ANALYSIS OF EXTENT AND IMPACT OF ADOPTION OF SOIL CARBON ENHANCING PRACTICES ON MAIZE YIELD AMONG SMALLHOLDER FARMERS IN KAKAMEGA AND VIHIGA COUNTIES, KENYA

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DECLARATION

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

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DEDICATION

I dedicate this thesis to my loving parents Ben Machaki and Margret Machaki, my siblings and friends for the unwavering support they have given me throughout this journey.

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ABSTRACT

Smallholder farmers account for nearly 80 percent of food production in sub-Saharan African (SSA), signifying their role in the achievement of food security. However, they are faced with low productivity due to poor agricultural management practices such as mono-cropping, land degradation, land fragmentation, low soil fertility, sub-optimal utilization of agricultural inputs and adverse effects of climate change. With the SSA population expected to double to 2 billion people by the year 2050, this creates a need to enhance food production. Despite the above challenges faced by smallholder farmers, enhancing productivity remains one of the viable solutions to increase food production. In light of climate change and deteriorating ecosystems, there is a need to adopt sustainable agricultural practices such as soil carbon enhancing practices (SCEPs). SCEPs are advocated for as they can sequester carbon, increase soil organic carbon thus enhancing soil fertility and have been proven to be low-cost agricultural practices that can help farmers mitigate and adapt to climate change.

Evidence from literature indicates that the adoption rate of these practices remains low despite their ability to enhance soil fertility. Moreover, previous studies failed to account for the effect of plot-specific characteristics on the adoption of SCEPs, as well as complementarity or substitution in adoption decisions of these practices hence the need for this study. The specific objectives were to: determine factors influencing the adoption of SCEPs, determine factors influencing the extent of adoption of the SCEPs and assess the impact of adopting SCEPs on maize yield among smallholder farmers in Vihiga and Kakamega Counties of Kenya. Primary survey data were collected from 334 randomly selected farm-households. A multivariate probit model was utilized to assess factors influencing the adoption of SCEPs, and the generalized ordered logit model was used to assess the extent of adoption, while the multinomial endogenous treatment effect model was used to assess the impact of adopting SCEPs on maize yield.

The results show that plot specific characteristics namely, plot size, distance to the plot, farmers' perceptions that their plots are affected by soil erosion, plot tenure, and plot slope influence the adoption of SCPEs. A farmer's farming experience, literacy level, participation in marketing, membership to agricultural groups, access to agricultural loan and tropical livestock unit significantly influenced the adoption of SCEPs. Notably, farmyard manure, intercropping with legumes and inorganic fertilizer were found to be adopted in complementarity. The extent of adoption as measured by the number of practices adopted was significantly influenced by plot size, the number of plots a farmer operated, the slope of the plot, gender of household head, access to agricultural loan and membership to an agricultural group. The adoption of farmyard manure and intercropping and the combination of both were found to have a significant and positive impact on maize yield.

These findings call for the promotion of SCEPs as a package given their impact and their adoption in complementarity. Nevertheless, the design and promotion of SCEPs by either local government, national government or private sectors should ensure gender inclusivity. Considering that the adoption of SCEPs is knowledge-intensive in nature, one of the strategies to enhance adoption would include strengthening the existing farmer groups to enhance capacity building and sharing of information. Additionally, given the influence of plot-specific characteristics on adoption is an indication that the incorporation of scientific soil testing in helping farmers better understand their soil characteristics can help in enhancing the adoption of specific low-cost SCEPs that enhance soil fertility.

Keywords: Soil carbon enhancing practices, soil fertility, productivity, generalized ordered logit, multivariate probit, multinomial endogenous treatment effect model, Western Kenya.

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ABBREVIATION AND ACRONYMS

AERC	African Economic Research Consortium
AFRINT	Agricultural Food Intensification in sub-Saharan Africa
AIC	Akaike information criterion
BIC	Bayesian information criterion
CIAT	International Center for Tropic Agriculture
CIDP	County Integrated Development Plan
CMAAE	Collaborative Masters in Agricultural and Applied Economics
CSA	Climate Smart Agriculture
FAO	Food and Agriculture Organization
FYM	Farmyard Manure
GDP	Gross Domestic Product
GOK	Government of Kenya
HH	Household
HHH	Household head
IEBC	Independent Electoral and Boundaries Commission
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change

KACP	Kenya Agricultural Carbon Project
KALRO	Kenya Agricultural and Livestock Research Organization
KM	Kilometres
KNBS	Kenya National Bureau of Statistics
LR	Log likelihood
MMNL	Mixed Multinomial Logit
MSL	Maximum Simulated Likelihood
MVN	Multivariate Normal Distribution
MVP	Multivariate Probit
SCEPs	Soil Carbon Enhancing Practices
SD	Standard Deviation
SDG	Sustainable Development Goals
SLM	Sustainable Land management practice
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	sub-Saharan Africa
TLU	Tropical Livestock Unit
VIF	Variance Inflation Factor

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

In sub-Saharan Africa (SSA), the agricultural sector remains among the leading contributors to Gross Domestic Product (GDP) at 26 percent, overall employment at 40 percent and rural employment at 70 percent (KNBS, 2018abc). The sector has been identified to enhance income, directly and indirectly, enhance employment (Gitau and Meyer, 2019) making the sector important in alleviating poverty among rural communities and achieving food security. The two benefits are among the key targets set by the Kenyan Government through Vision 2030 the United Nation sustainable development goals (SDGs) and the Malabo declaration of 2014.

Currently, Kenya is among the SSA countries that are unable to feed their population adequately. With the SSA population expected to double to 2 billion people by the year 2050, enhancing food production becomes a priority (FAO, 2017). Enhanced production within SSA over the years has been attributed to an increase in the area under production rather than enhanced productivity (Jayne *et al*., 2016). With the expected rise in population, increasing production through expansion of cultivated land to achieve food security is not feasible.

Like many other countries in SSA, Kenya is characterized by low agricultural productivity levels (Bekabil, 2014; FAO, 2017). This has been attributed to poor farming techniques, land degradation and soil erosion that lead to low soil fertility (Odendo *et al*., 2010; Jaetzold *et al*., 2010; Cavanagh *et al*., 2010; Kihara *et al*., 2017). Bearing in mind the low productivity levels, it has been predicted that by 2020, yield and income from maize and wheat production will have reduced by 50 percent (Mwungu *et al*., 2018). For instance, in Kenya, maize productivity has been declining at a rate of 0.07 ton/ha/decade (Mumo *et al*., 2018). This creates needs to enhance productivity in order to increase production and achieve food security.

Additionally, the agricultural sector is affected by the detrimental effects of climate change resulting from the rising atmospheric greenhouse gases. This has been attributed to increased use of fossil fuels and industrialization that has increased the level of atmospheric carbon dioxide by more than 40 percent (Harris and Roach, 2017). In response to this, the Paris agreement of 2015 was formulated by 196 nations to combat climate change and pursue efforts to limit the increase in global average temperature by 1.5 ^{0}C. This has drawn a critical focus for research and development organizations to find more sustainable measures that could be adopted by different stakeholders to combat climate change.

Schrag (2007) notes that there are three key strategies with the potential of lowering the atmospheric carbon dioxide namely: developing low or no-carbon fuels, reducing global energy usage and sequestration of carbon dioxide from the atmosphere. A viable solution that incorporates the agricultural sector is soil carbon sequestration (Lal, 2004; Lal, 2010). Adoption of carbon sequestration can act as both a mitigation and adaptation strategy (Lal, 2004; Lal 2010, Gattinger *et al*., 2012; Lal, 2016) considering that agricultural production contributes to 14 percent of the anthropogenic greenhouses emissions mainly through land-use change (Smith *et al*., 2008; Abbasi *et al*., 2014; Sommer *et al*., 2018).

Faced by increasing population, high poverty rates, low productivity, declining arable lands and the adverse effects of climate changes, Kenya needs to adopt sustainable agricultural technologies. Soil carbon sequestration has proven to be a viable solution to enhancing soil fertility by increased soil organic carbon through the adoption of low-cost agricultural management practices (Smith and Olesen, 2010; Kahiluoto *et al*., 2014). These practices are also referred to as soil carbon enhancing practices (SCEPs). SCEPs sequestration potential is high since most of the world soils have depleted organic carbon through cultivation (Lal, 2004; 2001; 2010; Gattinger *et al*., 2012). Depletion of soil carbon stock leads to a reduction in biomass productivity, soil quality, water holding capacity and increases atmospheric carbon (Lal, 2010).

In Kenya, most farmers are vulnerable to changing weather patterns and lag in adopting new practices that help in mitigating and adapting to climate change effects. For instance, Bryan *et al*. (2013) noted that most farmers either change their crop varieties, planting dates or cropping type. On the other hand, only 5 percent of the farmers can adjust their water and soil conservation practices, 7 percent apply fertilizer and 9 percent plant more trees around their farms. However, compared to other nations in Africa, Kenya is slightly better off as only 19 percent of the farmers do not adjust their farming practices compared to 37 percent and 67 percent in Ethiopia and South Africa respectively (Bryan *et al*., 2009).

Enhancing the adoption of soil carbon practices can help in alleviating low productivity as it increases soil organic carbon, improves soil's physical, chemical and biological properties which help enhance soil fertility thus improving agricultural productivity (Franzluebbers, 2010; Sommer and Braslow, 2016). SCEPs have been promoted in SSA but under different names. Some of the practices defined as SCEPs have also been referred to as sustainable land management (SLM), conservation agriculture and climate-smart agriculture. These practices have been promoted in Kenya as well as in other Sub-Saharan Africa such as Uganda, Ethiopia, Tanzania, and Zambia, as means of adapting to climate change while at the same time enhancing productivity.

However, given the potential of adopting SCEPs, in literature, there exist two views on their impact on crop yield. The first view supports the notion that SCEP enhances soil fertility thus improving agricultural productivity. This view has been supported by various studies in Kenya (Hunink *et al*., 2012; Mbau *et al*., 2015; Adolwa *et al*., 2015; Kiboi *et al*., 2017; Sommer *et al*., 2018). The second view indicates that some SCEP are none beneficial to the soil and thus do not enhance productivity. This notion is backed up by the facts that some soil carbon enhancing practices may have a negative impact or may compete for nutrients with farm crops. For instance, Rusinamhodzi *et al*. (2011) noted that mulching might be over effective in enhancing soil moisture leading to waterlogging. Moreover, it may lead to proliferation of pest, diseases and weeds born by crop residue (Thierfelder and Wall, 2007). Some of the practices, namely mulching, farmyard manure preparation and application have been established to lead to increased labour requirements thus resulting in low productivity (Giller *et al*., 2009; 2015).

1.2 Statement of the Research Problem

Soil carbon sequestration has proven to be one of the key solutions to dealing with the low productivity and adverse effect of climate change (Smith and Olesen, 2010; Lal, 2014; Kahiluoto *et al*., 2014). However, the adoption rate of SCEP still remains low despite the combined efforts from the private sectors and the government to encourage their adoption (Antle and Stoorvogel, 2008; Mucheru-Maina *et al*., 2012; Mutoko *et al*., 2013; Mutoko *et al*., 2014b; Dallimer *et al*., 2017). Several studies undertaken in Kenya have established that socio-economic and external support factors determine the adoption of SCEPs. Some of these factors are age, gender, experience in farming of the household, access to credit, extension services and participating in marketing (Marenya and Barrett, 2007; Mutoko *et al*., 2014ab; Dallimer *et al*., 2017). However, the studies failed to take into account plot characteristics namely: farmers' perception towards their plot fertility and erosion, plot slope, plots size, and soil type; which have been established to be key contributors to influencing adoption rate (Kassie *et al*., 2014; Telkwood *et al*., 2015; Manda *et al*., 2015). Consequently, the studies focussed on single practices and failed to account for the fact that farmers adopt practices in complementarity or substitution, therefore, leading to biased results. Additionally, studies that have studied the impact of adopting single technologies such as Jena (2019) on minimum tillage, Hassen (2018) on farmyard manure and Ngwira *et al*. (2012) and Midefa *et al*. (2014) on intercropping with a legume, failed to consider the complementarity and substitutability among individual practices and combination of these practices and if adopted in combination may offer a higher impact.

This study proposes to fill in the gap in the literature by assessing the factors that facilitate or constrain adoption, the extent of adoption and impact of adopting SCEPs among smallholder farmers in Kakamega and Vihiga Counties in Kenya. The study narrowed down the SCEPs to the use of organic manure, inorganic fertilizer, mulching, and intercropping with legumes. A better understanding of the factors that influence or constraint adoption of SCEPs and the impact of adoption can guide in the designing and implementation of more effective policy interventions to stimulate increased uptake of SCEPs practices among smallholder farmers.

1.3 Objectives

The objective of this study was to assess factors that influence the adoption, extent of adoption of SCEPs and its impact on maize yield among smallholder farmers in Vihiga and Kakamega Counties in Kenya.

Specific Objectives

1. To determine factors influencing the adoption of the soil carbon enhancing practices among smallholder farmers.
2. To determine factors influencing the extent of adoption of the soil carbon enhancing practices among smallholder farmers.
3. To assess the impact of adopting soil carbon enhancing practices on maize yield among smallholder farmers.

1.4 Hypotheses

1. Social-economic, external support, and plot specific characteristics factors have no effect on the adoption of soil carbon enhancing practices.
2. Social-economic, external support, and plot specific characteristics have no effect on a farmer's extent of adoption of soil carbon enhancing practices.
3. Adopting soil carbon enhancing practices has no significant impact on maize yield.

1.5 Justification

Information gathered from this study will play an essential role in decision-making for farmers, international organizations such as the International Center for Tropical Research (CIAT), and the Government of Kenya through Kenya Agricultural and Livestock Research Organization (KALRO), extension agents and local governments. Farmers will benefit from results obtained in both objective one and two and three. Understanding of factors that influence or constrain adoption of specific soil carbon enhancing practices and extent of adoption can be utilized to formulate training camps that target specific farmers' characteristics to enhance adoption. Additionally, factors that influence the extent of adoption will be useful in enhancing the adoption of more soil carbon enhancing practices. Results from the impact of adopting soil carbon enhancement practices will be vital as they can help act as a motivation to farmers in encouraging adoption if they have a positive and significant impact on yield.

Scientist in CIAT, KALRO and extension agents will also benefit the results of this study. Factors influencing or constraining adoption will be useful in designing extension platforms that can be utilized in disseminating the importance of adopting sol carbon enhancing practices. The extent of adoption will be a key indicator of what needs to be done to promote the adoption of more soil carbon enhancing practices. Subsequently, the impact of adopting the different practices can act as criteria on selecting the most important practices that need to be promoted among farmers. The Government of Kenya can use all the information to formulate policy briefs that would enhance investment on factors that facilitate the adoption of soil carbon enhancing practices.

Additionally, the results will contribute to existing literature gaps on factors that influence the adoption of soil enhancing practices and debate on the impact of some of the soil enhancing practices. Lastly, the study will be a contribution towards the fulfilment of Government of Kenya big four agenda, Vision 2030 and sustainable developments goals, namely goal 1 on no poverty goal 2 on zero hunger, goal 13 on mitigating climate change and goals 15 on increasing biodiversity based on the benefits of enhanced soil organic carbon.

1.6 Study Area

The study was conducted in Western Kenya, particularly in Vihiga and Kakamega Counties (Figure 1). The Counties were selected because they are classified as high agricultural potential areas but faced with low agricultural productivity due to low soil fertility, heavy leaching, poor farming techniques, soil erosion and degradation (Odendo *et al*., 2010; Jaetzold *et al*., 2010). The two Counties have nearly similar agro-ecological zones and characteristics. Vihiga receives an annual rainfall of 1900mm with a mean temperature of 23^{0}C (GOK, 2018a). While Kakamega receives 1971mm of rainfall and has a mean temperature of 23.5^{0}C (GOK, 2018b). In both Counties, short rains are experienced between March, April, and May and long rains in September, October, and November.

Increased population has amplified pressure on land leading to poor land management practices and continuous farming on the small available portion of lands. Vihiga is one of the densely populated Counties in Kenya with 1044 people per square KM, while Kakamega population density is 587 persons per square KM, which is still high compared to the national average of 66 persons per square KM (GOK, 2018ab). Poverty levels within the two Counties are also significantly high. Approximately 51.3 percent and 41 percent of the population live below the poverty line in Kakamega and Vihiga Counties respectively compared to an average of 39 percent within other rural areas in Kenya (KNBS, 2018)

Combining the high poverty level, poor soil fertility levels, and declining land sizes creates the need to come up with a low-cost solution to enhance productivity in the two regions. The two Counties Local Governments acknowledge the need to improve agricultural productivity as indicated on their County Integrated Development Plans (CIDPs) (GOK, 2018ab). SCEPs prove to be one of the low-cost technologies with numerous benefits of enhancing soil productivity that can be adopted in the area. There have been several programs that have been implemented in Western Kenya to alleviate low productivity. Some of these projects include the Kenya Agricultural Carbon Project (KACP), Climate Smart Agriculture (CSA) related Projects, and Agricultural Intensification in sub-Saharan Africa (AFRINT) project all promoting the adoption of SCEPs.

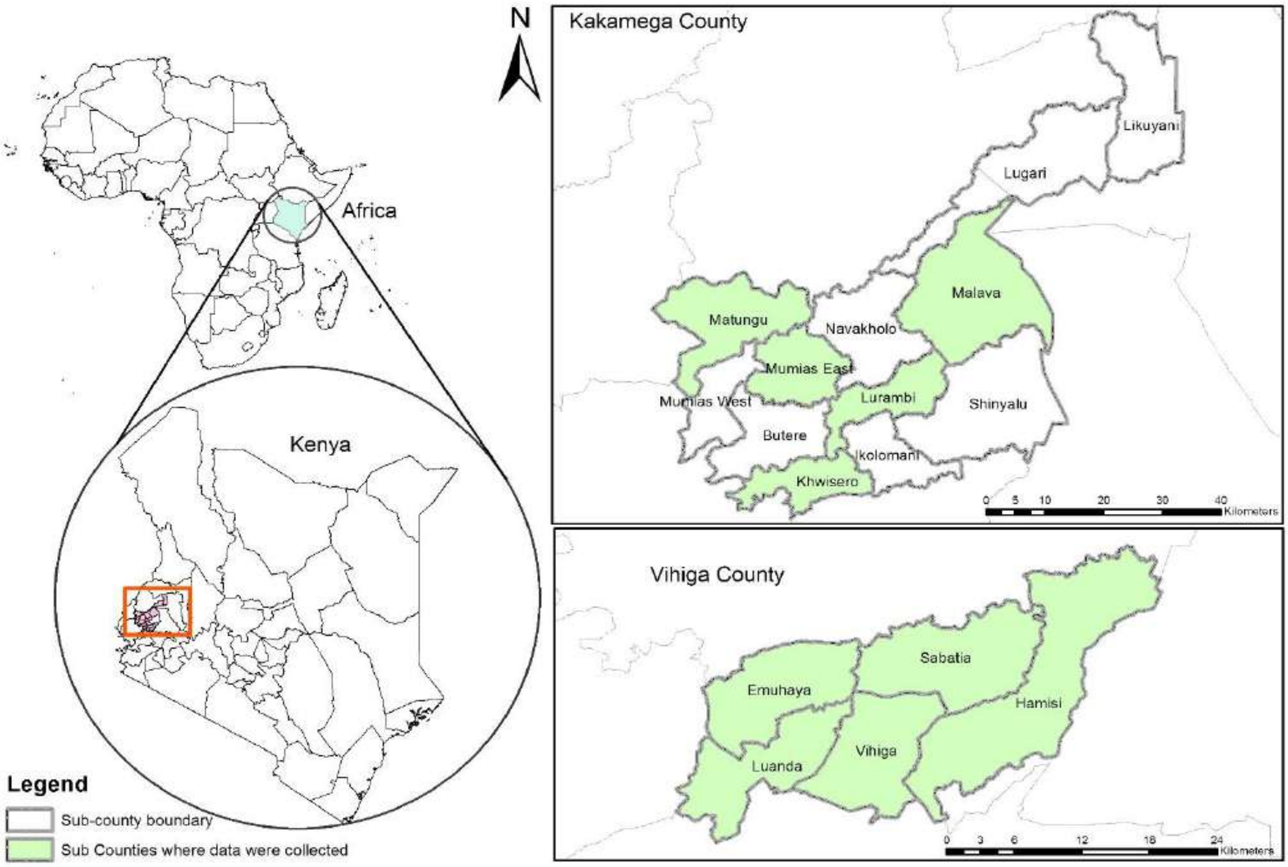

Figure 1.1: Map of the Study Area

Source: IEBC (2012)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil Carbon Sequestration

Soil carbon sequestration can be defined as transferring atmospheric carbon dioxide into long-lived pools and storing it securely to reduce its immediate remission (Lal, 2004a; Stockmann *et al*., 2013). Hutchison *et al.* (2007) defined it as simply the persistent increase in the amount of carbon stored in the soil. Soil carbon sequestration potential is measured in t C ha^{-1} yr^{-1}; this takes into consideration the annual biomass accumulation by a specific practice in the soil between the first and the second year and the amount of carbon in tonnes per hectare has been fixed to the soil.

Soils within the tropics and equatorial zones have been documented to have leached more carbon compared to soils in temperate zones as they are faced by hot to warm weather (Lal *et al*., 2015). Hobbies *et al*. (2000) states that temperate zones have higher carbon-rich soil compared to the tropic soils as they experience cool/ cold, humid weather. The low soil carbon levels within the tropics and equatorial zones increase soil carbon sequestration potentials in the zones.

Soil carbon sequestration is important as both as a mitigation and adaptive measure to climate change as it offers numerous benefits such as increased humification efficiency, reduction in erosion and leaching and increased net primary productivity (Lal, 2013). However, these advantages are broad and cannot be utilized to convince farmers to adopt the given practices. Therefore, the use of specific advantages to the crop such as an increase in yield or enhanced soil fertility can help convince farmers on the importance of adopting soil carbon enhancement practices.

The key benefits that trickle down from enhanced soil carbon include improved soil structure, aeration, water-holding capacity, and reduced plant water stress (Lal, 2013). Such benefits lead to increased nutrient retention and availability, enhanced germination, better plant growth, and good stand establishment and increased input use efficiency through the reduction in loss of nutrient and water. Additionally, some other benefits include enriched species diversity of soil biota and activity of macrofaunal, reduced soil erosion, and increased water infiltration capacity and reduction in the runoff and increase crop yields and livestock/land area. Lastly, due to increased soil carbon, it acts as a means of mitigation against climate change.

2.1.2 Loss in Soil Organic Carbon

Loss in soil organic carbon (SOC) has been attributed to soil disturbance from continuous tillage (Horwath and Kuzyakov, 2018). However, other enforcing factors increases the loss of SOC. This factors include (1) low returns in usage of manure and reduction in herd sizes; (2) monoculture resulting in reduction in crop species diversity; (3) poor fallowing techniques[1] resulting into soil erosion; (4) application of inefficient nutrients; (5) reduction in crop residue retention that are utilized either as fuel or animal feed; (6) burning of fields as a residue management technique.

2.1.3 Soil Carbon Sequestration Practices

From an agricultural point of view, certain practices increase soil carbon sequestration while other farming techniques reduce soil carbon pool. There are seven recommended farming techniques that help in enhancing soil carbon and include: (i) adoption of minimum tillage or no-tillage and elimination or reduction of mechanical tillage, (ii) the use of crop residue for surface mulching with incorporation of cover crop into rotation cycle, (iii) the use of ridges

[1] Poor fallowing involves leaving the land bare without any vegetative cover, making it susceptible to soil erosion. The recommended practice is improved fallowing that involves either planting grass, shrubs, fast growing trees, which helps restore degraded land

and contours to minimize soil and water losses by surface runoff, (iv) improved grazing systems that incorporate enhanced diet of livestock in order to reduce livestock enteric emissions, (v) the use of new farming systems that incorporate agroforestry techniques and mixed crop-livestock in order to enhance biodiversity, efficient resource use and sustenance of natural ecosystems, (vi) the reduction in runoff, evaporation and increased water use efficiency through drip irrigation and/ or fertigation techniques, and (vii) improving soil fertility through integrated nutrient management (Fig. 2).

Lal (2010) noted that the adoption of these techniques results in increased net primary productivity, increased humification efficiency, reduction in erosion and leaching. Two key strategies that help increase the efficiency of soil carbon sequestration are the use of organic amendments and integrated nutrient management (INM). Additionally, Lal (2010) noted that INM is important since it helps in the incorporation of other key soil nutrients namely, Nitrates (N), Phosphates (P) and Sulfates (S). It has been documented that the presence of these nutrients increases the efficiency of soil carbon sequestration (Malhi *et al*., 1997; Paustian *et al*., 1997; Janzen *et al*., 1998). Lal (2010) notes that soil with manure contained more soil organic carbon than un-manured soils. Additionally, soil carbon sequestration was established to be greater in soils that had both organic manure and chemical fertilizer (Lal, 2010).

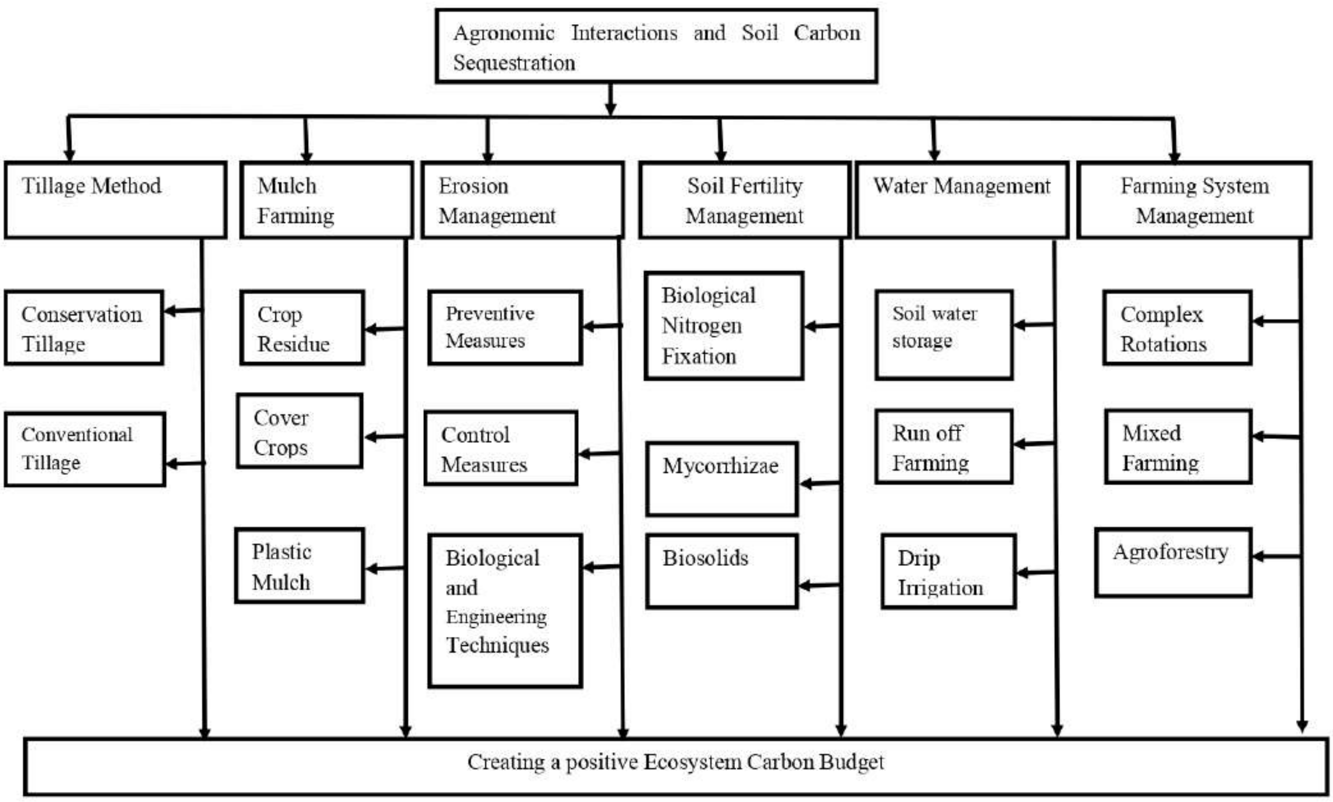

Figure. 2.1: Soil Carbon Enhancing Practices (Adapted From Lal (201)

Stockmann et al. (2013) note that soil organic carbon (SOC) is often confused with soil organic matter (SOM). However, soil organic matter is key in soil carbon sequestration as it contains 58 percent soil organic carbon and other products such as humus, charcoal, living microbes, and particulate organics. This makes the use of organic amendments, such as crop residue and cover crops key to increasing soil organic matter. A study by Stockmann et al. (2013) notes that humus is essential in soil carbon sequestration as it produces a stable carbon pool not easily leached out compared to surface plant residue, buried plant residue, and particulate organic matter. This is critical while developing a tool to demonstrate soil carbon sequestration and how it is achieved and its key benefits to farmers.

2.2 Practices Selection Criteria

A list of all SCEPs adopted in Western Kenya was created. The carbon sequestration potential, depth, time taken for soil carbon sequestration benefit to accrue, and cost that a farmer will incur in implementation of the practice were determined from the literature review. Based on the above criterion practices that took shorter time to realize sequestration, with the depth suitable for crop cultivation and were low-cost practice were intercropping with legumes, farmyard manure, inorganic fertilizer, mulching, improved fallowing, and grass strips (Table 1).

However, grass strips were eliminated from the analysis since literature states that if planted near crops they compete for nutrients with crops before they are mature (Paustian, 2014). Moreover, improved fallowing was not considered due to the low adoption rate among farmers in Western Kenya as they were faced by land resource constraints. Application of inorganic fertilizer can be costly; however, the National and Local Governments have installed measures to subsidize inorganic fertilizer making it more affordable to the farmers. Furthermore, farmyard manure is more preferred to residue retention because it adds more soil organic matter and decomposes at a higher rate thus sequestrating more soil organic carbon. The study, therefore, considered intercropping with legume, farmyard manure, inorganic fertilizer and mulching since they sequester carbon, have immediate impact on soil fertility through enhanced soil organic carbon and required low cost to implement.

Table 2.1Practices and Their Soil Carbon Sequestration Potential

Practices	C sequestration potential		Depth	Time taken for benefits to accrue	Cost	Reference
Intercropping with Legumes	0.88-0.69	t C ha^{-1} yr^{-1}	0-30 cm	Same cropping season	Purchase of seeds	Eagle *et al*. (2012); Kim *et al*. (2016); Kumar (2018)
Improved fallow [d]	0.1	t C ha^{-1} yr^{-1}	0-10 cm	2-3 cropping season	No cost (the only cost that can be considered is opportunity cost)	Vagen *et al*. (2004)
Residue Retention	0.24	t C ha^{-1} yr^{-1}	0-30 cm	3-4 cropping season	No cost (use crop residue from previous season)	Vagen *et al*. (2004); Horwath and Kuzyakov (2018)
Agroforestry	0.59-2.53	t C ha^{-1} yr^{-1}	0-100 cm	Depends on the type of trees planted	Purchase of seeds	FAO (2001); Paustian (2014)
Manure	0.45	t C ha^{-1} yr^{-1}	0-30 cm	Same cropping season	No cost (use of manure from animals kept)	Mbau *et al*. (2015); Horwath and Kuzyakov (2018)
Fertilizer	0.32	t C ha^{-1} yr^{-1}	0-20 cm	Same cropping season	Purchase of Fertilizer	Minasny *et al*. (2012)
Mulching	0.2-0.57	t C ha^{-1} yr^{-1}		Same cropping season	Use reside from the farm	Horwath and Kuzyakov (2018)
Cover crop	0.15- 0.23	t C ha^{-1} yr^{-1}		2-3 cropping season	Purchase of Seeds	Poudal *et al*. (2001); Swan *et al*. (2015); Horwath, and Kuzyakov (2018)
No-tillage – Minimum Tillage	0.48-0.27	t C ha^{-1} yr^{-1}	0-5 cm	3-4 cropping season	No cost	Mandlebaum and Nriagu, J. (2011); Paustian 2014; Horwath and Kuzyakov (2018)
Grass strips	0-34	t C ha^{-1} yr^{-1}	0-30	3-4 cropping season	Purchase of grass seeds	Paustian 2014

2.3 Conceptual Framework

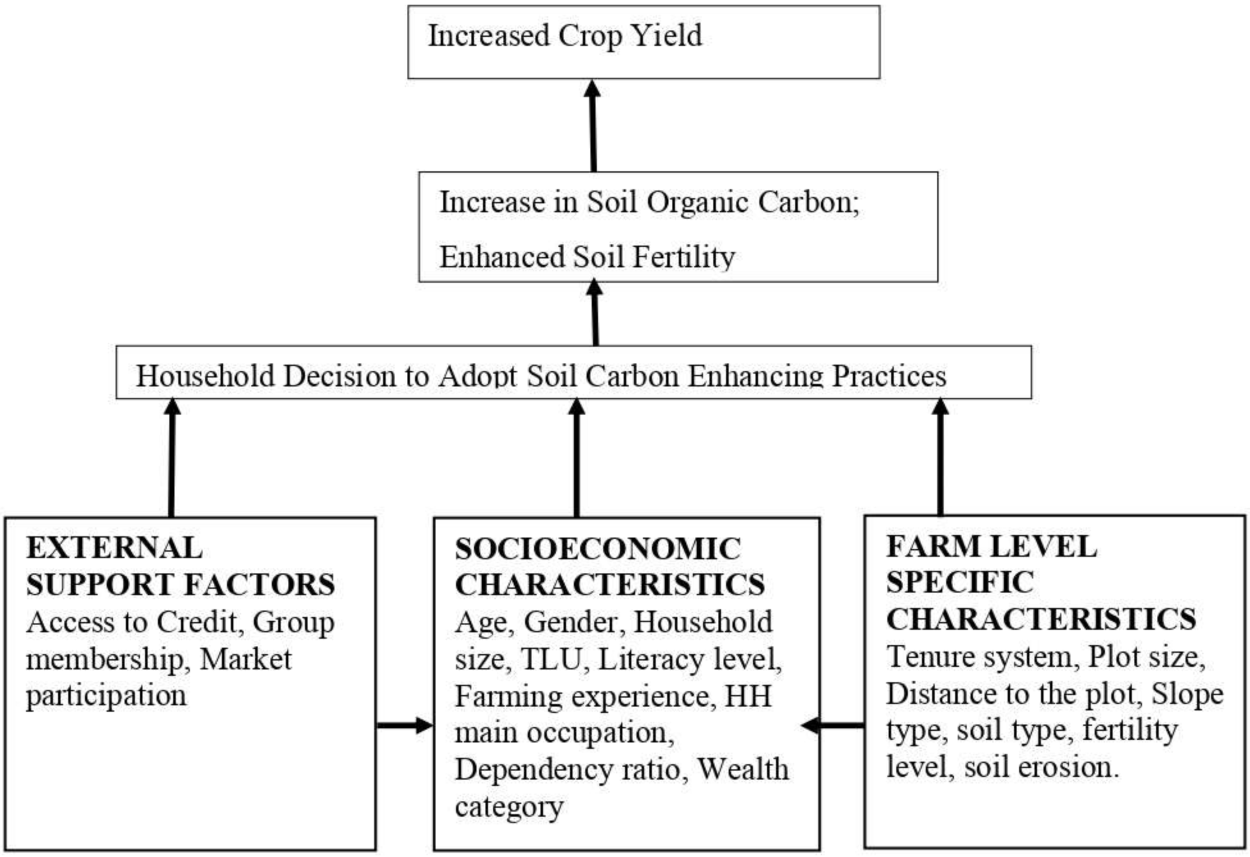

Figure 2.2: Conceptual Framework

Source: Author conceptualization

Counties at farm level is low soil fertility (Odendo *et al*., 2010; Jaetzold *et al*., 2010) which translates into food insecurity, increased carbon emission, and eventually climate change. However, the adoption of soil carbon enhancing practices is a potential way through which the challenges can be tackled, as illustrated in Fig.3. The recommended soil carbon enhancement practices include tillage method, erosion management, mulching farming, water management, soil fertility management, and farming system management. However, adoption and extent of adoption of these practices is influenced by several factors namely plot specific characteristics, socioeconomic, external and institutional factor

When a farmer adopts a given set of practices, benefits that trickle down include a reduction in plant water stress, enhanced nutrient retention and availability, increased water infiltration capacity, increased germination and better plant growth, and mitigation of climate change. All the benefits lead to enhanced soil physical, chemical and biological properties which translates into enhanced soil fertility and subsequently improved crop yield.

2.4 Theoretical Framework

The study was anchored on the expected utility theory developed by Daniel Bernoulli. The theory states that the decision by a farmer to adopt a technology; in this case, SCEPs, given the risk and uncertainties within their biophysical environment is based on a comparison of the expected utility of maximizing output (yield) (Schoemaker, 1982). However, the theory assumes that farmers are rational, and they aim at maximizing utility which can be measured by use of monetary values or output given a set of constraints. Farmers will, therefore, adopt a technology if the expected utility from adoption U_1 is greater than for non-adoption U_0 (Kassie *et al.*, 2015) as shown by Eq. 1:

$$Y_a^* = U_1^* - U_0 > 0 \quad (1)$$

Where Y^* is a latent variable associated with the benefits of adopting SCEPs.

Following Asfaw *et al.* (2012) utility from adopting SCEPs (Farmyard manure (FYM), intercropping, inorganic fertilizer and mulching) can be modelled as a link between the adoption decision and expected benefits. Therefore, the adoption decision can be determined by observable characteristics Z_a and a stochastic error term ε_i that is unobservable and hence is assumed to be normally distributed (Greene, 2003) as shown in Eq. 2:

$$Y_{ia}^* = \beta Z_{ia} + \varepsilon_i \; (a = 1, 2, 3, 4) \quad (2)$$

Where Y_a^* a latent variable associated with the benefits of SCEP a and farmer i can be translated into a binary outcome equation for each choice of SCEP as shown in Eq. 3:

$$Y_{ia} = 1 \text{ if } Y_{ia}^* > 0, and\ O\ otherwise\ (a = 1, 2, 3, 4) \quad (3)$$

The probability of adopting a SCEP can then be estimated as shown in Eq. 4:

$$\Pr(Y_{ia} = 1) = \Pr(Y_{ia}^{*} > 0) = 1 - D(-\beta Z_{ai}) \quad (4)$$

Where D is the cumulative distribution function of the error term ε_i.

2.5 Sampling Procedure

The survey incorporated a multistage sampling technique as follows: In the first stage, in order to increase the variability of data, five Sub-Counties were randomly selected in each county. Vihiga County all the Sub-Counties namely; Vihiga, Emuhaya, Hamisi, Sabatia and Luanda were selected. In Kakamega County, which has, twelve Sub-Counties, five were randomly selected. However, before randomly selecting the five Sub-Counties in Kakamega County, two Sub-Counties (Lugari and Likuyani) were eliminated since they lie in a different agro-ecological zone and have one planting season while the rest of the Sub-Counties in Kakamega and Vihiga have two planting seasons per year. This was done to ensure uniformity of the agro-ecological zone from which data were collected. The remaining ten Sub-Counties were assigned a random number and five Sub-Counties, namely Khwisero, Mumias East, Lurambi, Malava and Matungu were randomly selected.

In the second stage, due to time and budgetary constraints, two wards were selected from each Sub-County with the help of county extension officers. In the third stage, 16 villages from each county were selected distributed equally in the sub-Counties and the wards selected. The target sample frame was determined using Eq. 5 and Eq. 6 which resulted in 320 farmers (i.e., 160 farmers from each county).

$$n_0 = \frac{Z^2 pq}{e^2} \quad (5)$$

$$n_0 = \frac{1.96^2 (0.5 * 0.5)}{0.055^2} = 317\ (\sim 320) \quad (6)$$

Where n_0 is the sample size, e is the desired level of precision, Z^2 is the standard normal deviate at the selected confidence level (which is 95 percent confidence interval), p is the estimated proportion of an attribute that is present in the population, and q is 1-p.

In order to ensure the variability of data, the number of farmers was limited to 10 farmers per village. In the fourth stage, ten farmers from each village were interviewed by first picking a random farmer to start with then snowballing to get the other farmers. However, to cater for data problems, 14 additional respondents were interviewed leading to a final sample size of 334 farmers operating 710 plots.

In a general view, from each county the distribution of villages was as follows; in four sub-counties three villages were selected and in one sub-county four villages selected, to yield 16 villages. The villages were selected from the two wards already selected in each sub-county.

2.6 Data Needs and Data Collection Methods

The study utilized both secondary and primary data; primary data were used to analyse objectives one, two and three; while secondary data were utilized to justify results obtained from the analysis.

Two focus group discussions (FGDs) were held, one in each County to obtain meaningful insight from the different stakeholders regarding the practices implemented in the region, production patterns, and historical trends on practices and outputs. Participants in the focus group included 20 farmers (10 male and 10 female) and County agricultural extension officers in each County. The farmers were evenly distributed among the ten Sub-Counties sampled in the study. In each County the discussions were held in two separate groups one for the male participants and another for female participants. The discussions were open with the views from each farmer noted down, moderated with a guideline in form of a checklist containing open-ended questions (see appendix 5).

Data were collected through a semi-structured questionnaire that was programmed in Survey CTO to enable utilization of tablets to collect data. Trained field enumerators assisted in the collection of the data during face to face interviews with farmers. Interviews with key informants from KALRO and extension officers in two regions helped provide a better understanding of the area and the possibility of getting adopter and non-adopters in the area. After training of the enumerators, a pilot study was conducted in Kiambu County to test the reliability of the data collection tool. Total of 30 farmers were interviewed during the pilot study. Kiambu County was selected since farmers within the County also engaged in similar practices as farmers in Kakamega and Vihiga Counties.

2.7 Data Analysis

After the data were collected, STATA version 14 software was utilized to estimate the multivariate probit, generalized ordered logit and multinomial endogenous treatment effect models.

2.8 Model Diagnostic Test

2.8.1 Proportion Odds Assumption

While using ordered logistic models, the proportional odds or parallel lines assumption has to be tested. The assumption states that the corresponding coefficients (expect the intercepts) ought to be the identical across the different logistic regression (as defined by the number of practices adopted), other than differences resulting from sampling variability (Williams, 2016). The Brant test was used to test for the assumption. The test (Table A1.1) revealed that most variables utilized to assess the extent of adoption violated the assumption, therefore a generalized ordered logit model was utilized to correct for the violation of proportional odds assumption.

2.8.2 Goodness of Fit of Generalized Ordered Logit

To test for goodness of fit of the generalized ordered logit, The Akaike information criterion (AIC), Bayesian information criterion (BIC) and McFadden's Pseudo R^2 was utilized to compare other models suitable for count data that is ordered logit model and Poisson model. The model with the lowest value of AIC and BIC and the highest value of McFadden's Pseudo R^2 is considered to be the model that best fits the data. The generalized ordered logit model had the lowest AIC and BIC value and the highest McFadden's Pseudo R^2 as presented in Table A1.2.

2.8.3 Multicollinearity

Multicollinearity arises when a linear relationship exists between the independent or explanatory variables. To check for multicollinearity in the data the variance inflation factor (VIF) of the variables included in multivariate probit, generalized ordered logit and multinomial endogenous treatment effect model were calculated. Gujarati (2009) states that for any variable with VIF values greater than 10 is evidence of multicollinearity. There was no evidence of multicollinearity across the three models considered in the study (Table A1.3, A1.4 and A1.5)

2.8.4 Heteroscedasticity

Following Woodridge (2010), the Breusch-Pagan test was utilized to check if the variance across the error terms in the multivariate probit, generalized ordered logit and multinomial endogenous treatment effect models were constant. The results (Table A1.6, A1.7 and A1.8) indicate that we fail to reject the null hypothesis, there is no constant variance across the error terms in the models. To correct for heteroscedasticity, robust standard errors were utilized across the three models.

CHAPTER THREE

3.0 Prospects and Constraints in Smallholder Farmers' Adoption of Multiple Soil Carbon Enhancing Practices in Western Kenya

Abstract

Most smallholder farmers in sub-Saharan Africa (SSA) are affected by low soil fertility, land degradation and climate change-related shocks such as drought. These problems lead to low productivity and low household income. In addition, the adoption of soil carbon enhancing practices (SCEPs) remains low in Western Kenya. This study analyses the factors that influence the probability and extent of adoption of SCEPs in Western Kenya utilizing plot-level information, socioeconomic characteristics and external supporting factors. Multivariate probit model (MVP) and generalized ordered logit were utilized to assess the adoption of multiple SCEPs and the extent of adoption respectively. Results indicate that the adoption of SCEPs is correlated, suggesting interrelation in farmers' adoption decisions. Both the MVP and generalized ordered probit results indicate that the probability and extent of adoption of SCEPs are influenced by plot-level characteristics, literacy level, access to agricultural credit, agricultural group membership, participation in the market, and gender of the household. The results imply there is a need to promote the SCEPs as a package since the practices are interrelated. Additionally, there is a need to strengthen existing farmer groups, improve education level and ensure gender inclusivity in activities related to the promotion of practices that enhance the adoption of SCEPs.

Keywords: soil carbon enhancing practices; soil fertility; multiple adoption; generalized ordered logit; multivariate probit; Western Kenya.

3.1 Introduction

In most sub-Saharan Africa (SSA) countries', agricultural policies and areas of focus have targeted poverty reduction, the achievement of food security and the mitigation of effects resulting from climate change. Poverty, food insecurity and effects of climate change are evident among most African rural areas, where the main source of livelihood is farming. In Kenya, wheat and maize are considered the two most significant cereal crops (GoK 2008; Mati *et al*., 2011; Gitau *et al*., 2011). However, it has been predicted that by 2020 the income and yield from maize and wheat in SSA countries will have reduced by 50 percent (Mwungu *et al*., 2018). This is of key concern considering that an increase in production level in Africa has been largely attributed to an increase in land under cultivation rather than enhanced productivity (Jayne *et al*., 2016). Additionally, increased land pressure and reduction in land size holding among small-scale farmers who account for 75 percent of maize production (IPCC, 2007), has constrained the ability of smallholder farmers to expand the area under production.

Due to the reduction in land sizes, continuous cropping has become a common practice amongst smallholder farmers. This has reduced fallowing, a practice that was common in earlier years thus leading to land degradation which eventually results in low productivity. In light of land degradation, low productivity, and high poverty level among smallholder farmers makes the achievement of food security to be a big challenge in Kenya. Variability in climate change exacerbates the situation. Recent studies have indicated that soil carbon enhancing practices (SCEPs) that help in carbon sequestration offer to be a low-cost solution to enhancing productivity (Li *et al*., 2013). SCEPs help increase the amount of soil organic carbon content which has been universally proposed to be a measure of soil quality and soil fertility (Amundson *et al*., 2015). Since soil is one of the leading sources of atmospheric carbon it is important to consider it in reducing the atmospheric carbon level (Lal, 2013; Lal *et al*., 2015).

Considering that most soils in Kenya are characterized by soil nutrient deficiencies, soil degradation and poor land management practices (Cavanagh *et al*., 2010; Kihara *et al*., 2017), adoption of SCEPs can be key in improving soil's structure and fertility. Moreover, SCEPs enhance the sustainability of soil functions that are critical for ensuring that ecosystems functioning is maintained and hence enhancing crops and livestock production (Bekele and Drake, 2003; Powlson *et al*., 2014). Sommers *et al*. (2018) indicate that the long-term effects of adopting soil carbon sequestration practices may be low in reducing atmospheric carbon as the soil acts as both a sink and source of carbon. However, the emphasis on the short-term effects on enhancing farmer's productivity cannot be overlooked as the practices enhance soil fertility and subsequently productivity. Additionally, several field trials have shown the potential of adopting SCEPs in enhancing productivity and reducing land degradation (De Ponti *et al*., 2012; Otinga *et al*., 2013; Adamtey *et al*., 2016; Kafesu *et al*., 2018).

This study seeks to contribute to the limited literature on factors that influence the adoption of SCEPs utilizing plot-level information, household socioeconomic characteristics, and external supporting factors. The specific objective of the study was to assess factors that influence the adoption of SCEPs and the extent of adoption. In the present study, the extent of adoption was measured by the number of practices that a farmer has adopted. Previous studies have focused on some of the SCEPs practices but have separately analysed the components (e.g., intercropping and mulching) by using univariate models. This approach ignores the fact that the adoption of these technologies is path-dependent, where the decision to adopt a practice is partly dependent on earlier practices adopted. At the same time, these practices act as substitutes or complements. Therefore, analysis of one practice independently without considering other practice can lead to biased results.

The SCEPs considered in this study include intercropping (maize-legume intercropping), mulching, farmyard manure (FYM) and inorganic fertilizer. The four practices were considered due to their immediate impact in improving soil condition and enhancing productivity compared to other practices such as agroforestry and use of grass strips whose benefit take longer to be realized in terms of enhancing soil fertility and crop productivity.

3.2 Analytical Model

When analysing factors that may facilitate or inhibit the adoption of technology, univariate models such as logit and probit are utilized which consider a single equation for each SCEP technology. However, using a univariate model is disadvantageous in that it does not consider the interdependence of adopting technologies (Telklewold *et al*., 2013; Muriithi *et al*., 2018; Mwungu *et al*., 2018). Moreover, univariate models fail to account for the fact that farmers are more willing to adopt an additional practice based on the experience and benefits derived from the previously adopted technologies. Univariate models, therefore, fail to acknowledge that farmers adopt several technologies either to substitute or complement a previous technology to solve an underlying problem. However, the multivariate probit model (MVP) takes into account the simultaneous adoption of multiple SCEPs technologies by considering the correlation among the disturbance terms that may arise from the relationship between the four practices.

3.2.1. A Multivariate Probit Model

For this study, MVP helped overcome the main disadvantages of univariate modes while considering multiple practices and access the influence of plot-level information, socioeconomic, and external supporting factors on the prospects of adopting SCEPs.

The multivariate model can be modelled from the random utility framework. A farmer i will adopt a SCEP in plot p if and only if U_b that represents the benefit of adopting a SCEP is greater than U_a is the benefit derived from traditional or existing practice. However, B_a denotes a farmer's decision to adopt mulching (1), intercropping (2), FYM (3) and inorganic fertilizer (4). Thus, a farmer will adopt a practice on plot p if $Y_{ipa}^* = U_b^* - U_a > 0$. The net benefits that a farmer derives are influenced by the observed plot-level information, socioeconomic, and external supporting factors X_{ip}' and the error term ε_{ip} as illustrated in Eq. 7:

$$Y_{ipa}^* = X_{ip}' B_a - \varepsilon_{ip} \ (a = 1, 2, 3, 4) \tag{7}$$

Where Y_{ipa}^* a latent variable associated with the benefits of SCEP a and farmer i in plot p can be translated into a binary outcome equation for each choice of SCEP as shown in Eq. 8:

$$Y_{ipa} = 1 \text{ if } Y_{ipa}^* > 0, \mathit{and\ 0\ otherwise} \ (a = 1, 2, 3, 4) \tag{8}$$

The MVP ε_{ip} is the error term that follows a multivariate normal distribution (MVN) each with zero conditional mean and variance-covariance matrix Ω, where Ω has values of 1 on the leading diagonal and correlation ρip = ρip as off-diagonal elements as shown in Eq. 9:

$$\Omega = \begin{bmatrix} 1 & \rho 12 & \rho 13 & \rho 14 \\ \rho 21 & 1 & \rho 23 & \rho 24 \\ \rho 31 & \rho 32 & 1 & \rho 34 \\ \rho 41 & \rho 42 & \rho 43 & 1 \end{bmatrix} \tag{9}$$

The off-diagonal elements in the variance-covariance matrix represent the unobserved correlation between the disturbance terms associated with the different types of SCEPs. The correlation matrix helps us in identifying if the practices are either substitutes or complements. The model was estimated based on the maximum likelihood estimation. Additionally, to guarantee the accuracy of the model, the number of random draws was increased to 30 which is approximately equal to the square root of the valid number of plot observation utilized in the estimation rather than the default five draws for MVP in Stata.

3.2.2. Generalized Ordered Logit

The MVP model, as defined above, solely takes into consideration the probability of adopting the SCEPs. However, it does not take into account that farmers can adopt more than one practice, thus not taking into consideration the intensity of adoption. Following Wollni *et al.* (2010), Telklewold *et al.* (2013) and Muriithi *et al.* (2018) intensity of adoption can be measured by the total number of practices that a farmer has implemented in their plot. Generalized ordered logit model helps us assess the factors that might influence the extent of adoption.

A Poisson regression model would have been suitable for the analysis since the dependent variable – the extent of adoption – is a count variable. Nevertheless, the approach assumes that the probability of adopting any of the technologies is the same. In actual sense the likelihood of adopting the first technology may differ from the likelihood of adopting a second and any subsequent technology as a farmer has been exposed to the advantages of the technologies and information regarding the technologies; and has thus increased probability to adopt more technologies compared to a farmer that has not adopted any technologies (Teklewold *et al.*, 2013a; Muriithi *et al.*, 2018). Additionally, the ordered probit/logit model would have been suitable to analyse the data. However, the data violated the model's proportional odds assumption which states that the corresponding coefficients (expect the intercepts) ought to be identical across the different logistic regression (as defined by the number of practices adopted), other than differences resulting from sampling variability (Williams, 2016). Generalized ordered logit relaxes the assumption and is more powerful than ordered logit as it helps analyse factors that might influence a farmer adopting practices stepwise (Williams, 2016). It thus helps in determining what enhances or constrain a farmer from adopting the first practice compared to farmers that have adopted no practice, from the first practice to the second, from the second to the third practice and thereafter.

3.3 Description of Variables

3.3.1. Dependent Variables

The dependent variables (SCEPs) considered were intercropping (maize-legume intercropping), mulching, FYM, and inorganic fertilizer. Maize-legume intercropping is one of the practices that help in soil carbon sequestration (Lal 2013) while enhancing fertility through nitrogen fixation, suppressing weeds and reducing the incidence of pest and diseases (Muriithi *et al*., 2018). Use of FYM denotes the application of dried livestock waste to farming plots. Use of manure is essential in supplying nitrogen (N), potassium (K), and phosphorus (P) which are important macro-nutrients to the soil (Otinga *et al*., 2013). Additionally, it enhances soil fertility and organic matter content. Use of inorganic fertilizer is also important in improving productivity as it has an immediate impact in availing nitrogen (N), phosphorus (P), and potassium (K) to the plant (Otinga *et al*., 2013). Efforts to fight *Striga* infestation in Western Kenya showed that use of inorganic fertilizer was useful in suppressing the weed by correcting phosphorus (P) deficiency and this resulted in increase in maize yield (Gacheru and Rao, 2001; Muriithi *et al*., 2018). Mulching is useful in enhancing soil moisture, organic matter after the decay of crop residue and assists in decreasing surface soil erosion and preserve soil water content (Lal, 2013). The four practices taken together are thus important in improving soil fertility, restoring degraded farmland, controlling soil erosion, enhancing soil carbon and are also important measures in mitigating and adapting against climate change effects.

3.3.2. Independent Variables

3.3.2.1. Plot Characteristics

Plot characteristics are important variables that influence adoption, as shown by Teklewold *et al*. (2013a) and Manda *et al*. (2015). The plot characteristics considered were plot size, distance to the plot in walking minutes, farmers' perception of the plot fertility (assessed as either fertile or not), soil erosion (assessed as either affected by soil erosion or not) soil slope (assessed as either gentle, medium or steep) and soil type (assessed as either sandy, loam or clay). Plot size has been established to influence the adoption of certain practices such as the use of inorganic fertilizer. For instance, smallholder farmers with slightly large farms have a lower probability of applying inorganic fertilizer as it is costly to apply on the entire farm while at the same time it can be positive as the land size is utilized as a proxy to wealth (Ng′ang′a *et al.*, 2016).

A plot's slope is a determinant of a farm susceptibility towards soil erosion. It has been established that farmers owning farms with steep slopes invest more in practices that minimize erosion risk and enhance soil fertility. Ndiritu *et al.* (2014) indicate that farmers have a higher probability of applying fertilizer and manure on steep slopes compared to flat slopes. Kassie *et al.* (2013) and Manda *et al.* (2015) indicate that a farmer's perception towards their plot fertility and susceptibility to soil erosion influence their likelihood to adopt inorganic fertilizer and manure. Kafesu *et al.* (2018) note that farmers' rating of plot fertility is consistent with results from lab-based soil analysis, justifying farmer's accuracy in understanding their farm characteristics. This study hypothesizes that farmers who perceived their plots to be of low soil fertility are likely to adopt SCEPs compared to farmers that perceive their plots to be fertile.

Distance from the homestead to the plot can be used as a proxy for the attention and monitoring efforts that a farmer gives to a plot (Teklewold *et al.*, 2013b). Therefore, plots further from the homestead are expected to receive less attention and monitoring. In addition, the distance increases both transportation and transaction cost for the plots that are further from the homestead (Kassie *et al.*, 2014). Therefore, the cost of transporting bulky inputs to further plots increases, thus reducing the probability of adopting practices, for instance, application of manure (Telklewold *et al.*, 2013).

3.3.2.2. External Support Factors

Three factors considered were access to agricultural extension, credit and agricultural group membership. Access to agricultural extension was measured by farmers contact with private and public extension agents and whether the farmers utilized the information they obtained from the extension agents. Contact with agricultural extension agents has been shown to influence the adoption of agricultural technologies (Teklewold *et al.*, 2013b; Ndiritu *et al.*, 2014). However, the level of trust that farmers have in the agents determines the probability of farmers adopting the practices (Manda *et al.*, 2015). To correct for this, the study assessed whether farmers utilized the information they obtained as a proxy of their trust level in the agricultural agents.

Agricultural groups are important sources of social capital through collective action. They also provide avenues for information dissemination and opportunity for farmers to learn from each other, thereby acting as extension agents. Lastly, the study considered access to agricultural loans. Access to credit was also considered with a specific interest in agricultural loans. To assess the access to agricultural loans, the farmers were asked whether they accessed any loan/credit within the last one year and the purpose of the loan. This helped in determining whether the loan was for agricultural purpose or not.

3.3.2.3. Location Characteristics

Local markets act as both input and output markets. The distance to the local market is associated with transport and transaction cost of purchasing inputs and transporting their harvest to the market. Additionally, Kassie *et al.* (2013) note that distance to the market can influence the availability of information and new technologies.

3.3.2.4. Household Characteristics

Feder *et al.* (1985) noted that household characteristics influence the adoption of agricultural technologies. Some of the key household characteristics considered were age, gender, education level, experience in farming, the main occupation of the household head, household size, literacy level, and human dependency ratio. A farmer's age can impact the adoption of agricultural technologies as older farmers are perceived to be more experienced than younger farmers (Kassie *et al*., 2008; Kassie *et al*., 2013). However, age can be a poor measure of a farmer farming experience as it assumes that people start farming from a young age, therefore neglecting the fact that some farmers start farming after retirement from formal employment. To cater for this, farmer's experience in farming in years was utilized instead. A household that has educated household heads are likely to be more aware and appreciative of new technologies (Ndiritu *et al*., 2014; Kamau *et al*., 2014). However, considering only the education of the household head ignores the influence of other household member's education level. A household literacy level, which is computed after considering the education level of all household members, is preferred since other household members can influence the household head decision-making process (Mwungu *et al*., 2018).

Household size (the number of people in a household) is often utilized as a proxy for labour endowment (Kassie *et al*., 2008; Ndiritu *et al*., 2014; Manda *et al*., 2015). The larger the household size, the more the labour. However, household size may not be a true reflection of the availability of labour since a household may have more of its members' either younger (1-14 years) or older (above 65 years) and these members are not considered to be of active working age. Thus, the human dependence ratio was computed as it takes into consideration the different age groups of the household members. Lastly, the farmer's main occupation influences their time allocation to farming activities. If the household head main occupation is farming, that an indication that they spend most of their time in farming activities and thus may be more inclined to adopt some practices (such as mulching and manure) that may be time-consuming to implement.

3.3.2.5. Resources Constraints

To measure a household resource constraint, the study incorporates livestock ownership in tropical livestock unit (TLU) and the probability of a household being poor as measured by a wealth scorecard. The wealth scorecard is adopted from Schreiner (2007), where the farmers are asked a total of ten questions that help rate the poverty likelihood of the household. The likelihood is then converted into a dummy variable where 1 is the household is most likely not poor and 0 the household is most likely poor.

3.4 Results and Discussion

3.4.1. Descriptive Statistics

Table 2 presents summary statistics for the variables utilized in the analysis of adoption and the extent of SCEPs. Inorganic fertilizer (74 percent) intercropping (48 percent) were the most adopted practices at the plot level. While FYM and mulching adoption rates were 42 percent and 6 percent respectively. The plot-level variables include plot size, distance to plot farmers' perception of plot fertility and erosion, soil type and slope type. The average size of the plot and distance to the plot in walking minutes were 0.75 acres and 7 minutes, respectively. On average the farmer's age was 53 years, with 76 percent being male and with a farming experience of about 23 years. Additionally, 70 percent of the farmers were fulltime farmers.

Table 3.1 Definition and Summary Statistics of Variables in the Analysis

Variable	Description of Variable	Mean	SD
Practices adoption dummies (n= 640)			
Intercropping	Percent of households that have adopted intercropping	48%	
Farmyard manure	Percent of households that have adopted farmyard manure	42 %	
Inorganic fertilizer	Percent of households that have adopted inorganic fertilizer	74 %	
Mulching	Percent of households that have adopted mulching	6 %	
	Plot- Level Variables dummies (n= 640)		
Plot Size	Plot size in acres	0.75	0.71
Distance to Plot	Distance in walking minutes	6.63	23.42
Fertility Perception	Percent of plots that Household perceive to be Fertile	74 %	

Soil Erosion Perception	Percent of plots that Household perceive to be affected by soil erosion	73 %	
	1=Gentle	21 %	
	2= Medium	70 %	
Slope	3=Steep	9 %	
	1=Sand	10 %	
	2= Loam	83 %	
Soil type	3=Clay	7 %	
	Socioeconomic variables (n = 334)		
Age of HHH	Age of household head in years	53	14
Gender of the HHH	Percent of male HHH	76 %	
Occupation of HHH	Percent of HHH whose main occupation is farming	70 %	
Farming experience of HHH	Household head farming experience in years	23	15
Dependency Ratio	Proportion of dependents in the household	0.87	1.04
HH Size	Number of people in a household	5	2
Literacy Level	Household literacy level	0.17	0.13
TLU	Tropical livestock unit	3.22	4.12
Wealth	Percent of households classified as not poor	56 %	
Distance to Local Market	Distance in walking minutes	30.40	32.38
External Support Factors			
Crop Market Participation	Percent of households that sold their crop produce	57 %	
Agricultural Group Membership	Percent of households that are members of an agricultural group	34 %	
Access Agricultural credit	Percent of households that have access to agricultural credit	22 %	
Access Extension	Percent of households that have access to extension	62 %	

Note: HHH refers to Household Head, and HH refers to Household

Source: Survey Data (2018)

The average household size was 5 people with a dependency ratio of 0.87, literacy level of 0.17 and the nearest local market was about 31 minutes of walking. 56 percent of the household would be classified as non-poor with an average Tropical Livestock Unit (TLU) of 3.22. At least 34 percent of the farmer belonged to an agricultural group and 22 percent had access to agricultural credit while 62 percent reported having accessed extension services. About 57 percent of the farmers reported having sold at least one produce from their farms in the last 12 months.

3.4.1. Complementarity and Trade-off among SCEPs

Table 3.2 Complementarities and Substitutability of SCEPs: Correlation Coefficient of Error Term Matrix

	Mulching	Intercropping	Farmyard Manure	Inorganic Fertilizer
Mulching	1			
Intercropping	0.1791 (0.971)	1		
Farmyard Manure	-0.1125 (0.1051)	0.1529 ** (0.0638)	1	
Inorganic Fertilizer	0.0903 (0.1054)	0.5946 *** (0.0530)	0.2831*** (0.0670)	1

Notes: Robust Standard errors in parenthesis.
Likelihood ratio test of regression interdependence Chi-Square (6) = 96.898***
N=640. Statistical significance at *p<0.1, **p<0.05, ***p<0.01

Source: Survey Data (2018)

Table 3 presents the results on the substitutability and complementarities of SCEPs. The likelihood ratio test [Chi^2 (6) =96.898, p=0.0000] was significant, thus rejected the null hypothesis that there was zero association amongst the covariance of the error term in the equations. The results imply that there was a positive correlation coefficient between intercropping and FYM, intercropping and inorganic fertilizer, and between FYM and inorganic fertilizer. This indicates that there are complementarities between intercropping and FYM, intercropping and inorganic fertilizer, and between FYM and inorganic fertilizer. This is important because it indicates farmers use a combination of the practices to enhance their productivity. The results are consistent with Marenya and Barrett (2007) and Muriithi *et al.* (2018) that smallholder farmers in Kenya use manure and inorganic fertilizer as complements.

3.4.2 Determinants of Adoption of SCEPs MVP Model Results

The Wald Chi-Square [Chi^2 (68) =250, p=0.0000] statistics for the overall significance of the model was significant, justifying the use of the MVP for the analysis. Additionally, the use of MVP was reaffirmed by the significance of the LR test [Chi^2 (6) =96.898, p=0.0000] thus rejecting the null hypothesis that the agricultural practices under consideration (mulching, FYM, intercropping, and inorganic fertilizer) are independent. The two tests indicate that the adoption of these practices is interdependent and the use of univariate regression (logit and probit) would have yielded inefficient estimates.

Table 4 below presents the MVP regression results showing how plot characteristics, farmer characteristics, household characteristics and resources, external support factors influence the adoption of SCEPs. Plot size had a significant and positive effect on the implementation of intercropping and the use of inorganic fertilizer. This is consistent with findings of Ndiritu *et al*. (2014), Manda *et al*. (2015) and Muriithi *et al*. (2018) who stated that increase in plot size increases the likelihood of applying inorganic fertilizer and implementing intercropping with legumes to enhance soil fertility. On the one hand, the distance from the homestead to the plot had a negative and significant influence on the adoption of FYM. On the other hand, it had a positive and significant influence on the adoption of inorganic fertilizer. This suggests that farmers utilized manure in plots nearer to the homestead due to its bulkiness and labour requirements associated with spreading manure in the plot; while inorganic fertilizer which is less bulky than manure was utilized in plots further from the residence. Waithaka *et al*. (2007) state that application of manure is preferred in plots nearer due to its labour requirement in carrying and spreading, for instance Castellanos-Navarrete *et al*. (2015) note that its requires 2 man-days to collected 1kg of nitrogen (N) and 10 man-days to collect 1kg of potassium (P).

Plots perceived to be more fertile had a higher likelihood of having mulching implemented in them. This can be attributed to the fact that mulching is effective in improving soil condition by increasing soil organic matter and reducing soil water evaporation thus enhancing soil structure and soil fertility (Muriithi *et al*., 2018). However, interpretation of this result is approached with caution since enhanced soil fertility can be endogenous to mulching since the practice improves soil conditions and fertility. Therefore, without considering historical information of the plot, a causal inference of this result can be misleading.

Plots that were perceived to have been affected by soil erosion were more likely to have intercropping and inorganic fertilizer implemented on them, but mulching was less likely to be implemented on them. Applying inorganic fertilizer can be explained by the need to improve soil fertility to increase the productivity of the plots (Teklewold *et al*., 2013a). Adoption of intercropping was due to the ability of legumes in fixing nitrogen, thus enhancing soil fertility. The slope of the plot positively influenced the implementation of intercropping and application of inorganic fertilizer. Plots that had gentle and moderate slopes had a higher likelihood of having intercropping and inorganic fertilizer implemented in them compared to plots with steep slopes. This finding is contrary to previous studies by Ndiritu *et al*. (2014) who noted that farmers with steep slopes were less likely to adopt the practices compared with farmers that had plots with gentle and moderate slope. This can be attributed to farmers being risk averse.

Table 3.3 Adoption of SCEPs: Multivariate Probit Model (MVP) Results

	Mulching		Intercropping		Farmyard Manure		Inorganic Fertilizer	
	Coef.		Coef.		Coef.		Coef.	
Plot Size (in acres)	0.01	(0.11)	0.36***	(0.08)	-0.00	(0.08)	0.51***	(0.12)
Distance to Plot	-0.00	(0.01)	-0.00	(0.00)	-0.01***	(0.00)	0.03***	(0.01)
Fertility Perception	0.39*	(0.24)	-0.10	(0.12)	0.05	(0.12)	-0.04	(0.13)
Soil Erosion Perception	-0.52 ***	(0.18)	0.44***	(0.12)	-0.09	(0.12)	0.24*	(0.13)
Slope (Steep = Base Category)								
Plot Slope Moderate	-0.45	(0.28)	0.48***	(0.18)	0.07	(0.19)	0.53***	(0.20)
Plot Slope Flat	-0.06	(0.30)	0.80	(0.21)	-0.16	(0.21)	0.53**	(0.23)
HH Farming Experience	-0.01***	(0.01)	-0.00	(0.00)	-0.00	(0.00)	-0.01***	(0.00)
HH Main Occupation	-0.28	(0.18)	-0.09	(0.12)	0.40***	(0.12)	-0.00	(0.13)
TLU	0.04***	(0.01)	-0.01	(0.01)	-0.01	(0.01)	-0.01	(0.01)
Dependency Ratio	0.15**	(0.07)	-0.03	(0.06)	0.01	(0.06)	-0.07	(0.06)
Literacy Level	1.71**	(0.87)	-0.83*	(0.45)	0.96**	(0.49)	-0.06	(0.47)
Crop Market Participation	0.29	(0.18)	-0.32***	(0.11)	-0.33***	(0.11)	-0.10	(0.12)
Agricultural Group Membership	-0.17	(0.23)	0.37***	(0.12)	-0.16	(0.12)	0.14	(0.13)
Access Agricultural Loan	0.11	(0.23)	-0.06	(0.13)	-0.61***	(0.14)	-0.20	(0.15)
Access Extension	-0.14	(0.21)	-0.14	(0.12)	-0.01	(0.12)	0.11	(0.13)
Distance to Local Market	-0.01	(0.00)	0.00	(0.00)	-0.00	(0.00	0.00	(0.00)
Wealth Category	-0.14	(0.24)	-0.10	(0.12)	0.05	(0.12)	-0.21	(0.13)

Note: Robust standard error in parenthesis, Statistical significance at *p<0.1, **p<0.05, ***p<0.01.
N=640 (from Sample Size of 334 Households)
Log Pseudo likelihood = -1207.7895Wald Chi-Square (68) = 250.44 ***.
Likelihood ratio test of regression interdependence Chi-Square (6) = 96.898***

Source Survey Data (2018)

Experienced farmers were less likely to adopt mulching and use of inorganic fertilizer. This denotes that experienced farmers were less likely to adopt new technologies such as mulching and inorganic fertilizer as compared to farmers that just started farming (Manda *et al.*, 2015). If household heads main occupation was farming increased their probability of adopting application of manure. Considering that manure application is labour intensive, full-time farmers had more time on their disposal to transport and apply the manure on their plots and hence were more likely to adopt manure.

The livestock wealth (in TLU) and human dependency ratio positively influenced the adoption of mulching. Increase in the number of livestock kept in a household increases the feed requirement to sustain the animals. This leads to an increase in animal feed residue from plant straws and stover that are suitable materials for organic mulching (Tey *et al.*, 2014). Literacy ratio had a significant and positive influence on the adoption of mulching and FYM, while it had a negative influence on the adoption of intercropping. A plausible explanation for the negative relationship can be since most households in Western Kenya have small pieces of land and have been practicing intercropping for a long time; thus, as people get educated they stop practicing intercropping as they consider it as an old method of farming. This is in agreement with the finding of Kassie *et al.* (2014) and Ndiritu *et al.* (2014) who stated that level of education negatively influenced the adoption of intercropping. The positive influence of literacy level on mulching and FYM might be because households with a high literacy ratio were more likely to be searching for new information (Mwungu *et al.*, 2018); and therefore had more knowledge on the benefit of adopting newer technologies (mulching and FYM) on enhancing the formation of soil aggregated with the improvement of porosity, infiltration, and water-holding capacity (Gilley *et al.*, 2002).

Farmers that belonged to an agricultural group were more likely to adopt intercropping. This is because of information sharing between members of a group on the benefits and cons of intercropping (Kassie *et al*., 2008). Additionally, farmers that had accessed agricultural loans were less likely to adopt FYM. An explanation for the negative association is that farmers that access to loans were able to adopt other practices that require a larger capital outlay such as irrigation.

Access to markets measured in walking minutes to the local market negatively influenced the adoption of mulching which is in agreement with the finding of Tey *et al*. (2014). Distance to the market can be utilized as a proxy to information and technology (Kassie *et al*., 2013); thus, farmers nearer the market had access to information regarding mulching and its benefits explaining their adoption rate. Farmers that participated in the market were less likely to adopt intercropping and use of FYM. A plausible explanation is that most farmers in the region participating in markets were selling more of other crops such as bananas, African leafy vegetables and sugarcane (cash crop in Kakamega County) or tea (cash crop in Vihiga County) explaining why they were less likely to adopt intercropping

3.4.3. Determinants of the Extent of Adoption: Generalized Ordered Logit Results

The generalized ordered logit assumes that the effect of a variable may not be uniform across each level of the dependent variable. In this case, it means that the effect of an independent variable is not uniform across the number of practices adopted. A variable may, therefore, influence a farmer to adopt the first practice in their plot but may be ineffective in influencing them to adopt the second and the third practice.

Table 3.4 Extent of Adoption of SCEPs: Generalized Ordered Logit Results

Variables	Level 1 (0 to 1 practice) Coef.		Level 2 (1 to 2 practices) Coef.		Level 3 (2 to 3 practices) Coef.	
Number of Plots	-0.41***	(0.09)	-0.41***	(0.09)	-0.41***	(0.09)
Plot Size (in acres)	1.23***	(0.30)	0.54***	(0.16)	0.14	(0.15)
Distance to Plot	-0.00	(0.00)	-0.00	(0.00)	-0.00	(0.00)
Soil Erosion Perception	0.22	(0.25)	0.48**	(0.20)	-0.24	(0.23)
Slope (Steep = Base Category)						
Slope Moderate	0.57*	(0.29)	0.57*	(0.29)	0.57*	(0.29)
Slope Flat	0.61*	(0.34)	0.61*	(0.34)	0.61	(0.34)
Soil Type (Clay=Base Category)						
Soil Type Loam	0.36	(0.27)	0.36	(0.27)	0.36	(0.27)
Soil Type Sandy	0.41	(0.34)	0.41	(0.34)	0.41	(0.34)
TLU	0.01	(0.02)	0.01	(0.02)	0.01	(0.02)
Gender of HH	-0.52***	(0.19)	-0.52***	(0.18)	-0.52***	(0.18)
Age of HH	-0.01	(0.01)	-0.00	(0.01)	-0.01	(0.01)
Education level of HH	0.18	(0.18)	0.18	(0.18)	0.18	(0.18)
Household size	-0.00	(0.04)	-0.00	(0.04)	-0.00	(0.04)
HH Main Occupation	0.05	(0.18)	0.05	(0.18)	0.05	(0.18)
Crop Market Participation	-0.20	(0.16)	-0.20	(0.16)	-0.20	(0.16)
Access Agricultural Loan	-0.66***	(0.19)	-0.66***	(0.19)	-0.66***	(0.19)
Wealth Category	-0.03	(0.19)	-0.03	(0.19)	-0.03	(0.19)
Agricultural Group Membership	0.72***	(0.27)	0.37*	(0.20)	-0.06	(0.21)
Distance to Local Market	-0.00	(0.00)	-0.00	(0.00)	-0.00	(0.00)
_cons	1.85	(0.58)	0.88	(0.55)	-0.04	(0.56)

Note: Robust standard error in parenthesis, Statistical significance at *p<0.1, **p<0.05, ***p<0.01.
N=640 (from Sample Size of 334 Households)
Log Pseudo likelihood = -791.02283 Wald Chi-Square (25) = 97.29 *** Pseudo R^2 = 9.92 %

Source: Survey Data (2018)

There were four practices under consideration and thus five possible categories– zero practices, one practice, two practices, three practices, and four practices adopted. Along with the five categories, 103 plots had zero practice, 137 plots had one practice, 252 had two practices, 147 plots had three practices, and one plot had all the four practices implemented. However, for the model to run effectively, one of the requirement is that all categories need to have at least 30 observations; thus the plot with all the four practices implemented was merged with the plots that had three practices, and the observations in that category increased to 148 plots (147+1= 148). The results, therefore, contain three levels; level one moving from zero practice to one practice, level two moving from one practice to two practices, and level three moving from two practices to three practices. The results for the generalized logit model are presented in Table 5.

The number of plots a farmer owns had a significant and negative influence on the number of practices adopted. This could be an indication that farmers first adopted SCEPs on plots that they thought are of low soil fertility. Plot size positively influenced the extent of adoption to level two. The larger the plot a farmer had the higher the probability of them adopting the first and the second practices. This is consistent with the finding of Barungi *et al*. (2013) and Ndiritu *et al*. (2014) that farmers with the larger plot are more likely to adopted agricultural practices to enhance the soil condition of the plot.

Farmers' perception on their plot being affected by soil erosion was not strong enough to motivate them to become adopters but would influence them to adopt a second practice if they were already adopters. Mishra *et al*. (2018) indicate that farmers that are adopter of a given package of technologies have already developed a positive attitude about the practices are thus more likely to adopt more practices than non-adopters as they are motivated by the positive impact of the previously adopted practices. The type of slope of the plot had a significant, positive and uniform effect across the three levels. Farmers whose plot have gentle and moderate slopes compared to farmers with steep slopes had a higher probability of adopting more SCEPs. This contradicts the finding by Carlisle (2016) and Soule *et al*. (2000) who found that plots with sleeper slope and highly erodible lands were more likely to implement soil conservation practices. However, a plausible explanation is that farmers in Western Kenya are risk averse.

The results show that access to agricultural loan had a significant and negative influence on the number of practices adopted. A plausible explanation for this can be that farmers that have access to agricultural loans have enough capital to adopt other capital-intensive practices such as irrigation and not SCEPs that are low-cost practices. Additionally, female-headed households had a higher probability of adopting more SCEPs compared to male-headed households.

Membership to an agricultural group positively affected the number of SCEPs adopted. Being a member of an agricultural group increased the likelihood of a farmer becoming adopters (adopting the first practice) and also adopting an additional practice. However, it does not influence them adopting the third practice. A possible explanation is that once a farmer becomes a member of a group they get information on the need of adopting SCEPs; however, after they experience the benefits of adoption they will more likely to adopt the third practice due to the benefits of the practices rather than them having increased information flow from being member of an agricultural group. Therefore, indicating the initial significance of social capital on affecting adoption of SCEPs.

3.3 Conclusion and Policy Implications

In Western Kenya, farmers are faced with low farm income as a result of low yields emanating from low soil fertility and land degradation. Empirical evidence has shown that the adoption of SCEPs can play a significant role in solving some of the aforementioned problems. The study, however, acknowledged that the adoption of practices can be complementary or a substitute. The study utilized MVP to analyse the adoption of multiple SCEPs and generalized ordered logit to access the extent of adoption as measured by the number of practices adopted.

The correlation results indicate a high complementarity between the SCEPs, reflecting the interdependence between agricultural practices adoption. This proves that the study eliminates the potential biases that would have resulted if each practice was studied separately. The complementarities intercropping and FYM, intercropping and inorganic fertilizer, and between

FYM and inorganic fertilizer is an indication that policymakers and extension service providers should promote the adoption of agricultural technologies as a package instead of promoting a single technology at a time.

Results of the MVP model show that plot characteristics and household characteristics influence the probability of adopting SCEPs. In particular, farmer perception on soil erosion perception, distance to the plot, the slope of the plot, and literacy level are key in the adoption of multiple SCEPs. Additionally, the number of SCEPs adopted is influenced by external support services and gender of the household, plot characteristic namely; plot size, and slope of the plot.

The results acknowledge that the adoption of SCEPs is knowledge-intensive in nature, thus an indication that one of the strategies to enhance adoption should include strengthening the existing farmer groups to enhance capacity building. This is because enhanced access to information will greatly encourage adoption. The importance of plot characteristics on adoption is an indication that incorporation of scientific soil testing in helping farmers to understand their soil characteristics better will help in the adoption of specific low-cost SCEPs that enhance soil fertility. Key actors (research institutions, local governments and private sectors companies) involved in the promotion of SCEPs need to find appropriate combinations of technologies to help in solving farmers' underlying problem as some of the practices are adopted as complements.

CHAPTER FOUR

4.0 Does the Adoption of Soil Carbon Enhancing Practices Pay Off? Evidence on Maize Yields from Western Kenya

Abstract

Soil carbon enhancing practices (SCEPs) have been proven to be low-cost solutions in enhancing agricultural productivity and alleviate the detrimental effects of climate change. These practices can be adopted as complementary or as substitute practices due to their associated ecological benefits and cost. In view of this, there is limited literature on the impact of adopting a combination of SCEPs since their effect may be lower or higher than individual technologies. A structured survey was utilized to collect data from 334 households in Western Kenya. The study utilized the multinomial endogenous treatment effect model to assess the determinants and impact of adopting SCEPs on maize yield. The results reveal that adoption is influenced by plots specific characteristics (distance to the plot and tenure system), external support factors (access to credit and farmers' participation in markets), tropical livestock units and literacy level. In addition, the results showed that adoption of farmyard manure, intercropping, and intercropping and farmyard manure combination had a significant and positive impact on maize yield. This implies that there is a need to promote SCEPs adoption among smallholder farmers given its positive impact and associated low cost of implementation.

Keywords: Maize yields; low productivity; soil carbon enhancing practices; multinomial endogenous treatment effect; Western Kenya.

4.1 Introduction

By the year 2050, sub-Saharan Africa's (SSA) population is expected to double to nearly 2 billion people (FAO, 2017). The projected population growth is a concern considering SSA's inability to feed its current population (FAO, 2017). Agricultural production in SSA is currently characterized by sub-optimal use of inputs and low productivity (Lilyan *et al*., 2004; FAO, 2017). The total production of most staple foods across SSA has been on the rise as a result of increased land under production as opposed to increased productivity (Jayne *et al*., 2016). Additionally, it is predicted that by 2020, income and yield from maize and wheat will have reduced by 50 percent among SSA countries (Mwungu *et al*. 2018) due to decline reduction in productivity. The decline in productivity can be associated to poor land management practices (such as mono-cropping), soil degradation and low soil fertility (Odendo *et al*., 2010; Jaetzold *et al*., 2010; Cavanagh *et al*., 2010; Kihara *et al*., 2017). The situation has been complicated by the increased land pressure and reduction in land size holding among small-scale farmers who contribute to 75 percent and 70 percent of maize production and marketed output respectively (IPCC, 2007; Olwande, 2012); thus, constraining their ability to expand the area under production. This leaves enhancing productivity among the SSA countries the only viable solution to meet the constantly increasing demand for food. Within the last 3 decades, most SSA countries have shifted their focus to attaining food security through agricultural research and adoption of relevant technologies such as green revolution and climate-smart agriculture (Kotu *et al*., 2017).

Studies have highlighted the need to embrace the green revolution due to its success in enhancing productivity among Asian countries (Hazell, 2009; Pretty *et al*., 2011; Jayne *et al*., 2016). The green revolution involves the adoption of irrigation, chemical fertilizer, improved seeds and pesticides (Pretty *et al*., 2011). Despite the green revolution successful implementation in Asia, it has had some negative consequences namely increased soil acidity and reduction in crop biodiversity (Altieri and Nicholls, 2005; Kotu *et al*., 2017). Currently, SSA food production systems are under threat due to the destruction of ecosystems services such as nitrogen fixation, biological control of weeds and pest, nutrient cycling and soil regeneration (Snapp *et al*., 2010; Pretty *et al*., 2011; Teklewold *et al*., 2013b). Considering the negative impact of the green revolution and the deteriorating ecosystem, the importance of transitioning to more sustainable agricultural technologies has been emphasized (Pretty *et al*., 2011; Hinrichs, 2014; Liverpool-Tasie *et al*., 2015).

Adoption of technologies that can assist farmers in mitigating and adapting to climate change effects are of importance, as most farmers are vulnerable to changing weather patterns (Bryan *et al*., 2013). For instance, in Kenya maize yield has been decreasing at a rate of 0.07 ton/ha/decade with 50 percent and 68 percent variance in maize yield is accounted for by variation in seasonal climate indices and precipitation respectively (Mumo *et al*., 2018). The importance of maize in Kenya cannot be underestimated as it is a significant crop in respect to food security and as well as a source of income at the household level (Gitau and Meyer, 2019). Some of the sustainable technologies that have the potential to sequester soil carbon, regenerate ecosystems, provide low-cost solution to enhancing productivity, and acts as mitigation and adaption strategy among smallholder farmers are soil carbon enhancing practices (SCEPs) (Li *et al*., 2013; Lal, 2004b; Lal *et al*., 2015).

SCEPs include soil erosion management practices, mulch farming (crop residue and cover crop), tillage methods (conservation tillage), soil fertility management (organic fertilizer and chemical fertilizer), water management (drip irrigation, soil water storage and runoff farming) and farming systems management (agroforestry, intercropping, and crop rotation) (Lal, 2013). Therefore, SCEPs can be treated as climate-smart technologies that help farmers adapt to the negative effects of climate change, improve agricultural productivity, mitigate greenhouse gasses emissions and enhance the sustainability of the ecosystem.

SCEPs help increase the amount of soil organic carbon content, which has been universally proposed to be a measure of soil fertility and quality (Amundson *et al.*, 2015). Moreover, SCEPs enhance the sustainability of soil functions that are critical for ensuring that ecosystems functions are maintained and hence enhancing crops and livestock production (Bekele and Drake, 2003; Powlson *et al.*, 2014). Sommers *et al.* (2018) indicate that the long-term effects of adopting soil carbon sequestration practices may be lower in reducing atmospheric carbon as the soil acts as both a sink and source of carbon. However, the emphasis on the short-term effects on enhancing farmer's productivity cannot be overlooked as the practices enhance soil fertility and subsequently productivity. Additionally, several field trials have shown the potential of adopting SCEPs in enhancing productivity and reducing land degradation (De Ponti *et al.*, 2012; Otinga *et al.*, 2013; Adamtey *et al.*, 2016; Kafesu *et al.*, 2018).

SCEPs technologies can be adopted as substitutes or in complementary (Teklewold *et al.*, 2013a; Gebremariam and Wunscher, 2016; Muriithi *et al.*, 2018) and if adopted in combination may offer a higher impact. Extensive research has been conducted on the impact of adopting several technologies on agricultural productivity such as minimum tillage (Jena, 2019) on farmyard manure (Hassen, 2018), and on intercropping with a legume (Ngwira *et al.*, 2012; Midefa *et al.*, 2014). However, these studies failed to consider the complementarity and substitutability among practices and the combination of the practices under consideration. Several studies have been able to study the impact of individual and combination of technologies in Ethiopia (e.g. Teklewold *et al.*, 2013b), in Zambia (e.g. Manda *et al.*, 2015), in Malawi (e.g. Kassie *et al.*, 2014; Mutenje *et al.*, 2016), and in Ghana (e.g. Gebremariam and Wunscher, 2016; Kotu *et al.*, 2017). However, different agro-ecological and socio-cultural conditions, such as those found in Kenya (particular Western Kenya) limits the external validity of the existing findings.

In light of this, study sort to assess the adoption and impact of adopting SCEPs among maize smallholder farmers in Western Kenya. The study focused on Western Kenya because it is classified as a high potential area for maize production but is currently faced with decreasing land sizes due to high population growth. Moreover, the area is characterized by soil erosion, land degradation, low soil fertility and land degradation, which limits land productivity. The study considered two essential SCEPs that is farmyard manure (FYM) and intercropping maize with legumes[2]. The two were chosen from a wide list of SCEPs because of their associated low costs of implementation, immediate impact on soil fertility for increasing crop productivity and have been advocated for within the area by the Ministry of Agriculture, Livestock, Fisheries and Irrigation (formally known as the Ministry of Agriculture).

Focus group discussion in the area revealed that most farmers keep animals mostly for milk production and manure. Farmyard manure (FYM) has long term benefits as it releases nutrients to the soil slowly and helps increase organic matter (Place *et al.*, 2003). Moreover, it can reduce the infestation of *Striga hermonthica* a parasitic weed which results in 50-40 percent losses in maize yields since it increases soil organic matter contents which hinder the growth of the weed (Waithaka *et al.*, 2007; De Groote *et al.*, 2008). Intercropping with leguminous plants has also been promoted in Western Kenya due to its potential to suppress weeds, fix nitrogen and reduce the incidence of pest and diseases (Ehui and Pender, 2005; Waithaka *et al.*, 2007).

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[2] The study was unable to include mulching and inorganic fertilizer as proposed due to low and high adoption rates of the practices, respectively. Inclusion of the two practices resulted in some categories of the possible combination having less than 30 observations which violated the multinomial endogenous treatment effect model specification that each category should have more than 30 observations. Merging of different categories would have resulted in biased results. Therefore, intercropping, FYM and their combination were utilized for the analysis as they fulfilled the model specification.

The study was guided by seeking answers to two main research questions: what are the factors influencing the adopting of SCEPs and SCEPs' impact on maize yield? The study applies the use of maximum simulated likelihood estimation of multinomial endogenous treatment effect model that helps take into consideration the effect of observed and unobservable heterogeneity.

4.2 Econometric Framework

In agriculture, the decision to adopt a practice is not easy as it is anchored on several agricultural constraints such as drought, labour requirements, cash resources for the acquisition of inputs, weed, pest and disease control. Most agricultural technologies are often introduced to farmers as packages (Kassie *et al*., 2014; Teklewold *et al*., 2013a). The study utilizes the expected utility framework to model the adoption of SCEPs. The expected utility theory suggests that a farmer will adopt a specific technology if it offers greater expected utility than the utility before adopting the practice. In this study, farmers have four alternatives to choose from (not adopting, intercropping only, FYM only and the combination of both). A farmer will therefore only adopt a combination of SCEPs that maximizes their utility (in this case maize yield) subject to land, input cost, labour and other constraints

When farmers are classified into adopters and non-adopters, endogeneity problems arise because the decision to adopt is influenced by unobservable characteristics that might be associated with the output variables. Adoption decision of a specific practice may have been informed by the unobservable factor such as farmer's technical and managerial ability to incorporating technology to their farming system (Abdulai and Huffman, 2014; Manda *et al*., 2015). Failure to consider endogeneity can under or overestimate the exact impact of adopting a technology. The multinomial endogenous treatment effect model was, therefore, adapted to account for the unobserved and observed heterogeneity and control for self-selection. This analysis was done at the plot level in order to cater for farmer's unobservable characteristics that are likely to influence the results (Manda *et al*., 2015; Gebremariam and Wunscher, 2016).

4.2.1 Multinomial Endogenous Treatment Effect Model

The model as suggested by Deb and Trivedi (2006a) is a two-stage model. The first stage is a multinomial logit that models farmers' adoption decision. A farmer can adopt any of the four possible combinations (i.e. FYM, intercropping, FYM and intercropping or none of the practice) at their farm. The model assumes farmers are rational and will choose a practice that maximizes their indirect utility related to the practice adopted (Eq. 12)

$$V_{ji}^{*} = z_j' \alpha_i + \sum_{k=1}^{J} {}^{\delta}{}_{ik}\, l_{jik} + n_{ji} \tag{12}$$

Where V_{ji}^{*} is the indirect utility derived related to i $(i = 0,1,2,3)$ practice and specific to household j , z_j is the vector of factors hypothesized to influence the adoption of the SCEPs techniques, household characteristics, plot characteristics, and external support factors; α_i are the estimated parameters associated with hypothesized factors influencing the adoption of each practice i ; n_{ji} are the independently and identically distributed the error terms and specific to practice i and household j ; l_{jk} is the latent factor that considers the unobserved characteristic specific to a household j adoption of SCEPs and maize yield. The unobserved characteristics include self-motivation, technical and management of farmers that may influence the adoption of SCEPs (Abdulai and Huffman, 2014)

A suggested by Deb and Trivedi (2006b), let *i=0* denote non-adopters of any of the two practices and $V_{ji}^{*} = 0$. While V_{ji}^{*} is not observed, it can be determined by the combination of SCEPs that a farmer has adopted, which can be represented as a set of dichotomous variables d_j and can be collected by a vector, $d_j = d_{j1} d_{j2} d_{j3} \ldots . d_{jJ}$. Also, let $l_j = l_{j1} l_{j2} \ldots . l_{jJ}$. The treatment probability equation can, therefore, be written as Eq. 13.

$$\Pr(d_j | z_j l_j) = g(z_j' \propto_1 + \sum_{k-1}^{J} {}^{\delta}{}_{1k} l_{jk} + z_j' \propto_2 + \sum_{k-1}^{J} {}^{\delta}{}_{2k} l_{jk} + \cdots + z_j' \propto_J + \sum_{k-1}^{J} {}^{\delta}{}_{Jk} l_{jk}) \quad (13)$$

Where g is an appropriate multinomial probability distribution. Therefore, a mixed multinomial logit (MMNL) structure can be defined as shown in Eq. 14.

$$\Pr(d_j | z_j l_j) = \frac{\exp(z_j' \propto_i + {}^{\delta}{}_i l_{ji})}{1 + \sum_{k=1}^{J} exp(z_j' \propto_i + {}^{\delta}{}_i l_{ji})} \quad (14)$$

The second stage of multinomial endogenous treatment effect model examines the impact of adopting SCEPs combination on the natural logarithm of maize yields. The outcome equation can be given by Eq. 15.

$$E(y_j | d_j x_j l_j) = x_j' \beta + \sum_{i-1}^{J} \gamma_i d_{ji} + \sum_{i-1}^{J} \lambda_j d_{ji} \quad (15)$$

Where y_j the maize yield outcome associated with each household $j . x_j$ represents exogenous covariates with parameter vectors β in relation to each household j . γ_i represents the treatment effects of adopting $(i = 1,2,3)$ compared to the non-adopters$(i = 0)$. If a farmer's decision to adopt SCEPS techniques is endogenous and assuming that parameter d_{ji} is exogenous it would yield inconsistent and biased estimates of γ_j. This creates the need to test for exogeneity in the outcome equation (15). The latent factor represents the unobserved characteristics that may lead to self-selection, l_{ji} that is included in the model as a factor affecting the outcome in relation to each household (j) and practice under consideration(i). The factor-loading parameters are presented by λ_i. If the factor is positive (negative) it implies that the outcome and the treatment are correlated through unobservable characteristics; which presents evidence of positive (negative) selection. The model assumes a Gaussian (normal) distribution function since the outcome variable (maize yield) is a continuous variable. Equation (15) is then estimated through the maximum simulated likelihood (MSL) approach.

The independent variables in the outcome and adoption equation are identical in the model. However, Deb and Trivedi (2006a) guarantee a more robust identification if an instrumental variable is utilized in the model. Getting valid instrumental is a difficult task. However, a valid instrumental variable has to be an information related variable (Di Falco *et al*., 2011; Manda *et al*., 2015; Gebremariam and Wunscher, 2016). The study utilized agricultural group membership an instrumental variable. Kassie *et al*., (2013) indicate that agricultural groups are good sources of information regarding agricultural technologies' pro and cons, influencing farmer's adoption decision.

The instrumental variable was subjected to the simple falsification test to validate its usability as an instrumental variable. According to the test, a valid instrumental variable should influence the decision to adopt SCEPs but should not influence the outcome variable among the non-adopters (Di Falco *et al*., 2011; Manda *et al*., 2015; Gebremariam and Wunscher, 2016). Results from the first stage of the multinomial endogenous treatment effect model on the adoption of SCEPs (as presented in Table 1) indicate that agricultural group membership influences the adoption of intercropping and manure, but it does not influence the outcome variable (maize yield) for the non-adopting sub-sample (Table A2). This proves that membership to an agricultural group is a valid instrument.

Plot-level information was utilized to solve for farmers' unobserved effects that are likely to affect the model by constructing a panel data that can account for plot specific effects (Udry, 1996; Manda *et al*., 2015). However, due to the difficulty of incorporating standard fixed effects in the multinomial endogenous treatment effect model, the study follows the Mundlak (1978) approach to account for the unobservable characteristic. The mean values of plot-level specific characteristics are included in the model.

4.3 Results and Discussion

4.3.1 Descriptive Statistics

Table 4.1 Descriptive Statistics of Variables Included in the Model

Variable	Description of Variable	Mean	SD /Frequency
Output Variable			
Maize yield	Maize yield in tonnes per acre	0.82	0.56
Practices Adoption Dummies (n= 409)			
Intercropping	Percent of plots that have adopted intercropping only	40%	164
FYM	Percent of plots that have adopted farmyard manure only	15%	62
Intercropping plus FYM	Percent of plots that have adopted intercropping plus FYM.	34 %	137
Non-adopter	Percent of plots that have adopted none of the practices	11 %	46
Mean Plot- Level Variables (n-409)			
Plot Size	Plot size in acres	0.75	0.71
Distance to Plot	Distance in walking minutes	6.63	23.42
Fertility Perception	Percent of plots that Household perceive to be fertile	75 %	
Tenure system	Percent of plots that were owned with title deeds	49 %	
Socioeconomic Variables (n = 334)			
Age of HHH	Age of HHH in years	53	14
Gender of the HHH	Percent of male HHH	76 %	
HHH Participate in Farming	Percent of HHH that offer labour services to farming activities	91 %	
Literacy Level	Household literacy level	0.17	0.13
Tropical livestock unit	Tropical livestock unit (TLU)	3.22	4.12
Wealth	Percent of households classified as not poor	56 %	
Crop Market Participation	Percent of households that sold their produce	57 %	
Access Agricultural credit	Percent of households that had access to agricultural credit	22 %	
Access Extension	Percent of households that had access to extension	62 %	
Instrumental Variable			
Agricultural Group Membership	Percent of households that are members of an agricultural group	34 %	

HHH refers to Household Head

Source: Survey Data 2018

Table 6 above presents the summary statistics for the variables utilized in the analysis. Intercropping was adopted in 40 percent of the plots, FYM in 15 percent, a combination of both in 34 percent and non-adopters neither of the practices in 11 percent of the plot. This signifies the low adoption rate among the practices in Western Kenya. On average FYM application was approximately 1.8t ha^{-1}, which is below the optimal 4.05t ha^{-1} as recommended by the Ministry of Agriculture, Livestock, Fisheries and Irrigation in Western Kenya (Salasya, 2005). The average maize yield per acre was 0.83 tonnes (9bags of 90kg per acre per season). About 57 percent of the farmers reported having sold at least one product from their farms in the last 12 months.

The average size of a plot was 0.75 acres and distance to the plot from the homestead in walking minutes was 7 minutes. However, the total farm size that at household worked on average at 0.91 acres. The parcels of land are small due to high population density and uncontrolled subdivision of land. With land size been utilized as an indicator of wealth it confirms the results the poverty index that poverty rate within the area is high. On average 49 percent of the plots had secure tenure system as farmers owned title deeds to their plots. The majority (74 percent) of the farmers perceived their plots to be productive (fertile), but all agreed on the need to enhance their fertility further.

On average the farmer's age was 53 years, with 76 percent of the respondents being male. This is an indication that the majority of the farmers within the region were old farmers and with male farmers controlling the decision-making process in regard to what practices to adopt and what crops to grow. The average household literacy level was 0.17, and 56 percent of the households would be classified as not-poor with an average Tropical Livestock Unit (TLU) of 3.22. The results indicate that there was a high poverty rate (i.e., 44 percent) which is above the national average in rural areas at 39 percent. Majority of the respondents (70 percent) provided labour for farming activities an indication on time they devoted to farming activities. Besides, 34 percent of the farmers were members of an agricultural group while 22 percent had access to agricultural loan. This implies that majority of the farmers lacked access to agricultural credit to purchase inputs. Low membership in agricultural social groups signifies low information exchange among farmers. However, access to extension service was high at 62 percent, with most farmers receiving extension services mainly from Non-Governmental Agencies, and County extensional officer.

4.3.2 Determinants of Adoption of SCEPs: Multinomial Endogenous Treatment Effect Model Results

Table 4.2 Mixed Multinomial Logit Model Estimates of Adoption of SCEPs in Western Kenya

	Intercropping		Manure		Intercropping and Manure	
Variables	Coef.		Coef.		Coef.	
Gender of HHH	-0.030	(0.51)	-0.242	(0.56)	-0.567	(0.49)
Age of HHH	-0.003	(0.01)	-0.018	(0.02)	-0.010	(0.02)
HHH Participates in Farming	-0.906	(0.76)	1.303	(1.10)	1.226	(0.91)
Tropical Livestock Unit	.433***	(0.12)	.373***	(0.14)	0.397***	(0.13)
Literacy Level	-3.395**	(1.73)	1.624	(1.92)	0.796	(1.77)
Access Credit	-0.614	(0.41)	-1.240**	(0.51)	-1.081***	(0.42)
Access Extension	0.156	(0.46)	0.259	(0.53)	-0.435	(0.47)
Sell Crop Produce	-0.030	(0.46)	-1.273**	(0.54)	-0.817*	(0.46)
Wealth Category	0.063	(0.07)	-0.144*	(0.08)	-0.057	(0.08)
Mundlak fixed effect						
Plot Size	-0.384	(0.31)	-0.301	(0.42)	-0.572	(0.38)
Distance to Plot	-0.028**	(0.01)	0.011	(0.02)	-0.052**	(0.02)
Plot Fertility Perception	-0.067	(0.48)	1.039	(0.65)	-0.043	(0.50)
Plot Tenure	-0.760	(0.48)	1.730***	(0.50)	1.205***	(0.47)
Instrumental Variable						
Agricultural Group Membership	1.154**	(0.48)	-1.020*	(0.62)	0.551	(0.50)
_cons	1.724	(1.38)	-0.530	(1.81)	1.230	(1.48)

Robust Standard errors in parenthesis.
Log Pseudo likelihood = -539.5706 Wald Chi-Square (58) = 313.28 ***.
N=409 (from Sample Size of 324 Households). Statistical significance at *p<0.1, **p<0.05, ***p<0.01

Source: Survey Data (2018)

The first stage of the multinomial endogenous treatment effect model evaluates factors that affect the adoption of intercropping, FYM and combination of both as presented in Table 7.

Literacy level significantly (at 5 percent) and negatively influenced the adoption of intercropping. An explanation to this could be that most households in Western Kenya have small pieces of land and have been practicing intercropping for a long time; thus, as people get educated, they stop practising intercropping as they consider it as an old method of farming. Additionally, might suggest that people that were educated were more likely to be rich and thus had income to purchase fertilizer rather than intercrop. The negative effect of literacy level on intercropping is consistent with the finding of Kassie *et al*. (2014) and Ndiritu *et al*. (2014) who stated that level of education negatively influenced the adoption of intercropping in Ethiopia and Kenya respectively.

Tropical livestock unit (TLU) positively influenced the adoption of intercropping, manure and a combination of both. As the number of livestock kept in a household increases the feed requirements to sustain the animals also increases. Therefore, creating a need for farmers to intercrop to increase the amount of residue available to be fed to the animals. Additionally, having more animals increases the amount of manure available to be utilized on the farm.

Households classified as not being poor were less likely to apply FYM on their farm. A probable explanation could be that, as wealth increases households would tend to have enough capital outlay to invest in other capital-intensive practices such as irrigation and inorganic fertilizer. Cavanagh (2017) indicates that the wealth category of household determined the technologies they adopted with poorer household adopting fewer technologies that required more capital outlay in implementation. This is an indication of the role of resource endowment on adoption. Additionally, access to credit negatively influenced the adoption of manure and intercropping and manure combination. Farmers that had access to loans were able to adopt other practices that require a larger capital outlay such as irrigation and inorganic fertilizer.

Farmers that participated in markets through the sale of produce were less likely to implement manure and combination of intercropping and manure on their plots. A possible explanation is that most farmers in the region participating in markets were selling more of other crops such as bananas, African leafy vegetables and sugarcane (cash crop in Kakamega County) or tea (cash crop in Vihiga County) explaining why they were less likely to implement manure and intercropping and manure combination.

Households that owned title deed for their plots were more likely to adopt the use of manure and intercropping and combination of both. The results collaborate the finding of Kassie *et al*. (2013) and Manda *et al*. (2015) that secure land tenure encourages farmers to adopt agricultural technologies. This result reaffirms the importance of clearly defined property rights on the adoption of agricultural practices.

Distance to the plot from the residence negatively influenced the adoption of intercropping and its combination with manure. This is an indication that plots nearer to the residence were more likely to have intercropping and its combination with manure implemented than plots further from the residence. Considering that manure application and spreading is a time-consuming process and bulky to carry it is thus preferred for plots nearer the residence.

Agricultural group membership positively influenced the adoption of intercropping and negatively the adoption of manure. Groups play a key role in information sharing between members of the group on the pro and con of the two practices and also on inputs and other innovation (Mutenje *et al*., 2016; Gebremariam and Wunscher, 2016).

4.3.3 Impact of Adopting SCEPs

The study estimated the impact of adopting FYM and intercropping in isolation and as a combination in the second stage of the multinomial endogenous treatment effect model, as presented in Table 8. After controlling for unobservable heterogeneity, the results indicate that the adoption of either manure, intercropping or combination of both significantly resulted into increase in maize yield. On average the adoption of intercropping increases maize yield by 35 percent (3.2 bags of 90Kgs per acre per season), while manure by 18 percent (1.8 bags of 90Kgs per acre per season), and a combination of both by 33 percent (3.0 bags of 90Kgs per acre per season). The increase of 35 percent in maize yield through intercropping is consistent with field trials in Kenya which indicated the potential of 40-20 percent increase in maize yield (Woomer, 2007; Mucheru-Maina *et al*., 2010). Additionally, 18 percent increase in maize yield as a result of manure application is consistent with field trials that estimated that indicate the increase to ranges from 15-35 percent (Miriti *et al*., 2007; Woomer, 2007). The low application rate of manure would have resulted in the low impact of 18 percent on maize yield. This suggests that the application of manure at the recommended nutrition rate would result in higher impact. Additionally, the other exogenous factors (household characteristics, mean plot characteristics and support factors) also affect the maize yield per acre.

The loading factors (selection term) indicates that there was evidence of negative selection bias signifying that unobserved factors that enhance the probability of adopting SCEPs are related with maize yield than those expected under random assignment to be adopters of SCEPs. Additionally, the test of exogeneity of the treatment variable using the likelihood ratio was performed. The Likelihood ratio test value was [Chi^2 (3) =8.1894, p=0.0423], which was significant, thus rejecting the null hypothesis of exogeneity and concluding that the treatment variable is endogenous. This justified the use of multinomial endogenous treatment effects model.

Table 4. 3Multinomial Endogenous Treatment Effect Model Estimates of SCEPs Impact on Maize Yields

Endogenous Practice	Coef.		Percent change
Intercropping	0.3543***	(0.069)	35
Manure	0.1796*	(0.103)	18
Manure and Intercropping	0.3270***	(0.088)	33

Selection Term		
Intercropping	-0.1716***	(0.037)
Manure	-0.0136	(0.068)
Manure and Intercropping	-0.2024***	(0.069)
Lnsigma	-1.7403***	(0.306)
Exogenous Factors		
Gender of HHH	-0.0219	(0.038)
Age of HHH	-0.0018	(0.001)
HHH Participates in Farming	-0.1589**	(0.058)
Tropical Livestock Unit (TLU)	-0.0003	(0.007)
Literacy Level	0.0747	(0.137)
Access Credit	0.1100***	(0.033)
Access Extension	0.0399	(0.034)
Sell Crop Produce	0.1345***	(0.037)
Wealth Category	0.0144**	(0.006)
Plot Size	-0.1487***	(0.033)
Distance to Plot	0.0028***	(0.001)
Plot Fertility Perception	0.0185	(0.037)
Plot Tenure	0.0080	(0.048)

The baseline category are farm households that did not adopt any SCEPs. Sample size 409 plots and 334 households. 400 simulation draws were used

Robust Standard errors in parenthesis Statistical significance at *p<0.1, **p<0.05, ***p<0.01

Source: Survey Data (2018)

4.4 Conclusion and Implication

Soil carbon enhancing practices have the potential to alleviate the problem of low productivity faced by most SSA farmers at potentially low cost. These practices help in enhancing soil carbon and thus enhancing the regeneration of the ecosystem. Previous studies tried to assess the impact of adoption without taking into account the complementarity and substitutability practices. This study acknowledges the complementary of the practices while assessing the adoption and impact of adoption on maize yield by utilizing a multinomial endogenous treatment effect model.

The study reveals that adoption of SCEPS is affected by plot characteristics (distance to the plot from the residence and secure land tenure), literacy level, resource endowment (tropical livestock unit (TLU) and wealth category) and external support services (access to credit and participation in markets). The study confirms trial experimental results by ascertaining that the adoption of the SCEPs has a significant and positive impact on maize yield. The adoption of intercropping had the highest impact on maize yield, followed by the combination of intercropping and manure. Despite manure contributing the lowest at 18 percent in terms of increasing maize yield, its application at the optimal nutrition rate would generate higher output yields while utilized in combination with intercropping. Future intervention programs that are aimed at enhancing productivity should advocate for the adoption of a combination of SCEPs of intercropping with FYM. Additionally, the optimum nutrition amount of manure application should be encouraged for maximum gains to be achieved.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND IMPLICATION TO POLICY

5.1 Summary

The objective of this study was to assess factors that influence the adoption, extent of adoption of SCEPs and its impact on maize yield among smallholder farmers in Western Kenya with a focus on Kakamega and Vihiga Counties. The study focused on four practices mulching, farmyard manure (FYM), intercropping and inorganic fertilizer. The results indicated that adoption rates at plot level were low for mulching, intercropping and farmyard manure at 6 percent, 48 percent and 42 percent respectively, with inorganic fertilizer having a high adoption rate at 74 percent. The results further showed that most plots had on average two practices implemented.

The study analyzed factors that influenced adoption of SCEPs utilizing the multivariate probit model and the results indicated that, size of the plot, distance to the plot from the residence, plot's slope, farmer's perception towards the plot being susceptible to soil erosion, household head's farming experiences, literacy level, access to agricultural loan, group membership, and farmers' participation in markets influence the adoption of SCEPs. Therefore, the study rejected the null hypothesis and concluded that social-economic factors, external support factors and plot specific characteristics influenced the adoption of SCEPs. Further analysis indicated that the practices were adopted in complementarity namely intercropping, FYM and inorganic fertilizer

The study also assessed factors that influenced the extent of adoption of SCEPs. The generalized ordered logit model results indicated that the size of the plot, plot's slope, farmer's perception towards the plot been susceptible to soil erosion, the gender of the household head, access to agricultural loan and group membership influenced the extent of adoption of SCEPs.

Therefore, the study rejected the null hypothesis and concluded that social-economic factors, external support factors, and plot specific characteristics influenced the extent of adoption of SCEPs.

The study also analyzed the impact of adopting SCEPs on maize yield and the multinomial endogenous treatment effect model results showed that adopting FYM, intercropping, and the combination of the two had a positive and significant impact on maize yield. Adoption of FYM, intercropping and combination of the two increased maize yield by 18 percent, 35 percent and 32 percent respectively. The null hypothesis was therefore rejected, and it was concluded that adopting SCEPs has a positive impact on maize yield.

5.2 Conclusion

The results validated the contribution of social-economic factors, plots specific characteristics and external support factors on adoption and extent of adoption of SCEPs. Adoption and extent of adoption proved to be knowledge-intensive due to the positive influence of literacy level and agricultural group membership. Female-headed households were more likely to adopt more practices than male-headed household. The number of plots that a farmer had negatively influenced the number of practices adopted as farmers opted to increase the number of practices per plot gradually from plot to plot.

Farmers adopted practices in complementarity to enhance soil fertility and increase their yield. This signifies the need to encourage the promotion of SCEPs as packages that farmers can choose the best practices fit for their plots. The results also showed that the adoption of SCEPs has a positive impact on maize yield. This portrays the ability of the practices in enhancing soil fertility. Farmyard manure had the lowest impact on maize yield which can be partly explained by the sub-optimal application rate of manure compared to the recommended application rate.

This proves the need to encourage the application of adequate FYM as per the recommended nutrition application rate to maximize on the potential of FYM.

5.3 Policy Implication

Based on the finding of the study there is a need to supplement the effort of the County and National governments in Kenya in promotion of adoption of SCEPs as packages that can be adopted by farmers in complementary. The packages need to incorporate the low-cost practices that farmers can adapt based on the available resources at the farmers' disposal.

There is a need to encourage public-private partnerships in the provision of soil testing services to farmers. Farmer's better understanding of the plot characteristics through scientific soil testing can encourage the adoption of specific low-cost SCEPs that enhance soil fertility. This creates the need for Local government to partner with private soil testing companies and National government agencies to provide soil testing services at a subsidized price.

The national and local Governments need to strengthen the existing farmers' groups so that they can be used to relay information on the advantages and disadvantages of adopting SCEPs. Additionally, the participation of male in agricultural groups needs to be encouraged as male households were more likely to adopt fewer practices in their plots. Strengthening of farmer groups will provide great a platform where farmers can share experiences on the practices, they deem best, creating a feedback loop to researchers and local government extension agents and enhance the adoption of SCEPs.

The impact of manure was low due to the low application rate of manure as opposed to the recommended application rate. This creates a need for local government to encourage the application of manure at the recommended rate to maximize farmer's productivity and yield.

5.4 Contribution to Knowledge

The study showed the influence of socio-economic factors, external support services and plot characteristics on the extent of adoption of SCEPs. The study particularly highlighted the importance of plot characteristics that had been ignored by previous studies by narrowing the analysis at the plot level. The study also showed the interdependence in the adoption decision of farmers. Furthermore, the study highlighted the positive impact of adopting FYM and intercropping and the combination of the two on maize yield. The study contributes to the existing literature by emphasizing on the extent of adoption of SCEPs and the impact on maize yield at the plot level.

5.4 Areas for Further Research

Further research can focus on including farmers' socio-psychological factors such as attitude, social status, children and spouse's support, knowledge and trust in the adoption of SCEPs. This will enable a better understanding of the interaction of socio-psychological, socio-economic factors and plot characteristics and their role in the adoption of SCEPs. Additionally, further research can build on the impact of adopting multiple SCEPs by considering other practices not included in the study and other crops such as bean yield.

5.5 Challenges

During the study, a few challenges were encountered during the data collection and data analysis phases. During the data collection phase, on the first day of fieldwork activities, our principal contact person in Vihiga County lost his phone and thus had to reorganize the activities of that day and start with other regions within the county. Lastly, during the data analysis phase, challenges arose with modelling the third objective, particularly finding the Stata commands and reorganize the data. However, the challenges were a good learning curve and made me a better Agricultural Economist.

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APPENDICES

Appendix 1: Diagnostic Test

Table A1.1: Brant Test of Parallel Regression Assumption

	Chi-square	P value	df
All Variables	77.44	0.000	38
Each Variable Independently			
Number of Plots	4.82	0.09	2
Plot Size (in acres)	11.83	0.003	2
Distance to Plot	10.32	0.006	2
Soil Erosion Perception	13.25	0.001	2
Slope Moderate	1.1	0.577	2
Slope Flat	0.39	0.823	2
Soil Type Loam	1.62	0.445	2
Soil Type Sandy	1.22	0.543	2
TLU	1.67	0.434	2
Gender of HH	0.23	0.89	2
Age of HH	0.63	0.731	2
The education level of HH	5.33	0.07	2
Household size	1.13	0.569	2
HH Main Occupation	0.89	0.642	2
Crop Market Participation	2.97	0.227	2
Access Agricultural Loan	0.72	0.699	2
Wealth Category	0.23	0.892	2
Agricultural Group Membership	7.73	0.021	2
Distance to Local Market	3.53	0.171	2

Significant test statistics provide evidence that the parallel regression assumption has been violated.

Source: Survey Data (2018)

Table A1.2: Goodness of Fit of Generalizes Ordered Logit Comparison

Poisson Model		Ologit Model		Gologit2 Model	
Log-likelihood		Log-likelihood		Log-likelihood	
Model	-928.591	Model	-810.638	Model	-791.023
Intercept-only	-952.118	Intercept-only	-850.922	Intercept-only	-850.922
Chi-square		Chi-square		Chi-square	
Deviance (df=620)	1857.183	Deviance (df=618)	1621.276	Deviance (df=612)	1582.046
LR (df=19)	47.052	LR (df=19)	80.567	Wald (df=25)	97.286
p-value	0.000	p-value	0.000	p-value	0.000
R2		R2		R2	
McFadden	0.025	McFadden	0.047	McFadden	0.099
McFadden (adjusted)	0.004	McFadden (adjusted)	0.021	McFadden (adjusted)	0.037
Cox-Snell/ML	0.071	Cox-Snell/ML	0.118	Cox-Snell/ML	0.231
Cragg-Uhler/Nagelkerke	0.075	Cragg-Uhler/Nagelkerke	0.127	Cragg-Uhler/Nagelkerke	0.244
		Count	0.408	Count	0.423
		Count (adjusted)	0.023	Count (adjusted)	0.049
IC		IC		IC	
AIC	1897.183	AIC	1665.276	AIC	1638.046
AIC divided by N	2.964	AIC divided by N	2.602	AIC divided by N	2.559
BIC (df=20)	1986.412	BIC (df=22)	1763.429	BIC (df=28)	1762.967

Source: Survey Data (2018)

Table A1.3: VIF Generalized Ordered Logit Model

Variable	VIF	1/VIF
Number of Plots	1.37	0.730871
Plot Size (in acres)	1.15	0.870691
Distance to Plot	1.05	0.955573
Soil Erosion Perception	1.11	0.899313
Slope Moderate	2.75	0.363065
Slope Flat	2.89	0.34608
Soil Type Loam	2.36	0.424062
Soil Type Sandy	2.33	0.430061
TLU	1.23	0.814388
Gender of HH	1.21	0.828619
Age of HH	1.15	0.867381
The education level of HH	1.51	0.663622
Household size	1.3	0.766603
HH Main Occupation	1.29	0.774375
Crop Market Participation	1.17	0.858173
Access Agricultural Loan	1.14	0.880467
Wealth Category	1.49	0.672334
Agricultural Group Membership	1.23	0.814246
Distance to Local Market	1.09	0.917679
Mean VIF	1.52	

Source: Survey Data (2018)

Table A1.4: VIF Multivariate Probit Model

Variable	VIF	1/VIF
Plot Size (in acres)	1.1	0.910841
Distance to Plot	1.05	0.956836
Plot Fertility Perception	1.1	0.906153
Soil Erosion Perception	1.08	0.927175
Slope Moderate	2.77	0.360644
Slope Flat	2.85	0.350266
HH Farming Experience	1.15	0.867931
HH Main Occupation	1.13	0.887893
TLU	1.15	0.869966
Dependency Ratio	1.3	0.766637
Literacy Level	1.2	0.831275
Crop Market Participation	1.11	0.897898
Agricultural Group Membership	1.32	0.755853
Access Agricultural Loan	1.17	0.856332
Access Extension	1.28	0.780247
Distance to Local Market	1.12	0.891081
Wealth Category	1.4	0.715012
Mean VIF	1.37	

Source: Survey Data (2018)

Table A1.5: VIF Multinomial Endogenous Treatment Effect Model

Variable	VIF	1/VIF
Wealth Category	1.49	0.671615
Agricultural Group Membership	1.33	0.75237
Access Extension	1.32	0.759129
Plot Tenure	1.3	0.767015
HH Age	1.23	0.810567
Plot size	1.21	0.829179
Literacy Level	1.2	0.836081
TLU	1.2	0.836354
Distance to the Plot	1.15	0.865915
Access Credit	1.15	0.870934
HH participates in farming activities	1.13	0.883995
Crop Market Participation	1.12	0.890162
Plot Fertility Perception	1.12	0.894742
HH Gender	1.09	0.920031
Mean VIF	1.22	

Source: Survey Data (2018)

Table A1.6: Heteroscedasticity Multinomial Endogenous Treatment Effect Model

Breusch-Pagan / Cook-Weisberg test for heteroscedasticity	
	H_o: Constant Variance
	Variables: fitted values of X1
	chi2(1) = 3.05
	Prob > chi2 = 0.0810

Source: Survey Data (2018)

Table A1.7: Heteroscedasticity Multivariate Probit Model

Breusch-Pagan / Cook-Weisberg test for heteroscedasticity	
	H_o: Constant Variance
	Variables: fitted values of Mulching
	chi2(1) = 248.93
	Prob > chi2 = 0.0000

Source: Survey Data (2018)

Table A1.8: Heteroscedasticity Generalized Ordered Logit Model

Breusch-Pagan / Cook-Weisberg test for heteroscedasticity	
	H_o: Constant Variance
	Variables: fitted values of practices ranked
	chi2(1) = 16.09
	Prob > chi2 = 0.0001

Source: Survey Data (2018)

Appendix 2: Test of Validity of Instrumental Variable

Table A2: Test of Validity of Instrumental Variable

	Ln Maize Yield Coef.	
Gender of HHH	0.1773	(0.187)
Age of HHH	0.0050	(0.007)
HHH Participates in Farming	-0.1224	(0.256)
Tropical Livestock Unit (TLU)	0.0624	(0.052)
Literacy Level	-0.2371	(0.469)
Access Credit	0.0534	(0.168)
Access Extension	0.1506	(0.169)
Sell Crop Produce	0.3211**	(0.150)
Plot Size	-0.2260*	(0.133)
Distance to Plot	0.0003	(0.004)
Plot Fertility Perception	-0.0452	(0.163)
Tenure	0.0082	(0.151)
Wealth Category	0.0187	(0.032)
Agricultural Group Membership	-0.0733	(0.216)
_cons	2.0153***	(0.693)

Robust Standard errors in parenthesis

Statistical significance at *p<0.1, **p<0.05, ***p<0.01

Sample size 46 R squared 32 percent Adjusted R squared 1.33 percent

Source: Survey Data (2018)

Appendix 3: Adoption of Inorganic Fertilizer

Table A3.1: Kruskal-Wallis equality-of-populations rank test

	Observation	Rank Sum
Non-Adopters	46	91000.00
Intercropping	164	34568.50
FYM	62	12078.50
Intercropping plus FYM	137	28098.00

Source: Survey Data (2018)

Chi-squared = 1.022 with 3d.f.

Probability= 0.7958

Chi-squared with ties = 3.951 with d.f

Probability = 0.2668

Table A3.2: Dunn's Pairwise Comparison of Inorganic Fertilizer by X1 (Bonferroni)

	Non-Adopters	Intercropping	FYM
Intercropping	-1.291445 0.5896		
FYM	0.257348 1.000	1.781177 0.2247	
Intercropping plus FYM	-0.709319 1.000	0.817284 1.000	-1.11687 0.7921

Source: Survey Data (2018)

The two tests reveal that adoption of inorganic fertilizer is not statistically different across the three groups. Therefore, use of inorganic fertilizer would not influence the results on the Multinomial endogenous treatment effect model.

Appendix 4: Household Survey Questionnaire

Informed Voluntary Consent to Participate in Research Study

Project Title: ***"An integrated approach for understanding the factors that facilitate or constrain the adoption of soil carbon enhancing practices in East Africa, specifically Kenya and Ethiopia"***

Invitation to participate, and benefits: You are invited to participate in a research study conducted with smallholder l farmers in the Vihiga and Kakamega Counties in Western Kenya, and in Yasir and Azugashube Watershed in Ethiopia. We identified some soil carbon enhancing practices during the in the first phase of this study (i.e., the focus group discussion) in your area and would like to understand the factors that constrain or facilitate the adoption of each practice at the farm level. The study's aim is to understand the specific socio-economic, plot/farm level, institutional, and biophysical characteristics that affect the adoption of practices that increases soil carbon, so as to improve decision-making in adaptation for sustainable development of agriculture in East Africa. I believe that your experience would be a valuable source of information and hope that by participating you may gain useful knowledge too.

Procedures: During this study, you will be asked to give some information related to your households, plot, farm, and time and labor spent on different activities on-farm, as well as how far different infrastructures such as the market in relation to your homestead, and as it relates to a specific soil carbon enhancing practice. You will also be asked some questions related to the yield of crops affected by the soil carbon enhancing practices and the market prices. The interview will take approximately 1-1.5 hours

Risks: There are no potentially harmful risks related to your participation in this study.

Disclaimer/Withdrawal: Your participation is completely voluntary; you may refuse to participate, and you may withdraw at any time without having to state a reason and without any prejudice or penalty against you. Should you choose to withdraw, the researcher commits not to use any of the information you have provided without your signed consent. Note that the researcher may also withdraw you from the study at any time.

Confidentiality: All information collected in this study will be kept private in that you will not be identified by name or by affiliation to an institution. Confidentiality and anonymity will be maintained, as pseudonyms will be used.

What signing this form means:

By signing this consent form, you agree to participate in this research study. The aim, procedures to be used, as well as the potential risks and benefits of your participation, have been explained verbally to you in detail, using this form. Refusal to participate in or withdrawal from this study at any time will have no effect on you in any way. You are free to contact me (s.karanja@cgiar.org or +254720876806), to ask questions or request further information, at any time during this research.

I agree to participate in this research (tick one box)

☐ Yes ☐ No _________

Section 1: **General information**

QID

______________________________	______________________________	________
Name of Participant	Signature of Participant	Date
______________________________	______________________________	________
Name of Researcher	Signature of Researcher	Date

[______________]

Date [____/______/_____] (*Date/Month/Year)*
Enumerator's Name [________________]
Interview: start time [________________]

Section 1: *Site characteristics and GPS coordinates*

1.1 County [________________]
1.2 Sub-county [________________]
1.3 Location [________________]
1.4 Sub-location [________________]
1.5 Village name [________________]

GPS coordinates:
Northing: [_____________] Easting: [______________] Altitude [_____________] masl

Section 2: **Household respondent**

2.1 Name of the respondent [______________ ________________]
2.2 How many years have you been involved in farming [___________] years?
NB*: Question 2.3 needs to be answered if and only if the household head is* ***NOT*** *the respondent*
2.3 How many years has the household head been involved in farming [___________] years?

Section 3: **Household demographic characteristics**

3.1 How many people including you live and eat in this household? *Please provide us with details to fill the following table*

3.1.1	3.1.2	3.1.3	3.1.4	3.1.5	3.1.6	3.1.7	3.1.8
No.	list name of HH members *(first name only)*	What is "__" relationship to HH head *(See Codes)*	Gender *1=Male, 2=Female*	Age (years)	Level of education? *(see Codes)*	Occupation *(See Codes)*	Does the person participate in Farming activities (Provide Labour)? *1=Yes, 0= No*

Codes for: Relation to HH	**Codes for: occupation**	**Code for: education level**
1=Wife / Husband	1=Farming (Crop and Livestock)	0=No Education
2=Son/ Daughter	2=Employed (Informal Sector)	1=Primary
3=Father/Mother	3=Employed (Formal Sector)	2=Secondary
4=Brother/ Sister	4=Business	3= Technical/Vocational Training
5=Grandchild	5=Student	4=University
6=Others…Specify	6=Others…Specify	5=Others…Specify

3.2 What is the distance in walking minutes of the household to the infrastructure listed in the table below: *(fill in yourself if you know, ask only if appropriate*

3.2.1	3.2.2
Infrastructures	Distance from the household in walking minutes to
Motorable road (All Weather road)	
Tarmac road	
Local market	
Nearest livestock market	
Nearest urban market	
Nearest electricity	
Nearest clinic	

3.3 Please provide us with the following information about your household to enable us to fill this simple wealth scorecard

3.3.1	3.3.2				3.3.3
Indicator	Values				Points
How many people in the family are aged 0 to 17?	5 or more	3 or 4	1 or 2	zero	
	0	7	16	27	
Does the family own a gas stove or gas range?	No		Yes		
	0		13		
How many television sets does the family have	Zero	1	2 or more		
	0	9	18		
What are the house's outer walls made of?	Mud, bamboo, sticks		iron, aluminum, concrete, brick, stone, wood, asbestos		
	0		4		
How many radios does the family own?	Zero	1	2 or more		
	0	3	10		
Does the family own a sofa set?	No		Yes		
	0		9		
What is the house's roof made of?	Light (Salvaged, makeshift		Strong (Galvanized iron, aluminum tile, concrete, brick, stone, or asbestos)		
	0		2		
What kind of toilet facility does the family have	None, open pit, closed pit, or other		Water sealed		
	0		3		
Do all children in the family of ages 6 to 11 go to school?	No	Yes	No children ages 6-11		
	0	4	6		
Do any family members have salaried employment?	No		Yes		
	0		6		

Section 4: **Plot characteristics, perception on soil erosion and fertility, yields and inputs**

4.1Land access of the household and Plot Characteristics

4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.1.6	4.1.7	4.1.8	4.1.9	4.1.10	4.1.11
Plot ID	Plot Description	Plot size/area *(acres)*	Tenure system *(See Code)*	Who manages the plot *(See Code)*	If rented, rent value *(KSh/year)*	Distance from the house into the plot *(in walking minutes)*	Do you perceive the plot to be fertile? *1= Yes 0= No*	Plot Slope *(See Code)*	Soil type *(See Code)*	Perceive soil erosion as a problem *1= Yes 0= No*

Codes:

Plot description: 1= Homestead, 2= Cash crop, 3= Food crop, 4= Fodder crop, 5= Grazing land, 6=Others, please specify [______]

Tenure system: 1= Owned with title, 2= Owned without title, 3= Communal/public, 4= Rented in, 5= Rented out

Who manages the plot: 1= HH head, 2= Spouse, 3= Joint (HH head & spouse), 4= other male, 5= Other female, 6= Others, please specify [______]

Plot Slope: 1=flat, 2=moderate steep, 3=very steep

Soil type: 1=Clay, 2=Loam, 3=Sandy

Note hectare = 2.471 acres

4.2 Do you see any importance of implementing soil management practices that improves soil fertility in any of the plot [____] *(1= Yes 0= No)*.
If the answer is yes in question 4.4 above, please indicate the specific plot where you deem it necessary to implement soil fertility enhancing practices (including providing the reason why) in the Table below

4.2.1	4.2.2	4.2.3	4.2.4	4.2.5	4.2.6
Soil enhancing practices *(use Practice codes below)*	On which plots *(use plot IDs in 4.1)* is this practice implemented?	What is the plot proportion under the (4.4.1) practices *(In percentage)*	How many years have you been implementing this practice	What is the reason for implementing this practice? *(use code A)*	Which are the main challenges associated with implementing this practice *(use code B)*

Codes:

Practice: 1=Agroforestry, 2=Terraces, 3=Minimum tillage, 4= Mulching, 5=Intercropping with Legumes, 6=Improved, 7=Grass Strips, 8=Farm Yard Manure, 9=Inorganic Fertilizer, 10= Maize with Legumes. (compost manure) …. crop rotation

A: Reasons for implementing the practice: 1=Increase fertility, 2=Enhances sequestration of soil carbon, 3=Was recommended by extension officers, 4= Because neighbours are using it, 5= Reduces soil erosion, 6=Conserves water, 7=Was recommended within my social groups, 8=Others, please specify [__________]

B: The main challenges 1=Labour requirements, 2=Competition for straw with animals, 3=Expensive inputs, 4=Lack of knowledge, 5=Limited access to input market, 6=Lack of capital, 7= Others, please specify [__________]

4.3 For the different plots on your farm, could you please indicate the main crops, their yield per year (by seasons) in the Table below

4.1.1	4.3.1	4.3.2	4.3.3		4.3.4		4.3.5	4.3.6
Plot ID	The main crop(s) or crop names	percent occupied by the crop	How much quantity was harvested during the 1st season 2017 *(use yield codes)*		How much quantity was harvested during 2nd season in 2017 *(use yield codes)*		What proportion of residue was left in the plot?	For what purpose was the rest of the residue used for *(use residue purpose codes)*
			Quantity	*Unit (See Codes)*	*Quantity*	*Unit (See Codes))*	*(In percentage)*	*(See Codes)*

Codes
unit: 1=90kg bag, 2=70kg bag, 3=50kg bag, 4= gorogoro(2kg) 5=Bunch, 6=Kgs
Season 1 is equivalent to long rain season
Season 2 is equivalent to short rain season
Residue: 1=Animal Feed. 2=Fuel, 3=Cooking Vegetable, 4=Soil fertility enhancement, 5 Others, please specify [ ]

4.4 Did you sell any produce from the last cropping season (2017)? [____] *(1=Yes, 0=No).*
If yes proceed fill the table below if NO skip to question 5.1

4.4.1	4.4.2	4.4.3
Crop names	Please indicate the quantity of crop yield that was sold (Use the unit codes)	What is the price in (KSh) per unit *(use the unit codes below)*

Codes
Unit: 1=90kg bag, 2=70kg bag, 33=50kg bag, 4= others please specify [ ]

4.5 For the different crops grown on the farm could you please indicate the if you use the following inputs and their costs, per year in the Table below

4.1.1	4.5.1	4.5.2	4.5.3.		4.5.4	4.5.5	4.5.6	4.5.7		4.5.8	4.5.9
Plot ID	Did you use inorganic fertilizer on this plot last year? 1= Yes 0= No	Please specify the fertilizer type *(use codes)*	Specify the quantity of fertilizer that you use *(see codes for markets below)*		Source of fertilizer *(use Fertilizer source code)*	Price per Unit (if bought)	Did you use manure on this plot in the last one year? *1= Yes 0= No*	How much manure did you use? *(see codes for manure unit below)*		Source of Manure *(use manure source code)*	Price per unit of manure
			Qty	*unit*				*Qty*	*unit*		

Codes:
Fertilizer Type: 1=CAN, 2=NPK, 3=DAP, 4=Urea, 5=Liming, 6 others, please specify [_____]
Fertilizer Unit: 1=50kg bag, 2= 25 Kg 3=10Kg 4= others, please specify [_____]
Fertilizer Source: 1=NGO's, 2=Government, 3= Agrovet Store 4= others, please specify [_____]
Manure Source: 1=Own farm, 2= Purchased, 3= others, please specify [_____]
Manure Unit: 1=Debe, 2= Wheelbarrow, 3= Bucket, 4= Suck, 5= others, please specify [_____]

4.6 Where do you source your labor for farm activities? [_____] *use the codes below*
Codes 1= Family labor only; 2=Hired Labor only; 3=Family and Hired Labor.

4.7 Do you provide labour to other farms during the start of the season before working on your farmland for the purpose of getting income? [____] (1= Yes 0= No)

4.8 Do you own any livestock? [_____] (1= Yes 0= No)

If YES fill the table. IF No move skip to Section 5

4.8.1	4.8.2	4.8.3
Type of Livestock *(use the livestock type codes below)*	The number of Livestock owned.	Purpose for Keeping Livestock *(Use purpose code below)*

Codes
Livestock Type: 1=Cattle, 2=Goat, 3=Sheep, 4=Donkey, 5=Poultry 6= others, please specify [_____]
Purpose: 1=Source of Food, 2=Source of Income, 3= Source of Manure, 4= Form of Saving (Asset), 5= others, please specify [_____]

4.9 Did you sell any of you Livestock in the last 12 months? [______] (1= Yes 0= No)
If Yes fill the table below. IF No Skip to Section 5

4.9.1.	4.9.2	4.9.3
Type of Cattle Sold *(Use of the livestock type codes below)*	The number Sold	Unit Price in KSHs

Codes
Livestock Type: 1=Cattle, 2=Goat, 3=Sheep, 4=Donkey, 5=Poultry, 6= others, please specify [_____]

Section 5: Social capital

5.1 Did you belong to a farmer groups or organization in your community during the last 12 months? [______] (1=Yes, 0=No).
If Yes fill the table below. IF No skip to question 5.2

5.1.1	5.1.2	5.1.3	5.1.4	5.1.5
Type of Group/Organization *(See the Type of Group codes below)*	What is the most important function of the group or organization? *(See the function codes below)*	Is there a Membership fee? *1=Yes 0=No*	If yes in 5.1.3 How much in Ksh.	Role in the Group *(See the Role codes below*

Codes:
Type of Group: 1=Women Group/ Chama, 2=SACCO/Credit Group, 3=Farmer Cooperative, 4Input Supply Group, 5=Producer and Marketing Group, 6= Youth Group, 7=Others, please specify [__________]
Function:1=Produce marketing, 2=Input access, 3=Savings and credit, 4=Farmer trainings, 5=Transport services, 6= Share Inputs (Labor, Capital), 7=Other, please specify [__________] multiple
Role: 1= Administrative, 2= Ordinally Member, 3= Other, please specify [__________]

5.2 If you have NOT been a member of any community group/organization for the last 12 months, why? [_____] *use codes below*
Codes: 1=They are not available, 2=They are time wasting, 3=I am not interested in being a member, 4= The group/organization are corrupt/ poorly managed, 5=Gender restriction, 6=Other reason, please specify [________________________]

Section 6: Access to credit

6.1 Did you acquire loan during the last 12 months [____] (1=Yes, 0=No).

6.2 If No in 6.1 Why NO [____] *use the codes below*
Codes 1=No need, 2=Not aware of the availability of credit, 3=Lack of enough collateral to secure a facility, 4=High interests for the credit 5=Long credit application procedures. 6=. Other, please specify

6.2.1	6.2.2	6.2.3
Loan type *(use codes below)*	The main purpose for which the credit was acquired *(use codes below)*	Amount Received

Codes:
Loan type: 1=Formal bank, 2=Micro finance institution, 3=SACCO, 4=Community groups, 5= Informal Sources (e.g. Neighbour / Family), 6=Mobile money, 7=Others, please specify [_________]
Loan purpose: 1=Farm inputs, 2=School fees, 3=Food, 4=Land, 5=Livestock, 6= Expand business, 7=Farm implements/equipment 8=Other, please specify [_________]

Section 7: **Access extension services**

7.1 Did you receive extension services in the last 12 months [____] *(1=Yes, 0=No).*
If Yes, fill the table below: If *No* skip to question 7.2

7.1.1	7.1.2	7.1.3	7.1.4	7.1.5
Source of extension services *(use the extension source code)*	What kind of information did you receive from this source (*use the codes below)?*	Did you receive this information at the appropriate time? *(1= Yes ,0=No)*	Did you apply this information? *(1= Yes, 0=No)*	What were the terms of provision of the extension services (*use the codes below)*

***Codes*:**
Extension Source: 1= Researchers, 2=Farmer to farmer, 3=Media (Magazine, TV/radio, 4=Out grower (seed companies), 5=County Government,6=NGO, =Development Organization, 7=Online Groups (Facebook, WhatsApp), 8=Religious Group (Churches, church committee), 9=Others (specify)

Kind of information: 1=Pests and diseases, 2=Markets & prices, 3=Government initiatives/ projects, 4= Good agricultural practices, 5= Post-harvest 6= Other, please specify [__________] inputs
Terms of provision of the extension services: 1=Free, 2= Paid, 3=Others, please specify [__________]

Section 8: **Information on other incomes and their sources**

8.1 For the different sources of income specified in the table below, please specify whether the household earned any income.

8.1.1	8.1.2
Income Source	Did anyone in the household earn income from this source *(1= Yes, 0=No)*
Formal salaried employment (e.g., civil servant, private sector employee)	
Informal Salaried Employment	
Business – Trade or services	
Sale of natural resources products (e.g., Sand harvesting, Mining, Timber)	
Pensions	
Renting out land	
Remittances	
Others, please (specify) ______________________	

Section 9: **Follow up**

9.1 If you don't mind, could you please share your phone number, so that I can call if I need a clarification in any of the responses that you have provided [___________]

Concluding information

Interview: end time [______________]

Thank you very much for your time.

Appendix 5: Focus Group Discussion (FGD) Questionnaire

Assessment of the application of soil carbon enhancing practices in Western Kenya

The purpose of this FGD is to obtain exploratory insights from farmers and various stakeholders' in western Kenya on various soil management practices applied by households in the area. It is also intended to give a broader understanding of the importance of these practices, and the constraints or challenges and opportunities revolving around the same.

Checklist for discussion;

1. What are the economic activities practised by most households in this area? (*Hint: crop or livestock production, small business, informal or formal employment)*
2. What are the crop varieties commonly grown in the area (Hint: *food crop, cash crop, fodder crops)*? What are the benefits of growing these crops to households *(Hint: income, food, forage, enhance soil fertility*)?
3. What soil types and their characteristics (Hint:|*example Clay or loam and their oil colour and size of particles*) are found in this area?
4. How would you compare soil fertility now and 5-10 years ago (Hint: *Has it improved, declined or remained the same, Explain*)?
5. Have the changes (4 above) affected the environment (*e.g., water pollution, soil erosion*), crop yields *(e.g., increase or decrease*), household income and food security (*e.g. Food availability and variety*) over the years?
6. What are some of the soil management practices employed by households to improve fertility? (*Hint: List all the practices mentioned by farmers*)
7. Of the practices listed (in 6 above) which are the four most important? (Hint *as practiced by a majority (more than 60 percent) of farmers)*?
    a) Can you assess the benefits (*other than enhanced soil fertility)* of the practices listed in 7 above?
    b) What are some of the challenges faced in implementing the practice in 7 above (*from the male and female perspective*)?
8. Do you or have you received any information or training on implementing practices listed in 6 in the last 2 years? (*Will be a yes or no answer, Record the percentage of farmers*)
    a) Where to you get this information *(Hint NGOs, Extension officer (govt), Researchers, Other Farmers, Tv, Radio, Religious Groups*) (*We will follow up on farmers that said Yes in 8)*

b) And are there challenges faced in accessing such information? (*Hint: reliability, accessibility, availability, timeliness*)

c) Which actors (*e.g. extension officers, NGOs, community groups, other experienced farmers*) do you think would be important in ensuring more households adopt soil fertility management practices?

9. Apart from the practices named in 6 above, would you be willing to implement other soil fertility management practice of introduced to you (*Hint: we will ask about other practices that we are aware of but the farmers are not practising or have not mentioned)*

10. What are the main sources of cooking fuel? (*Hint: crop residue, firewood, kerosene, gas: record percentage of farmers using different sources*)

11. Do you work in other people farms for income before or after working on your farm? (*Yes or No answer Capture labour trade-off)*

Thank You