	-.2573577	.2003847
hhh_occupation	.0603988	.0599969	1.01	0.314	-.0571929	.1779905
hh_size	-.0636073	.0443559	-1.43	0.152	-.1505432	.0233286
Owner_female	-.0638851	.3620385	-0.18	0.860	-.7734676	.6456974
Owner_male	.3238368	.3647677	0.89	0.375	-.3910949	1.038768
Manager_female	-.1727099	.2174077	-0.79	0.427	-.5988212	.2534013
Manager_male	-.7894241	.2388259	-3.31	0.001	-1.257514	-.321334
Income_Gross	4.69e-07	7.39e-07	0.63	0.526	-9.80e-07	1.92e-06
TRAINING	-.0386938	.0886982	-0.44	0.663	-.2125391	.1351516
contracts	-.0239682	.5762744	-0.04	0.967	-1.153445	1.105509
market_info	.7921501	.408211	1.94	0.052	-.0079287	1.592229

other_farm_income	7.96e-07	4.07e-07	1.96	0.050	-8.92e-10	1.59e-06
off_farm_income	5.27e-07	3.93e-07	1.34	0.180	-2.44e-07	1.30e-06
credit_access	-.105839	.2404082	-0.44	0.660	-.5770303	.3653524
h_6_group	-.0000674	.3497902	-0.00	1.000	-.6856437	.6855088
h_9_market	.0103136	.0056636	1.82	0.069	-.000787	.0214141
h_10_salemarket	-.0095572	.0056127	-1.70	0.089	-.0205579	.0014434
h13_extension	-.5666436	.1978682	-2.86	0.004	-.9544581	-.1788291
a27_district_county	-.0101632	.1604186	-0.06	0.949	-.3245779	.3042514
_cons	-.183688	.6176628	-0.30	0.766	-1.394285	1.026909
row_intercrop						
hhh_gender1	1.13083	.3290652	3.44	0.001	.4858737	1.775786
Age hhh_education	-.0004159	.0077162	-0.05	0.957	-.0155395	.0147076
hhh_occupation	.1162416	.1424503	0.82	0.414	-.1629559	.3954391
hh_size	.2196228	.0720083	3.05	0.002	.078489	.3607565
Owner_female	-.0798844	.0566596	-1.41	0.159	-.1909352	.0311664
Owner_male	.2102062	.3830118	0.55	0.583	-.5404831	.9608955
Manager_female	-.668015	.3817032	-1.75	0.080	-1.41614	.0801096
Manager_male	-.0590284	.2876178	-0.21	0.837	-.622749	.5046922
Income_Gross	-.0006543	.2982725	-0.00	0.998	-.5852577	.5839491
TRAINING	-6.74e-06	2.39e-06	-2.81	0.005	-.0000114	-2.05e-06
contracts	-.0497741	.115056	-0.43	0.665	-.2752798	.1757315
market_info	-4.976932	320.3927	-0.02	0.988	-632.935	622.9811
other_farm_income	-4.784628	276.0232	-0.02	0.986	-545.7802	536.2109
off_farm_income	1.58e-06	5.60e-07	2.83	0.005	4.87e-07	2.68e-06
credit_access	-3.13e-10	5.61e-07	-0.00	1.000	-1.10e-06	1.10e-06
h_6_group	-4.567069	127.5701	-0.04	0.971	-254.5999	245.4658
h_9_market	-4.972411	180.3595	-0.03	0.978	-358.4705	348.5257
h_10_salemarket	.0005563	.0023481	0.24	0.813	-.0040459	.0051585
h13_extension	-.0002542	.0021333	-0.12	0.905	-.0044354	.0039269
a27_district_county	-.4808204	.2255431	-2.13	0.033	-.9228768	-.038764
_cons	.7697433	.2052123	3.75	0.000	.3675346	1.171952
	-3.146647	.7488001	-4.20	0.000	-4.614268	-1.679026
border_cropping						
hhh_gender1	-.0600322	.3048655	-0.20	0.844	-.6575577	.5374933
Age hhh_education	-.0020232	.0075509	-0.27	0.789	-.0168228	.0127763
hhh_occupation	.1363219	.1311033	1.04	0.298	-.1206357	.3932796
hh_size	-.0361492	.0653982	-0.55	0.580	-.1643273	.0920288
Owner_female	.0085781	.0491218	0.17	0.861	-.0876988	.104855
Owner_male	.0481664	.3110903	0.15	0.877	-.5615593	.6578921
Manager_female	.1077428	.3116805	0.35	0.730	-.5031398	.7186253
Manager_male	.5676341	.2707408	2.10	0.036	.0369919	1.098276
Income_Gross	-.2144665	.2843778	-0.75	0.451	-.7718368	.3429038
TRAINING	9.94e-08	1.00e-06	0.10	0.921	-1.86e-06	2.06e-06
contracts	.0922821	.0815373	1.13	0.258	-.0675281	.2520922
market_info	.0693266	.7100722	0.10	0.922	-1.322389	1.461042

other_farm_income	.4006588	.4787752	0.84	0.403	-.5377233	1.339041
off_farm_income	6.79e-07	4.21e-07	1.61	0.106	-1.45e-07	1.50e-06
credit_access	1.22e-07	4.70e-07	0.26	0.796	-7.99e-07	1.04e-06
h_6_group	-.0880181	.2563273	-0.34	0.731	-.5904103	.4143741
h_9_market	-.6675505	.4618568	-1.45	0.148	-1.572773	.2376723
h_10_salemarket	-.0016107	.0032175	-0.50	0.617	-.007917	.0046955
h13_extension	.0002006	.0027369	0.07	0.942	-.0051637	.005565
a27_district_county	.4635682	.1913271	2.42	0.015	.0885739	.8385625
_cons	-.5172714	.2053986	-2.52	0.012	-.9198453	-.1146976
	-1.432171	.6628239	-2.16	0.031	-2.731282	-.1330603
crop_rotation						
hhh_gender1	-.1313778	.2326177	-0.56	0.572	-.5873	.3245445
Age	.0000111	.0052598	0.00	0.998	-.010298	.0103201
hhh_education	.104168	.0949212	1.10	0.272	-.0818741	.2902102
hhh_occupation	-.0721321	.0493847	-1.46	0.144	-.1689244	.0246602
hh_size	.0086476	.0357544	0.24	0.809	-.0614297	.0787248
Owner_female	.1031735	.2591121	0.40	0.690	-.4046768	.6110238
Owner_male	.060212	.2555124	0.24	0.814	-.4405831	.5610071
Manager_female	.1569592	.190592	0.82	0.410	-.2165941	.5305126
Manager_male	.4766183	.199501	2.39	0.017	.0856034	.8676331
Income_Gross	5.67e-07	7.02e-07	0.81	0.419	-8.09e-07	1.94e-06
TRAINING	.1388727	.0786973	1.76	0.078	-.0153713	.2931167
contracts	-.4528137	.4984103	-0.91	0.364	-1.42968	.5240526
market_info	-.7219713	.3988865	-1.81	0.070	-1.503774	.0598318
other_farm_income	7.34e-07	4.10e-07	1.79	0.074	-7.05e-08	1.54e-06
off_farm_income	-2.45e-07	3.70e-07	-0.66	0.508	-9.71e-07	4.81e-07
credit_access	.0438334	.2037574	0.22	0.830	-.3555237	.4431905
h_6_group	.0037296	.3018045	0.01	0.990	-.5877963	.5952555
h_9_market	.003017	.0021505	1.40	0.161	-.0011979	.0072319
h_10_salemarket	.0014724	.0016771	0.88	0.380	-.0018147	.0047595
h13_extension	.2841092	.1515369	1.87	0.061	-.0128976	.581116
a27_district_county	.3056909	.1418825	2.15	0.031	.0276064	.5837754
_cons	-.3353309	.4986703	-0.67	0.501	-1.312707	.6420449
/atrho21	-.0556673	.105429	-0.53	0.597	-.2623044	.1509697
/atrho31	-.4781723	.1513813	-3.16	0.002	-.7748741	-.1814705
/atrho41	-.1942633	.1183562	-1.64	0.101	-.4262372	.0377105
/atrho51	.215578	.0917184	2.35	0.019	.0358132	.3953428
/atrho32	.3612762	.1450565	2.49	0.013	.0769707	.6455816
/atrho42	-.1778543	.1255882	-1.42	0.157	-.4240027	.0682941
/atrho52	.0669754	.091927	0.73	0.466	-.1131983	.247149
/atrho43	.0244801	.117692	0.21	0.835	-.206192	.2551523
/atrho53	-.0928151	.0957571	-0.97	0.332	-.2804956	.0948653

/atrho54	.0079636	.1041039	0.08	0.939	-.1960764	.2120035
rho21	-.0556099	.105103	-0.53	0.597	-.2564496	.1498331
rho31	-.4447787	.1214338	-3.66	0.000	-.6497547	-.1795044
rho41	-.1918559	.1139996	-1.68	0.092	-.4021719	.0376927
rho51	.2122993	.0875846	2.42	0.015	.0357979	.375957
rho32	.3463376	.127657	2.71	0.007	.076819	.568688
rho42	-.1760024	.1216979	-1.45	0.148	-.4002971	.0681881
rho52	.0668754	.0915159	0.73	0.465	-.1127172	.2422368
rho43	.0244753	.1176215	0.21	0.835	-.2033188	.2497557
rho53	-.0925495	.0949369	-0.97	0.330	-.2733637	.0945817
rho54	.0079634	.1040973	0.08	0.939	-.1936016	.2088834

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: chi2(10) = 28.8445 Prob > chi2 = 0.0013

Appendix E: Marginal Effect Estimates of the Multivariate Probit Analysis of the Factors Influencing Adoption of Agroecological Cropping Systems

```
. margins, dydx(*)

Average marginal effects                                    Number of obs = 546
Model VCE: OIM

Expression: Pr(mixed_cropping), predict ()
dy/dx wrt:  hhh_gender1 Age hhh_education hhh_occupation hh_size Owner_female Owner_male
            Manager_female Manager_male Income_Gross TRAINING contracts market_info
            other_farm_income off_farm_income credit_access h_6_group h_9_market
            h_10_salemarket h13_extension a27_district_county
```

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
hhh_gender1	-.2630295	.0732199	-3.59	0.000	-.4065379	-.119521
Age	.0005066	.0013025	0.39	0.697	-.0020463	.0030596
hhh_education	-.0001587	.0239537	-0.01	0.995	-.047107	.0467896
hhh_occupation	.0139231	.0127058	1.10	0.273	-.0109799	.0388261
hh_size	-.0017667	.0089399	-0.20	0.843	-.0192886	.0157552
Owner_female	-.1319798	.0717399	-1.84	0.066	-.2725874	.0086278
Owner_male	.0799315	.0762739	1.05	0.295	-.0695626	.2294256
Manager_female	.0444573	.0501412	0.89	0.375	-.0538176	.1427322
Manager_male	.1727632	.0517526	3.34	0.001	.07133	.2741963
Income_Gross	-7.70e-07	2.72e-07	-2.83	0.005	-1.30e-06	-2.37e-07
TRAINING	-.0020209	.0167886	-0.12	0.904	-.0349259	.0308841
contracts	-.0201345	.1443541	-0.14	0.889	-.3030633	.2627943
market_info	-.094456	.1049584	-0.90	0.368	-.3001707	.1112587
other_farm_income	8.15e-08	9.10e-08	0.90	0.370	-9.69e-08	2.60e-07
off_farm_income	-1.16e-07	1.15e-07	-1.01	0.313	-3.42e-07	1.10e-07
credit_access	-.0325792	.0529869	-0.61	0.539	-.1364316	.0712732
h_6_group	.0847262	.0680679	1.24	0.213	-.0486844	.2181368
h_9_market	.0006378	.0005479	1.16	0.244	-.000436	.0017116
h_10_salemarket	-.0005374	.0005195	-1.03	0.301	-.0015557	.0004808
h13_extension	.1041539	.0344397	3.02	0.002	.0366533	.1716544
a27_district_county	.0210899	.0338872	0.62	0.534	-.0453277	.0875076

```
. margins, dydx(*)

Average marginal effects                                    Number of obs = 546
Model VCE: OIM

Expression: Pr(strip_cropping), predict ()
dy/dx wrt:  hhh_gender1 Age hhh_education hhh_occupation hh_size Owner_female Owner_male
            Manager_female Manager_male Income_Gross TRAINING contracts market_info
```

```
other_farm_income off_farm_income credit_access h_6_group h_9_market
h_10_salemarket h13_extension a27_district_county
```

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
hhh_gender1	-.0642529	.0511153	-1.26	0.209	-.164437	.0359311
Age	-.0013224	.0011832	-1.12	0.264	-.0036414	.0009966
hhh_education	-.0035336	.0207281	-0.17	0.865	-.04416	.0370928
hhh_occupation	.0120986	.0105458	1.15	0.251	-.0085707	.0327679
hh_size	-.010488	.0079208	-1.32	0.185	-.0260126	.0050366
Owner_female	-.0108293	.0637286	-0.17	0.865	-.135735	.1140764
Owner_male	.0507647	.0639278	0.79	0.427	-.0745314	.1760608
Manager_female	-.0324193	.0385403	-0.84	0.400	-.1079569	.0431183
Manager_male	-.138256	.0421767	-3.28	0.001	-.2209208	-.0555911
Income_Gross	8.80e-08	1.32e-07	0.67	0.504	-1.70e-07	3.47e-07
TRAINING	-.0054207	.0158144	-0.34	0.732	-.0364163	.0255749
contracts	-.0014318	.1021264	-0.01	0.989	-.2015958	.1987322
market_info	.1393599	.0715997	1.95	0.052	-.0009728	.2796927
other_farm_income	1.36e-07	7.21e-08	1.88	0.060	-5.45e-09	2.77e-07
off_farm_income	9.56e-08	6.93e-08	1.38	0.168	-4.02e-08	2.31e-07
credit_access	-.0159567	.0425436	-0.38	0.708	-.0993406	.0674272
h_6_group	.0011439	.0615909	0.02	0.985	-.119572	.1218598
h_9_market	.0017645	.0009723	1.81	0.070	-.0001412	.0036703
h_10_salemarket	-.0016337	.0009638	-1.70	0.090	-.0035228	.0002554
h13_extension	-.1020404	.0352342	-2.90	0.004	-.1710982	-.0329827
a27_district_county	-.0006461	.0285375	-0.02	0.982	-.0565786	.0552864

```
. margins, dydx(*)

Average marginal effects                                   Number of obs = 441
Model VCE: OIM

Expression: Pr(row_intercrop), predict ()
dy/dx wrt:  hhh_gender1 Age hhh_education hhh_occupation hh_size Owner_female Owner_male
            Manager_female Manager_male Income_Gross TRAINING contracts market_info
            other_farm_income off_farm_income credit_access h_6_group h_9_market
            h_10_salemarket h13_extension a27_district_county
```

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
hhh_gender1	.1682568	.0495219	3.40	0.001	.0711956	.2653179
Age	.0001324	.0011282	0.12	0.907	-.0020788	.0023436
hhh_education	.0203562	.0215195	0.95	0.344	-.0218212	.0625336
hhh_occupation	.0295881	.0102217	2.89	0.004	.0095539	.0496224
hh_size	-.008809	.0081651	-1.08	0.281	-.0248123	.0071944

Owner_female	.0220684	.0574417	0.38	0.701	-.0905152	.1346521
Owner_male	-.1088616	.0575895	-1.89	0.059	-.221735	.0040118
Manager_female	-.0048354	.043892	-0.11	0.912	-.090862	.0811913
Manager_male	.0074447	.0453334	0.16	0.870	-.0814071	.0962965
Income_Gross	-1.02e-06	3.67e-07	-2.77	0.006	-1.74e-06	-2.99e-07
TRAINING	-.0061106	.0172841	-0.35	0.724	-.0399868	.0277656
contracts	0	(omitted)				
market_info	0	(omitted)				
other_farm_income	2.08e-07	8.19e-08	2.54	0.011	4.77e-08	3.69e-07
off_farm_income	-1.31e-08	8.33e-08	-0.16	0.875	-1.76e-07	1.50e-07
credit_access	0	(omitted)				
h_6_group	0	(omitted)				
h_9_market	.0001182	.0003566	0.33	0.740	-.0005806	.000817
h_10_salemarket	-.000077	.0003257	-0.24	0.813	-.0007154	.0005613
h13_extension	-.0657722	.0334003	-1.97	0.049	-.1312355	-.0003088
a27_district_county	.095389	.029854	3.20	0.001	.0368762	.1539018

```
. margins, dydx(*)

Average marginal effects                                  Number of obs = 546
Model VCE: OIM

Expression: Pr(border_cropping), predict ()
dy/dx wrt:  hhh_gender1 Age hhh_education hhh_occupation hh_size Owner_female Owner_male
            Manager_female Manager_male Income_Gross TRAINING contracts market_info
            other_farm_income off_farm_income credit_access h_6_group h_9_market
            h_10_salemarket h13_extension a27_district_county
```

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
hhh_gender1	-.0011225	.039031	-0.03	0.977	-.0776218	.0753769
Age	-.0003861	.0009808	-0.39	0.694	-.0023084	.0015363
hhh_education	.0185715	.0170513	1.09	0.276	-.0148483	.0519914
hhh_occupation	-.0055362	.0084626	-0.65	0.513	-.0221226	.0110502
hh_size	.00032	.0063262	0.05	0.960	-.0120791	.0127192
Owner_female	.0032025	.0408848	0.08	0.938	-.0769303	.0833352
Owner_male	.0105093	.0406458	0.26	0.796	-.0691549	.0901735
Manager_female	.0744374	.0353017	2.11	0.035	.0052475	.1436274
Manager_male	-.0233699	.0367729	-0.64	0.525	-.0954434	.0487037
Income_Gross	-1.25e-08	1.33e-07	-0.09	0.925	-2.73e-07	2.48e-07
TRAINING	.0123864	.0106096	1.17	0.243	-.0084081	.0331808
contracts	.01572	.0911068	0.17	0.863	-.1628461	.1942862
market_info	.0489763	.0607115	0.81	0.420	-.070016	.1679686
other_farm_income	9.61e-08	5.43e-08	1.77	0.077	-1.03e-08	2.03e-07
off_farm_income	1.63e-08	6.05e-08	0.27	0.788	-1.02e-07	1.35e-07
credit_access	-.008997	.0328725	-0.27	0.784	-.0734259	.055432

h_6_group	-.0815543	.0597601	-1.36	0.172	-.198682	.0355734
h_9_market	-.0001893	.000425	-0.45	0.656	-.0010222	.0006436
h_10_salemarket	5.75e-06	.0003654	0.02	0.987	-.0007105	.000722
h13_extension	.0613657	.0250142	2.45	0.014	.0123388	.1103927
a27_district_county	-.0677334	.0269152	-2.52	0.012	-.1204863	-.0149805

```
. margins, dydx(*)

Average marginal effects                                  Number of obs = 546
Model VCE: OIM

Expression: Pr(crop_rotation), predict ()
dy/dx wrt:  hhh_gender1 Age hhh_education hhh_occupation hh_size Owner_female Owner_male
            Manager_female Manager_male Income_Gross TRAINING contracts market_info
            other_farm_income off_farm_income credit_access h_6_group h_9_market
            h_10_salemarket h13_extension a27_district_county
```

	dy/dx	Delta-method std. err.	z	P>|z|	[95% conf.	interval]
hhh_gender1	-.0362335	.0630752	-0.57	0.566	-.1598587	.0873916
Age	-.0000548	.0014222	-0.04	0.969	-.0028423	.0027328
hhh_education	.0266103	.0259078	1.03	0.304	-.024168	.0773886
hhh_occupation	-.018214	.0134866	-1.35	0.177	-.0446471	.0082192
hh_size	.0029248	.0096824	0.30	0.763	-.0160523	.0219019
Owner_female	.0333507	.0704985	0.47	0.636	-.1048238	.1715252
Owner_male	.019475	.0693805	0.28	0.779	-.1165083	.1554583
Manager_female	.0428923	.0513547	0.84	0.404	-.057761	.1435457
Manager_male	.1243069	.0532212	2.34	0.020	.0199953	.2286185
Income_Gross	1.42e-07	1.91e-07	0.75	0.455	-2.31e-07	5.16e-07
TRAINING	.0384689	.0213825	1.80	0.072	-.00344	.0803778
contracts	-.127662	.1393291	-0.92	0.360	-.4007419	.145418
market_info	-.179744	.1089238	-1.65	0.099	-.3932308	.0337428
other_farm_income	1.94e-07	1.12e-07	1.74	0.082	-2.49e-08	4.13e-07
off_farm_income	-5.67e-08	1.01e-07	-0.56	0.574	-2.55e-07	1.41e-07
credit_access	.0099857	.0550985	0.18	0.856	-.0980053	.1179768
h_6_group	-.0120441	.0814728	-0.15	0.882	-.1717279	.1476396
h_9_market	.0008298	.0005883	1.41	0.158	-.0003233	.0019829
h_10_salemarket	.0004297	.0004593	0.94	0.350	-.0004705	.0013299
h13_extension	.0753378	.0407396	1.85	0.064	-.0045104	.155186
a27_district_county	.0873561	.0380571	2.30	0.022	.0127656	.1619466

Appendix F: Parameter Estimates of Effects of Adoption of Alternatives of Agroecological Cropping Systems on Performance – Using a Multinomial Logit Model

```
Multinomial logistic regression                         Number of obs =    546
                                                        LR chi2(63)   = 200.27
                                                        Prob > chi2   = 0.0000
Log likelihood = -558.31161                             Pseudo R2     = 0.1521
```

Cropp_syst_Comb	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
M0C0	(base outcome)					
M0C1						
hhh_gender1	.4789637	.5426856	0.88	0.377	-.5846806	1.542608
Age	-.0051101	.0116653	-0.44	0.661	-.0279737	.0177536
hhh_education	-.1088199	.2057311	-0.53	0.597	-.5120453	.2944056
hhh_occupation	-.1043928	.1166948	-0.89	0.371	-.3331105	.1243248
hh_size	-.0371352	.0776512	-0.48	0.632	-.1893287	.1150583
Owner_female	.5299982	.5648249	0.94	0.348	-.5770384	1.637035
Owner_male	.277104	.5545382	0.50	0.617	-.8097709	1.363979
Manager_female	-.109127	.4085457	-0.27	0.789	-.9098618	.6916078
Manager_male	.3378512	.4353352	0.78	0.438	-.5153901	1.191093
lnnewIncome_Gross	.0240074	.0534461	0.45	0.653	-.0807451	.1287598
TRAINING	.1775333	.177043	1.00	0.316	-.1694646	.5245311
contracts	-.1148618	1.200342	-0.10	0.924	-2.467489	2.237766
market_info	-.4675158	.9331809	-0.50	0.616	-2.296517	1.361485
lnnewother_farm_income	.1031699	.0265541	3.89	0.000	.0511247	.155215
lnnewoff_farm_income	-.001278	.0272219	-0.05	0.963	-.054632	.0520759
credit_access	-.2448559	.402441	-0.61	0.543	-1.033626	.5439139
h_6_group	-.0640567	.6481669	-0.10	0.921	-1.334441	1.206327
a27_district_county	.5336613	.3181349	1.68	0.093	-.0898716	1.157194
lnh_9_market	-.2739093	.2239899	-1.22	0.221	-.7129215	.1651029
h_10_salemarket	.0060317	.0033615	1.79	0.073	-.0005568	.0126202
h13_extension	.0606356	.3408615	0.18	0.859	-.6074406	.7287119
_cons	.2089961	1.410163	0.15	0.882	-2.554872	2.972864
M1C0						
hhh_gender1	.6454675	.8075813	0.80	0.424	-.9373628	2.228298
Age	-.0016722	.0174963	-0.10	0.924	-.0359644	.03262
hhh_education	-.498562	.3131269	-1.59	0.111	-1.112279	.1151555
hhh_occupation	.1506463	.1565733	0.96	0.336	-.1562318	.4575243
hh_size	-.2610517	.131862	-1.98	0.048	-.5194966	-.0026068
Owner_female	-.056215	.9535619	-0.06	0.953	-1.925162	1.812732
Owner_male	.1540949	.9339972	0.16	0.869	-1.676506	1.984696
Manager_female	-.5656523	.635747	-0.89	0.374	-1.811694	.6803889

```
           Manager_male |   -.285018    .678273    -0.42   0.674    -1.614409   1.044373
      lnnewIncome_Gross |  -.2608809   .0593562    -4.40   0.000    -.3772168  -.1445449
               TRAINING |   .0590181   .3098602     0.19   0.849    -.5482967   .666333
              contracts |   1.801787    1.39198     1.29   0.196     -.926444   4.530019
            market_info |   2.354051    1.29726     1.81   0.070    -.1885324   4.896634
 lnnewother_farm_income |   .0803686   .0429891     1.87   0.062    -.0038884   .1646257
   lnnewoff_farm_income |   .0663267    .039894     1.66   0.096    -.0118641   .1445175
          credit_access |  -1.701626   .9981757    -1.70   0.088    -3.658015   .2547623
              h_6_group |  -.2432737   1.028733    -0.24   0.813    -2.259554   1.773007
    a27_district_county |  -.0651775   .4839385    -0.13   0.893    -1.013679   .8833245
            lnh_9_market |  -.0321683   .3934831    -0.08   0.935     -.803381   .7390443
       h_10_salemarket |  -.0092395   .0073697    -1.25   0.210    -.0236838   .0052048
          h13_extension |   -.427921   .5633545    -0.76   0.447    -1.532076   .6762336
                  _cons |   2.725406   2.053178     1.33   0.184    -1.298748   6.749561
-----------------------+----------------------------------------------------------------
M1C1                   |
            hhh_gender1 |  -.2635089   .5809928    -0.45   0.650    -1.402234   .875216
                    Age |   .0000792    .012759     0.01   0.995    -.0249279   .0250863
          hhh_education |   .1375244   .2204345     0.62   0.533    -.2945193   .5695681
         hhh_occupation |  -.0548017   .1233421    -0.44   0.657    -.2965478   .1869444
                hh_size |  -.0734096   .0834109    -0.88   0.379    -.2368919   .0900728
           Owner_female |   .4065709   .6098211     0.67   0.505    -.7886565   1.601798
             Owner_male |   .4560233   .6068141     0.75   0.452    -.7333104   1.645357
         Manager_female |   .0308355   .4524837     0.07   0.946    -.8560161   .9176872
           Manager_male |    .729653   .4810291     1.52   0.129    -.2131467   1.672453
      lnnewIncome_Gross |  -.0596944   .0546702    -1.09   0.275     -.166846   .0474571
               TRAINING |   .2905143   .1818285     1.60   0.110     -.065863   .6468915
              contracts |  -.6695136   1.316691    -0.51   0.611    -3.250181   1.911154
            market_info |  -.3138211   .9948763    -0.32   0.752    -2.263743   1.636101
 lnnewother_farm_income |   .1941692   .0322114     6.03   0.000      .131036   .2573024
   lnnewoff_farm_income |    .056387   .0292688     1.93   0.054    -.0009789   .1137528
          credit_access |  -.2870204   .4439693    -0.65   0.518    -1.157184   .5831434
              h_6_group |  -.1450809   .6939137    -0.21   0.834    -1.505127   1.214965
    a27_district_county |   .6604404    .341525     1.93   0.053    -.0089363   1.329817
            lnh_9_market |   .1799449   .2521222     0.71   0.475    -.3142055   .6740954
       h_10_salemarket |   .0029005   .0036999     0.78   0.433    -.0043512   .0101521
          h13_extension |   .5042627   .3595009     1.40   0.161    -.2003461   1.208871
                  _cons |  -2.682155   1.535218    -1.75   0.081    -5.691127   .3268176
----------------------------------------------------------------------------------------

Average marginal effects                                   Number of obs = 546
Model VCE: OIM

dy/dx wrt: hhh_gender1 Age hhh_education hhh_occupation hh_size Owner_female Owner_male
            Manager_female Manager_male lnnewIncome_Gross TRAINING contracts   market_info
            lnnewother_farm_income lnnewoff_farm_income credit_access h_6_group
            a27_district_county
```

```
1._predict: Pr(Cropp_syst_Comb==M0C0), predict(pr outcome(0))
2._predict: Pr(Cropp_syst_Comb==M0C1), predict(pr outcome(1))
3._predict: Pr(Cropp_syst_Comb==M1C0), predict(pr outcome(2))
4._predict: Pr(Cropp_syst_Comb==M1C1), predict(pr outcome(3))

------------------------------------------------------------------------------
                       |            Delta-method
                       |      dy/dx   std. err.      z    P>|z|     [95% conf. interval]
-----------------------+------------------------------------------------------------------
hhh_gender1            |
              _predict |
                     1 |  -.0275847   .0532622    -0.52   0.605    -.1319766    .0768072
                     2 |   .1244606   .0788321     1.58   0.114    -.0300474    .2789686
                     3 |   .0319683   .0414548     0.77   0.441    -.0492816    .1132183
                     4 |  -.1288442   .0718699    -1.79   0.073    -.2697065    .0120182
-----------------------+------------------------------------------------------------------
Age                    |
              _predict |
                     1 |   .0003278   .0011625     0.28   0.778    -.0019506    .0026061
                     2 |  -.0011067   .0017027    -0.65   0.516     -.004444    .0022305
                     3 |   .0000393   .0009001     0.04   0.965    -.0017249    .0018034
                     4 |   .0007397   .0015929     0.46   0.642    -.0023822    .0038617
-----------------------+------------------------------------------------------------------
hhh_education          |
              _predict |
                     1 |   .0074467   .0201998     0.37   0.712    -.0321443    .0470376
                     2 |   -.028853   .0298619    -0.97   0.334    -.0873813    .0296753
                     3 |  -.0305188   .0160812    -1.90   0.058    -.0620374    .0009997
                     4 |   .0519252   .0270582     1.92   0.055     -.001108    .1049583
-----------------------+------------------------------------------------------------------
hhh_occupation         |
              _predict |
                     1 |   .0065799   .0111976     0.59   0.557     -.015367    .0285267
                     2 |  -.0202049   .0183959    -1.10   0.272    -.0562601    .0158504
                     3 |   .0133686   .0080638     1.66   0.097    -.0024362    .0291733
                     4 |   .0002564   .0165349     0.02   0.988    -.0321514    .0326643
-----------------------+------------------------------------------------------------------
hh_size                |
              _predict |
                     1 |   .0073672    .007704     0.96   0.339    -.0077324    .0224667
                     2 |   .0088787   .0113659     0.78   0.435    -.0133981    .0311555
                     3 |  -.0132483   .0070954    -1.87   0.062    -.0271549    .0006584
                     4 |  -.0029976   .0103984    -0.29   0.773    -.0233781    .0173829
-----------------------+------------------------------------------------------------------
Owner_female           |
              _predict |
                     1 |  -.0449489   .0561472    -0.80   0.423    -.1549955    .0650976
                     2 |   .0654661    .083023     0.79   0.430     -.097256    .2281881
```

```
               3  |  -.0274813   .0513848    -0.53   0.593    -.1281935     .073231
               4  |   .0069642   .0767445     0.09   0.928    -.1434523    .1573806
------------------+-------------------------------------------------------------------
Owner_male        |
          _predict |
               1  |  -.0332596   .0551634    -0.60   0.547    -.1413777    .0748586
               2  |  -.0036404    .084202    -0.04   0.966    -.1686733    .1613924
               3  |  -.0086627   .0501744    -0.17   0.863    -.1070027    .0896774
               4  |   .0455627   .0784759     0.58   0.562    -.1082472    .1993725
------------------+-------------------------------------------------------------------
Manager_female    |
          _predict |
               1  |   .0116027   .0404809     0.29   0.774    -.0677385    .0909439
               2  |  -.0126996   .0622716    -0.20   0.838    -.1347497    .1093504
               3  |  -.0321969   .0336244    -0.96   0.338    -.0980995    .0337057
               4  |   .0332939   .0588678     0.57   0.572    -.0820848    .1486725
------------------+-------------------------------------------------------------------
Manager_male      |
          _predict |
               1  |  -.0411977   .0433079    -0.95   0.341    -.1260796    .0436843
               2  |  -.0145288   .0644545    -0.23   0.822    -.1408573    .1117997
               3  |  -.0433793   .0352266    -1.23   0.218    -.1124222    .0256636
               4  |   .0991058   .0606378     1.63   0.102    -.0197421    .2179536
------------------+-------------------------------------------------------------------
lnnewIncome_Gross |
          _predict |
               1  |   .0031808   .0049575     0.64   0.521    -.0065357    .0128973
               2  |   .0207059   .0069704     2.97   0.003     .0070442    .0343676
               3  |  -.0152616   .0022617    -6.75   0.000    -.0196944   -.0108287
               4  |  -.0086251   .0060109    -1.43   0.151    -.0204063    .0031561
------------------+-------------------------------------------------------------------
TRAINING          |
          _predict |
               1  |  -.0208402   .0177534    -1.17   0.240    -.0556363    .0139558
               2  |  -.0009979   .0230968    -0.04   0.966    -.0462669     .044271
               3  |  -.0079385   .0164458    -0.48   0.629    -.0401717    .0242947
               4  |   .0297767   .0194736     1.53   0.126    -.0083909    .0679443
------------------+-------------------------------------------------------------------
contracts         |
          _predict |
               1  |   .0097489   .1171627     0.08   0.934    -.2198857    .2393835
               2  |   .0138093   .1812575     0.08   0.939    -.3414489    .3690676
               3  |    .128436   .0628952     2.04   0.041     .0051637    .2517083
               4  |  -.1519942   .1723792    -0.88   0.378    -.4898513    .1858629
------------------+-------------------------------------------------------------------
market_info       |
          _predict |
               1  |   .0141076   .0918275     0.15   0.878     -.165871    .1940862
```

```
                   2  |  -.1283607   .1297971    -0.99   0.323    -.3827583     .126037
                   3  |   .1640181   .0647907     2.53   0.011     .0370307    .2910055
                   4  |   -.049765   .1189517    -0.42   0.676     -.282906     .183376
----------------------+----------------------------------------------------------------
lnnewother_farm_income |
              _predict |
                   1  |  -.0134088   .0024885    -5.39   0.000    -.0182862   -.0085313
                   2  |  -.0052779   .0044778    -1.18   0.239    -.0140542    .0034984
                   3  |  -.0023716   .0022368    -1.06   0.289    -.0067557    .0020125
                   4  |   .0210582   .0044611     4.72   0.000     .0123146    .0298019
----------------------+----------------------------------------------------------------
lnnewoff_farm_income  |
              _predict |
                   1  |  -.0024312   .0026569    -0.92   0.360    -.0076386    .0027763
                   2  |  -.0097246   .0038739    -2.51   0.012    -.0173174   -.0021319
                   3  |   .0028131   .0020241     1.39   0.165    -.0011541    .0067803
                   4  |   .0093427   .0035498     2.63   0.008     .0023852    .0163001
----------------------+----------------------------------------------------------------
credit_access         |
              _predict |
                   1  |   .0420266   .0401574     1.05   0.295    -.0366806    .1207337
                   2  |   .0315082   .0663475     0.47   0.635    -.0985306    .1615469
                   3  |  -.0906079   .0584904    -1.55   0.121    -.2052469    .0240311
                   4  |   .0170732   .0620236     0.28   0.783    -.1044909    .1386372
----------------------+----------------------------------------------------------------
h_6_group             |
              _predict |
                   1  |   .0111372   .0641314     0.17   0.862    -.1145581    .1368326
                   2  |   .0119934   .0949933     0.13   0.900    -.1741902    .1981769
                   3  |  -.0097871   .0551366    -0.18   0.859    -.1178529    .0982787
                   4  |  -.0133435   .0858444    -0.16   0.876    -.1815954    .1549084
----------------------+----------------------------------------------------------------
a27_district_county   |
              _predict |
                   1  |  -.0532546    .031708    -1.68   0.093    -.1154012     .008892
                   2  |   .0324101   .0436803     0.74   0.458    -.0532018     .118022
                   3  |  -.0338714   .0244814    -1.38   0.166     -.081854    .0141112
                   4  |   .0547159   .0397038     1.38   0.168    -.0231021    .1325338
---------------------------------------------------------------------------------------
```

Appendix G: Abstract Pages of Publications

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Article

Farmers' Knowledge, Attitude, and Practices Regarding the Use of Agroecological-Based Pest Management Practices in Crucifers and Traditional African Vegetable (TAV) Production in Kenya and Tanzania

Essy C. Kirui [1,2], Michael M. Kidoido [1,*], Daniel M. Mutyambai [1], Dickson O. Okello [2] and Komivi S. Akutse [1]

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Abstract: Crucifers and traditional African vegetables (TAVs) are important to smallholders in Kenya and Tanzania, but yield remains below potential due to pests and diseases. Agroecological production methods present a nature-based solution to pest and disease management in crucifer and TAV production. We explore the status of farmers' knowledge, attitudes, and practices regarding agroecological-based production pest management practices. Structured and pretested questionnaires were used to collect data from 1071 vegetable farming households in Kenya and Tanzania. Using descriptive statistics, parametric, and non-parametric analysis, our study revealed that less than 20% of farmers had received training on agroecological-based practices and less than 25% were aware of most of these practices. Among those who were aware of the practices and could confirm their effectiveness less than 12% had adopted them, except for crop rotation and handpicking of pests. This study attributes the low adoption to farmers' negative attitudes towards the practices. Nonetheless, the study further revealed that training significantly and positively influences the adoption of the practices. Therefore, we recommend that governments and other stakeholders promote targeted awareness campaigns and increase access to training on vegetable production using sustainable pest and disease management practices.

Keywords: agroecological pest management; cruciferous vegetables; traditional African vegetables; sustainable agriculture; environmentally friendly agriculture systems; biodiversity conservation; Kenya; Tanzania

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Citation: Kirui, E.C.; Kidoido, M.M.; Mutyambai, D.M.; Okello, D.O.; Akutse, K.S. Farmers' Knowledge, Attitude, and Practices Regarding the Use of Agroecological-Based Pest Management Practices in Crucifers and Traditional African Vegetable (TAV) Production in Kenya and Tanzania. *Sustainability* **2023**, *15*, 16491. https://doi.org/10.3390/su152316491

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1. Introduction

Horticulture is the second-largest foreign exchange earner in Kenya, and the country is the largest supplier of vegetables to European Union (EU) markets [1]. Similarly, Tanzania's horticulture sector is growing at 11% per annum, surpassing its agricultural growth rate of 4%, and the country is one of the world's top 20 producers of vegetables [2]. Kenyan and Tanzanian households commonly cultivate cruciferous vegetables such as cabbages and kales [3–5]. Traditional African vegetables (TAVs) have also been part of the food systems of these countries for generations since they are exceptional sources of vitamins, dietary fiber, and minerals [3,6]. The most popular traditional African vegetables found in Kenya and Tanzania's urban and rural markets include amaranth (*Amaranthus* spp.), spider plant (*Cleome gynandra*), jute mallow (*Corchorus olitorius*), cowpea leaf (*Vigna unguiculata*), African nightshade (*Solanum scabrum.*), and African eggplant (*Solanum macrocarpon*) [7,8].

Crucifers and TAVs are essential in enhancing food security, improving nutrition, and mitigating health risks. These vegetables are nutrient-dense with great potential to reduce

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Article

Factors Influencing the Adoption of Agroecological Vegetable Cropping Systems by Smallholder Farmers in Tanzania

Essy C. Kirui [1,2], Michael M. Kidoido [1,*], Komivi S. Akutse [1,3,*], Rosina Wanyama [4], Simon B. Boni [4], Thomas Dubois [1], Fekadu F. Dinssa [4] and Daniel M. Mutyambai [1,5]

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Abstract: Vegetable production is vital to smallholder farmers, who often struggle to overcome pests, diseases, and extreme weather. Agroecological cropping systems offer sustainable solutions to these issues but their adoption rates in Tanzania remain low. This study examines the factors influencing smallholder farmers' adoption of selected agroecological cropping systems for vegetable production in Tanzania, which remains underexplored. Using a multistage sampling technique, cross-sectional data were gathered from 525 crucifer and traditional African vegetable farming households within the Arusha and Kilimanjaro regions. Multivariate probit regression analysis, which accounts for the simultaneous adoption of multiple systems, revealed several significant variables influencing adoption. The number of training sessions attended and access to market information positively influenced adoption ($p < 0.01$), while gross income from vegetable production also had a positive influence ($p < 0.05$). Conversely, the age of the household head and the region where the farm was located showed negative effects on adoption ($p < 0.05$). These findings highlight the need for targeted extension services and training sessions focusing on the benefits, methods, and management techniques of agroecological cropping systems. Gender-sensitive policies and interventions should also be developed to address the factors influencing the adoption of agroecological cropping systems.

Keywords: agroecology; cropping systems; smallholder farmers; crucifers; traditional African vegetables; Tanzania

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1. Introduction

Vegetable production in sub-Saharan Africa (SSA) significantly enhances nutrition and food security, improves household income, creates employment opportunities, and generates foreign exchange [1,2]. Tanzania stands out as a leading vegetable producer within SSA, ranking among the top 20 globally [3]. The sector has experienced rapid growth with an average annual rate of 11% in recent years, making it the fastest-growing subsector within Tanzania's agricultural sector [4,5]. Smallholder farmers, who operate on less than two hectares of land, are the backbone of vegetable production in Tanzania [4,6]. They grow a variety of crops that include cruciferous vegetables, such as cabbage, kale,