ASSESSMENT OF IMPACT OF CLIMATE CHANGE ADAPTATION INTERVENTIONS ON HOUSEHOLD INCOME: CASE OF ADOPTION OF IMPROVED PIGEON PEAS UNDER *FANYA JUU* TERRACES IN SOUTHEASTERN 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 University.

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To my mother, Dammar Nasbwon, to the loving memory of my late father, Jesse Mulunda Matere, and my sons, Shaddy Osambulla and Sidi Jesse Matere.

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ABBREVIATIONS AND ACRONYMS

AEZ	Agro ecological zone
ASALs	Arid and Semi-arid Lands
FAO	Food and Agricultural Organization of the United Nation
GDP	Gross Domestic Product
GoK	Government of Kenya
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute (Currently KALRO)
KES	Kenya Shillings
KIHBS	Kenya Integrated Household Budget Survey
KMD	Kenya Meteorological Department (currently Kenya Meteorological Services)
KNBS	Kenya National Bureau of Statistics
MoALF	Ministry of Agriculture, Livestock and Fisheries
SEK	South Eastern Kenya
SWC	Soil and Water Conservation
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change

ABSTRACT

Climate change presents a formidable challenge to agricultural production in developing countries that largely depend on natural resources and agriculture for livelihood. For a long time, the integration of improved pigeon pea varieties in *fanya juu* terraced plots has been promoted in semi-arid areas of Kenya to improve smallholder pigeon pea production's resilience to climate change. However, farmer's perception of the technology as an adaptation strategy, the factors influencing its adoption, and the impact of the adoption on smallholder farming households are unknown. This study evaluated the impact of adoption on the pigeon pea gross margins in farming households in Machakos, Makueni, and Kitui counties. The specific objectives were to: (i) assess the factors influencing farmers' perception of the usefulness of integrating improved pigeon pea varieties in *fanya juu* terraced plots as an adaptation strategy to climate change, (ii) evaluate the factors influencing the adoption, and (iii) determine the impact of integrating improved pigeon pea varieties in *fanya juu* terraced plots as an adaptation strategy to climate change on household's gross margins. Cross-sectional data were collected from 400 households that were selected through multistage and random sampling approaches. The characteristics of respondents were established from the data. A multivariate probit was used to evaluate factors influencing farmers' perception of the usefulness of the technology and the endogenous switching regression model was used to assess the factors influencing adoption of the technology and the impact of adoption on the gross margins. The study found that farmers perceived that growing improved pigeon pea varieties in *fanya juu* terraced plots enhances the resilience of pigeon pea production to climate change, increases yields, makes it easy to carry out the technology, and increases crop residue fodder and fuel wood.

The slope of the plot cultivated, the female household head, and access to agriculture extension services significantly influenced farmers' positive perception of the usefulness of the technology as an adaptation strategy to climate change. About 34% of the households sampled were growing improved pigeon peas in *fanya juu* terraces. The years of experience in farming, ownership of land and livestock, the slope of cultivated land, positive perception of the usefulness of the technology in adapting to climate change, contact with agricultural extension services providers, and membership in farmers groups of the household head significantly influenced the adoption. The integration of improved pigeon pea varieties in *fanya juu* terraced plots increased the household gross margins. Accordingly, adopters got on average KES 31,852 per acre per year compared to KES 22,028 in non-adopting households. In a hypothetical case that farmers who adopted, did not adopt, they would have earned 14.6% less income. In another case, if nonadopters, actually adopted, they would have earned 33.8% more than those not adopting. The study concludes that the integration of improved pigeon pea varieties in *fanya juu* terraced plots as an adaptation strategy to climate change increases gross margins in pigeon pea production. The study recommends that policy interventions, designers, and promoters of agricultural adaptation to climate change should consider appropriate targeting to wide-scale adoption of climate change adaptation technologies to increase returns.

CHAPTER 1: INTRODUCTION

1.1 Background

Climate change impacts are predominantly adverse and are felt across global, regional, and national and farther down to the local scales. The Intergovernmental Panel on Climate Change (IPCC) defines "climate change" as "a change in the state of the climate that can be identified by changes in the mean and/ or the variability of its properties, and that persists for an extended period, typically decades or longer" (IPCC, 2007). Climate change manifests notably in the form of extreme climatic and weather conditions including droughts, floods, strong winds, frost, and heatwaves among other extremes that often pose unprecedented threats to livelihoods, economies, and overall well-being of the current population, and future generations (IPCC, 2018; Ranasinghe *et al.,* 2021). Climate change presents a formidable challenge to agriculture and the dependent socio-economic sectors in terms of reduced productivity, increased food prices, and loss of livelihoods (IPCC, 2022). Agricultural production in developing countries is largely rain-fed and constitutes the mainstay of national economies and community livelihoods that are susceptible to disruption by extreme climatic events (IPCC, 2014). The dependency of the agricultural sector on climatic conditions makes it vastly susceptible to variability in climate. For example, studies report that an increase in atmospheric temperature by 2 degrees Celsius is anticipated to reduce the performance of the agricultural sector particularly in developing countries, leading to a significant drop in economic growth (Dell *et al.* 2012; Savo *et al*., 2016; Ranasinghe *et al.,* 2021).

Worldwide climate change is already on course and is projected to have adverse biophysical and socio-economic impacts on African Agriculture (Affoh *et al.,* 2022; IPCC, 2007; Niang *et al.,* 2014; Woetzel *et al.,* 2020). Some of the predicted biophysical impacts include the deterioration in the quality and quantity of crops, livestock, land, soil, and water resources (Affoh *et al.,* 2022; Rosenzweig *et al*., 2014; Woetzel *et al.,* 2020). For example, the current drought-like conditions in much of the developing world have put downward pressure on crops and livestock yields, and increased food prices (IPCC, 2022). This has reduced the contribution of agriculture to the national gross domestic product (GDP) and increased the proportion of populations at risk of hunger and nutrition insecurity in Sub-Saharan Africa (FAO, 2019; IPCC, 2007; Partey *et al.,* 2020).

In Kenya, rain-fed farming is the main occupation of the majority of resource-poor, rural communities (Kalele *et al.,* 2021; Kimani *et al.,* 2015). Stable temperature and adequate and well-distributed rainfall are major determinants of agricultural productivity and success in agricultural production systems (Gichangi *et al.,* 2015; Kalele *et al*., 2021; Kwena *et al*., 2018). Rapid population growth against declining high-potential arable land areas has led to increased cultivation in the already water-stressed, arid, and semi-arid lands (ASALs) that has compromised agricultural productivity (Kogo *et al*., 2020; Ngugi *et al.,* 2015). Additionally, continued cultivation of the steeply sloping terrain in marginal areas has inexorably accelerated land degradation through soil erosion and moisture loss, deforestation, and shortening of fallow periods between cropping cycles (Kalele *et al.,* 2021; Ngugi *et al.,* 2015). Uncontrolled cultivation of semi-arid areas that are susceptible to droughts and occasional flooding has negated efforts made towards sustainable long spells of food security (Kogo *et al*., 2021). With a yearly population increment rate of 2.2% in Kenya (KNBS, 2020) and a resultant increase in demand for food against a dwindling arable land size and declining agricultural productivity, it is increasingly necessary for farmers to adopt appropriate agro-technologies that improve and sustain agricultural productivity.

Insistence on adaptation to changes and variability in climate to minimize its adverse effects and exploit any benefits brought about by the changes has been widely made (IPCC, 2007; 2014; 2018; Lipper and Zilberman, 2018; Ranasinghe *et al.,* 2021). To minimize the footprints of climate change that cannot be reduced through mitigation actions, the IPCC (2014) notes that Africa needs to adapt, emphasizing that adaptation brings benefits both today and in the future. UN SDG number 13 calls upon all UN member countries to "strengthen resilience and adaptive capacity of developing countries to climate-related hazards and natural disasters" (Blanc, 2015; UN, 2012). While responding to the aforementioned SDG, the Food and Agriculture Organization (FAO) generated the "climate-smart agriculture" (CSA) concept to (i) promote agricultural technologies that sustainably upsurge productivity to increase income, food security and economic growth in developing countries; (ii) strengthen adaptive capacity and resilience of farming systems to climate shocks and (iii) diminish GHG emission and increasing carbon sequestration where possible (Lipper *et al.,* 2018).

Extensive adaptation technologies and practices have already been successfully used by farmers in the semi-arid lands of Kenya. Notable ones include the growing of drought-tolerant crop varieties, shifting planting dates, irrigation, soil and water conservation (SWC), tree planting, rainwater harvesting, changing crop types, and keeping of drought-tolerant livestock breeds that have increased productivity and strengthened farming resilience to climate change (Bryan *et al.*, 2013, Kalele *et al.*, 2021; Kichamu *et al.*, 2018; Musafiri *et al.*, 2022; Recha *et al.*, 2016).

The southeastern region of Kenya (SEK) covers Machakos, Makueni, and Kitui counties that fall under the semi-arid zone (Kalele *et al.,* 2021; Gichangi *et al.,* 2015). The zone is epitomized by variable and sporadic rainfall in terms of onset, intensity, distribution, and cessation (Gichangi *et al.,* 2015). The region suffers from low farm productivity, high occurrence of crop and livestock pests and ailments, and high and rising poverty (Kalele *et al.,* 2021; Kwena *et al.*, 2018) It is no wonder that a large number of residents are in a high risk of hunger, nutritional deficiencies and poverty ascribed to the adversarial effects of climate variation (FAO, 2019; Kalele *et al*., 2021; Kogo *et al.,* 2021; McSweeney *et al*., 2009).

Pigeon pea (*Cajanus cajan*) is among the major staple and cash crops produced in the SEK region. The region produces two-thirds of the total pigeon pea production in the country (GoK, 2016; Kwena *et al.,* 2021). Apart from being a food staple, pigeon pea is also used as fodder (biomass) for livestock and fuel wood (stems) (Esilaba *et al.,* 2021; Mergeai *et al.* 2001; Shiferaw *et al*., 2008). The grains are verily nutritious containing protein, starch, crude fiber, minerals, and fat (Saxena *et al*., 2018). The crop fixes nitrogen into the soil and releases soil-bound phosphorus, thus ameliorating the nitrogen and phosphorus deficiencies that typify most soils in dry areas in Kenya (Esilaba *et al.,* 2021; Odeny, 2007). Thus, pigeon pea production in SEK has great potential to enhance household income, boost food and nutrition security, improve soil fertility, and enhance the farming system's resilience to the changing climate.

Climate change exerts biotic as well as abiotic stress on pigeon pea production, especially on the indigenous landraces grown in the SEK region. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) collaborated with the University of Nairobi and Kenya Agricultural and the Livestock Research Organization (KALRO) and developed improved varieties (Esilaba et al., 2021; Ojwang *et al*., 2016). The varieties have high-yielding, early-maturing, drought-tolerance and *Fusarium* wilt disease resistance traits (Ojwang *et al*., 2016). To improve household food security, and income and enhance smallholder farming systems adjustment to changes in climate. The improved varieties were disseminated in SEK by the

Ministry of Agriculture, KALRO, and ICRISAT under the dryland seed and small seed packs programs and through the Kenya Climate Smart Agriculture project (Esilaba *et al*., 2021).

In addition to the deployment of drought-tolerant crop cultivars, SWC has been recommended as a crucial adaptation approach to mitigate growing water scarcities, deteriorating soil health, drought plus desertification, and crop loss due to diminishing and erratic rainfall (Ackermann *et al*., 2012; Deressa *et al.*, 2009; FAO, 2014; Ngugi *et al*., 2015; Recha et al., 2016). The typical SWC technologies used in smallholder farming systems in Kenya include terraces, water-retention ditches, stone bunds, grass strips hedgerows (Recha *et al.*, 2016). Terraces and stone bunds are constructed to abate runoff, increase soil water retention capacity, and abate denudation of cropping fields (Mati, 2005; Recha *et al.*, 2016).

The integration of drought-tolerant crop varieties in SWC practices is commended for resilience to changing climate in semi-arid areas of East Africa (FAO, 2014; Njiru *et al.*, 2022) and in Kenya (Bryan *et al.*, 2013; FAO, 2014; Ngugi *et al.*, 2015; Recha *et al.*, 2016). The incorporation of improved pigeon peas in SWC has been shown to triple crop yields compared to local landrace produce (Kwena *et al.*, 2017). *Fanya juu* (a Swahili word for ‘do upwards’) terracing, notably on sloppy terrain, is a widespread SWC practice in the semi-arid areas of SEK (Recha *et al.*, 2016) (see Figure 1.1). For many years since the 1930s, *fanya juu* terraces have been established in Kenya to abate land degradation (Tiffens *et al.*, 1994). The spread of the technology intensified in the 1980s under the National Soil and Water Conservation Program (Ericksson, 1992) and has continued under the Land Resource Management programs (Karuku, 2018).

Figure 1.1: Image of improved pigeon peas on a *fanya juu* terraced plot in Kyale village, Makueni County

Fanya juu terracing is an *in-situ* water conservation technology where rainwater is conserved where it falls (Mati, 2005). Stone terrace walls can be built to reinforce the embankment on very steep slopes. The terraces are made by burrowing ditches and trenches along the contour and throwing the soil uphill (or throwing soil downhill *fanya chini*) to form an embankment to abate soil erosion and conserve water (Mati, 2005). As the gradient of the terraces slowly shrinks yearly, more fertile soil is preserved in the crop-growing area. Establishment of diversion ditches within the terraces helps to control excess water runoff (Recha *et al*., 2016). The ability of the terraces to facilitate adaptation is in optimizing the use of water (Delgado *et al*., 2011; Deressa *et al.*, 2009; FAO, 2014). This is achieved through improved collection and distribution of water in the soil that increases crop yields (FAO, 2014).

Fanya juu terracing is a popular SWC technology promoted in the area (Gachene *et al*., 2019; Njiru *et al.*, 2022; Miriti *et al*., 2012; Recha *et al*., 2016). Farmers are expected to adopt improved pigeon pea in *fanya juu* terraced plots to ameliorate the effects of variability and changing climate and heighten food production and income in resource-limited, small-scale farming systems in dry areas of Kenya (Esilaba *et al.*, 2021). However, the decision of the farmers to adopt an innovation depends on the perceived attributes of the technology (Adesina and Baidu-Forson, 1995; Maina *et al.,* 2021). Therefore, technology uptake is contingent on users' judgment of the value of the technology to them (Adesina and Baidu-Forson, 1995; Davis, 1989). The information on how farmers perceive growing improved pigeon peas under *fanya juu* terraces is vital in informing and/or strengthening the promotion of improved pigeon pea planting in *fanya juu* terraces among resource-poor farmers in semi-arid areas of SEK.

1.2 Statement of the Research Problem

Agriculture in the SEK region is predominantly rain-fed and carried out by smallholder farmers who experience low and declining productivity (Kalele *et al.,* 2021). The region is ecologically fragile and susceptible to the changing climate that manifests through increased frequency and severity of droughts, declining rainfall amounts, and disrupted seasonal patterns (Gichangi *et al.*, 2015; Kwena *et al.*, 2021). About 35% of the populace in SEK lives beneath the poverty line of US dollars 1.9 per day (KNBS, 2018). The annual population growth rate in SEK is estimated at 1.8% and 31.4 % food poverty with per capita food consumption expenditure below KES 2,000 in rural areas and below Ksh 2,600 in urban areas (KNBS, 2019). Low farm yields in the farming communities aggravate household poverty.

Although the improved pigeon pea-*fanya juu* technology package has been promoted in SEK as a remedy for ameliorating the climate change-induced low cereal productivity in SEK (Esilaba *et al.*, 2021: Miriti *et al*., 2012; Njiru *et al.*, 2022), however, the adoption is low (Makena *et al*., 2021; Wambua, *et al*., 2017). A knowledge gap exists in farmers' perception of the usefulness of the package in adjusting to changes in climate, the adoption of the package, and the effect of the adoption of the technology package on household income. This study aimed to fill these gaps in knowledge.

1.3 Objectives of the study

The overall objective of this study was to examine the effect of the adoption of improved pigeon peas under *fanya juu* terraces on household income among smallholder farmers in SEK. The specific objectives were to:

1. Assess farmers' perception of the usefulness of adopting improved pigeon peas on *fanya juu* terraced fields in adapting to climate change.
2. Evaluate the factors influencing the adoption of improved pigeon peas in *fanya juu* terraced fields as an adaptation strategy to climate change.
3. Assess the effect of the adoption of improved pigeon peas on *fanya juu* terraces on household income.

1.4 Hypothesis tested in the study

1. Farmers do not perceive the positive usefulness adopting of improved pigeon peas on *fanya juu* terraced fields in adapting to climate change.
2. Socio-economic factors do not influence farmers' adoption of improved pigeon peas in *fanya juu* terraced fields.
3. Adoption of improved pigeon peas in *fanya juu* terraced fields does not increase households' farm income.

1.5 Justification of the study

Farmer's perception of a technology influences adoption (Rahman, 2003). It has been shown empirically that farmers' perception of the relative advantage of the technology, often in terms of economic benefits, plays a significant role in its adoption (Maina *et al*., 2021; Murage *et al*., 2015).

Farmers' perception of an adaptation technology and its adoption could be influenced by many socio-economic, and environmental factors. Examining farmers' perception of integrating improved pigeon peas in *fanya juu* terraced plots as an adaptation technology and its adoption within a semi-arid environment could help to identify the constraints and opportunities to adaptation and thus generate knowledge that is important for formulating specific policies favorable for semi-arid farming environments.

Assessing the effect of food legume technology uptake can be supported by providing feedback to research programs and informing policy formulators, agricultural extension service providers, and other promoters of the technology on the effects of adopting agricultural technologies and providing information on whether or not clientele get value propositions from the research products and the modifications required to increase adoption and its positive effects. This could add to the body of knowledge and practice that meets the increasing demand for impact assessment to generate a superior understanding of the convergence of agricultural technology and its contribution to alleviating food insecurity in developing countries that are characterized by smallholder resource-limited farmers. This study will contribute towards providing requisite information.

The linkage between adaptation to climate change and enhanced productivity, income, and food security is context- and location-specific (Skoufias *et al.,* 2012; Olsson *et al.,* 2014). Therefore, integrating improved pigeon pea crop varieties with existing SWC practices in the smallholder farming systems of SEK will contribute immensely towards the Government's goal of enhancing the dryland farming system's bounciness to climate change and contribute to Kenya's Vision 2030 and the second and 13th United Nation's Sustainable Development Goal on reduction of household hunger and climate action.

CHAPTER 2: LITERATURE REVIEW

2.1. Pigeon pea production in Kenya

Pigeonpea (*Cajanus Cajan* L. Millsp.) is the third main grain legume internationally (FAOSTAT, 2020). It is grown on about 7.32 million hectares, producing 7.2 million metric tons yearly and yielding 1005kg per hectare (FAOSTAT, 2020). The main producers in Africa, are Malawi producing 424, 333 tons, Tanzania (136, 274t), Kenya (123, 627t), and Uganda (17,914t) (FAOSTAT, 2020). Kenya is ranked fifth globally, producing 2.1% after India (62.7%), Myanmar (21.3%), Malawi (6%), and Tanzania (4.9%) (FAOSTAT, 2020). In Kenya, pigeon pea is predominantly produced in semi-arid areas due to their adaptability to dry weather conditions (Kwena *et al.,* 2017; 2018; Esilaba *et al.,* 2021). Soil water management practices are used to enhance soil moisture in pigeon pea production in semi-arid areas (Esilaba *et al*., 2021; Kwena *et al.,* 2017).

Pigeon pea is an important crop for food and nutritional security and a source of income in semi-arid Kenya (Kwena *et al.,* 2021). It yields during the dry spells when other grain legumes and cereals wilt and dry up as a result of heat and moisture stress (Kwena *et al.,* 2018; 2019). The growth period ranges between 90 to 130 days for annual types and 130 to 365 days for perennials. Pigeon pea provides essential amino acids, fiber, vitamins, and minerals for human nourishment (Karri and Nalluri, 2017). It is a cheaper source of protein than meat, making it an ideal complement to typical starch-based diets (Esilaba *et al.,* 2021; Kwena *et al.*, 2018; Ojwang *et al*., 2016). Protein-richness is crucial for nutrition security because about 55% of the rural population in SEK is poor and hence not able to purchase sufficient animal proteins (KNBS, 2015). The crop is grown for multiple purposes (Esilaba *et al.,* 2021; Kwena *et al.,* 2018). The foliage and stems are used as fodder for livestock and firewood respectively, it's also grown as hedgerows for windbreaks and ground cover. The foliage fall enriches soil fertility. Its nitrogen fixation properties make it a useful source of green manure leading to little fertilizer input. The contribution of pigeon peas to household food production favors women whom the responsibility of sourcing food for the household is culturally bestowed upon Me-Nsope and Larkins (2016). The benefits of pigeon peas make it suitable for resource-poor especially women who often face deficient farm inputs (especially fertilizers) and fuelwood.

Pigeon pea production in SEK is undertaken by smallholder farmers on 0.2 -1.4 hectares (Kwena *et al.,* 2018). Pigeon pea is intercropped with cereals or tubers in sub-humid areas or planted in pure stands in dry areas. Usually, the crop is planted at the start of the September/October short rains season. Vegetable/green peas from the short and medium-maturing varieties are harvested in February and April while the long-duration varieties are harvested in June and July typically for food. The dry grain is harvested in August and September both for food and sale. The conventional varieties yield 0.6ton ha^{-1} while the improved ones range from 1.2-2.5 ton ha^{-1} (Kwena *et al.,* 2019). Past studies of pigeon pea production in SEK found low productivity in pigeon pea production in most smallholdings that was attributed to poor agronomic practices particularly poor seed selection, low soil moisture, and poor construction of the SWC structures (Kwena *et al*., 2021; Njiru *et al.*, 2022; Wambua *et al*., 2022).

2.2 Adaptation to climate change

Adaptation is a process by which approaches used to moderate and manage climate change and the opportunities brought about by climate change are enhanced, developed, and implemented (IPCC, 2007; 2022). The typologies of adaptation are categorized as anticipatory, autonomous, and planned (IPCC, 2014; Parry *et al.,* 2007). Anticipatory adaptation is a proactive action to alleviate the expected adversative consequences of the changing climate and therefore occurs before the effects of climate change happen (IPCC, 2014; Parry *et al.*, 2007). Autonomous adaptation is prompted by environmental changes in the natural and/or anthropological systems (IPCC, 2022; Parry *et al.*, 2007). Planned adaptation is the result of an intended policy pronouncement, based on cognizance to achieve a favorable state (IPCC 2007; 2022).

Farmers' adaptation to climate change is mainly autonomous (IPCC, 2001), as they take specific actions to ameliorate their livelihoods from the existing and anticipated risks of climate change (Ozor *et al*., 2010). Farm-level adaptations include water management practices, growing drought and disease-tolerant cultivars, irrigation in crop production, adjusting planting dates, diversification in the cropping system, and improved disease and drought-tolerant livestock breeds (Belay et al., 2017; Bryan *et al.*, 2013, Gbetibouo *et al*., 2010; Kichamu *et al*., 2021). The adaptability of pigeon peas to limited soil moisture and medium temperatures makes them an appropriate crop for semi-arid areas (Kwena *et al.*, 2021.

2.2.1 Adaptation strategy to climate change in Kenya

The Government of Kenya officially acknowledges climate change as a noteworthy danger to national development. The Government prepared the National Climate Change Response Strategy (NCCRS) to respond to the challenges of climate change (GOK, 2017). The strategy recommended robust and actionable adaptation measures to minimize risks linked to climate change while taking advantage of rising opportunities and also provided the requisite policies, and institutional framework to adapt to climate change. The strategy identified sector-specific research needs such as developing and disseminating agricultural technologies that would ameliorate the farming communities' hunger and poverty (GoK, 2017).

The National Climate Change Action Plan (NCCAP) was set up to execute the NCCRS by providing the analysis and enabling mechanisms to make implementation successful. The NCCAP provides an all-encompassing institutional framework that outlines the roles and responsibilities in reacting to and managing climate change risks at the second-tier, County-level of governance. It advocates for the provision of seasonal forecasts to farmers, and the generation and dissemination of appropriate adaptation technologies. The enactment of various actions in the NCCAP requires the representative involvement of all the stakeholders (GoK, 2017). The National Government sectors are required to incorporate the NCCAP into their policies and action plans and the County Governments integrate it into the County Integrated Development Plans (CIDPs).

The Climate Change Act of Kenya, 2016 was enacted to operationalize the NCCAP. The Act of law gives a regulatory framework to enhance reaction to climate change and gives a mechanism and measures to achieve low greenhouse gas emissions. The Act was enacted for application in all sectors of the economy.

2.3 Farmers' perceptions of agricultural technologies

Perception is a process where individuals organize and interpret their sensory impressions to give meaning to their environment (Rahman, 2003). Individual characteristics such as past experiences, interests, attitudes, motives, and expectations influence an individual's perception of technology. An individual's positive perception is likely to increase adoption and sustain it in the future. On the contrary, a negative perception is likely to reduce adoption (Lord and Maher, 1999). The sustainability of agricultural production is largely dependent on the actions of farmers and their decision-making abilities given the level of knowledge and information that is available to them (Rahman, 2003).

Based on perceived attributes of a technology, Nutley *et al*. (2002) propose five characteristics upon which the rate and likelihood of adoption of a technology are judged. Some of these characteristics are intrinsic to the technology itself while others concern the adopters' characteristics and their usage of the technology. They are relative advantage, compatibility, complexity, trial-ability, and observability. Relative advantage is how a given technology is perceived as superior to any technology it might replace. It is dependent upon a farmer's unique set of interests, influenced by the expected cost structure and yields, social factors (current circumstances), and cultural factors namely beliefs and norms within which the innovation will be applied. Farmers' perception of the relative advantage of the technology plays a significant role in adoption among farmers, often in terms of short-term economic benefits (Maina *et al*., 2021; Meijer *et al*., 2015; Pannell, *et al*., 2006).

Compatibility of a technology refers to how the technology is perceived to be consistent with adaptors' existing values and practices (Davis, 1989; Nutley *et al*., 2002). How synchronized a new technology is with an existing one increases the chances of adoption since it makes the new technology relatively familiar. Complexity refers to the difficulty of understanding the application and actual use of a given technology (Davis, 1989; Nutley *et al*., 2002). If a potential adopter perceives an innovation to be complex, it reduces the chances of adoption (Davis, 1989; Meijer *et al*., 2015). Trialability refers to the opportunity for a potential user to test a technology in an experimental setting (Nutley *et al*., 2002). The targeted user can also test the merits and demerits of a technology without necessarily committing to adopting it (Davis, 1989; Nutley *et al*., 2002). This plays a critical role in enhancing persuasion and implementation of the technology by minimizing uncertainty and risk associated with the adoption of such technology (Pannell, *et al*., 2006), and is dependent on the observability of results (Cary *et al*., 2001).

Observability refers to how visible the use of the technology is to others (Reimer *et al.*, 2012). Seeing, hearing, and knowing that other individuals are using the technology significantly encourages adoption (Reimer *et al.*, 2012). This study assumes that the integration of improved crop varieties in soil and water conservation structures whose results are observable to potential adopters is more likely to increase adoption. Perceived attributes, particularly observability of a practice play a key role in influencing the norms and control beliefs of the adaptor (Reimer, *et al.*, 2012). Access to information is regarded to be a key factor influencing both perception and adoption. The decision to adopt an innovation is regarded as a mental process that follows a sequence of stages: knowledge, persuasion, decision, implementation, and confirmation (Rogers, 2003).

Several studies have been undertaken on farmers' perceptions of SWC practices. Morges and Taye (2017) examined the determinants of farmers' perception of utilization and investment in SWC technologies in the wet, north-western highlands of Ethiopia. They used descriptive statistics and a logistic regression model in their data analysis. They found that the level of education of the respondents, plot size, terrain, and slope type, land ownership of land, access to training, and contact with extension officers positively and significantly determined the farmers' perception of SWC technologies. Conversely, age and plot distance from the homestead negatively but significantly influenced the farmer's perception. They concluded that farmers' perception of SWC technologies was highly affected by socioeconomic, institutional, attitudinal, and biophysical factors.

Mekonnen *et al.* (2016) assessed the factors determining farmers' perception of farmers in Eastern Ethiopia using the general linear model. They found that farmers' training, plot size, and number of ploughing influence perception positively while manure application and distance of the field from the homestead affected perception negatively.

Several studies have analyzed farmers' perception of climate change and adaptation strategies undertaken in response to climate change including Bryant (2000) in Canada, Gbetibouo *et al.* (2010) and Maddison (2006) in South Africa, and Ndambiri *et al.* (2014) in Kenya. The studies reported that farmers perceived that there is climate change in terms of increased temperatures and reduction of rainfall over time. The analysis showed that farmers' perceptions of climate change were in line with the climatic data records. Farmers responded to the changes by diversifying crop and livestock production, irrigating their farms, using soil and water conservation practices, changing their planting dates, and growing drought and pest-tolerant varieties among other farm practice adjustments. However, there is limited information on farmers' perception of technology as an adaptation measure to climate change.

2.4 Overview of agricultural technology adoption studies

Agricultural technology can be recently developed in a particular location or to farmers but has already been adopted in another place (Loevinsohn *et al.*, 2013). Agricultural technologies aim to make better an existing situation or reverse the status quo to a more recommendable level (Loevinsohn *et al.,* 2013). Adoption is the incorporation of an innovation into the prevailing practice, it is a process starting from the time the farmer hears about it, takes time to understand it, and finally accepts to utilize it (Loevinsohn *et al.*, 2013). The rate of technology uptake (adoption) is defined as the percentage of farmers who implemented a given technology while the intensity of adoption is described by the proportion of the farms under the technology (Rogers, 2003). The rate, pattern, and intensity of innovation requirements (Loevinsohn *et al.*, 2013). In developing countries adoption of agricultural technologies has got enormous attention because technology adoption varies with crop type and location, and the specific majority of the populations derive their livelihood from agricultural activities. Some studies found that innovations offer opportunities to amplify productivity and income (Cunguara, and Darnhofer, 2011; FAO, 2014; Khonje *et al.,* 2015; Mignouna *et al.,* 2011; Noltze *et al.,* 2013). New technologies increase agricultural productivity, especially when efficient, and require relatively low cost. Yield-enhancing technologies are appropriate for areas previously deemed impossible to meet the needs of a growing population given the restraining land size (Rogers, 2003). Constraints to the adoption of new technologies reduce productivity; in such cases, it necessitates studies to identify such constraints and ascertain modifications that are likely to enhance adoption. The proof of constraints in the adoption of agricultural technologies is normally reflected in the low adoption rates. Farm and farmer characteristics cause observed differences in the adoption rates (Feder *et al.,* 1985; Khonje *et al.,* 2015). Studies have explained the pattern of adoption behaviour (Abdulai and Huffman, 2005; Herrero *et al.,* 2014, Tiamiyu *et al.,* 2009, Simtowe *et al.,* 2012a).

Several studies have analyzed the adoption of pigeon peas and water conservation practices separately. Simtowe *et al*. (2012) used a probit model to analyze the determinants of adopting improved pigeon peas in the drylands of Kenya. They found out that awareness of the existence of improved seeds and access to the seed significantly influenced adoption They also found that the adoption rate in the observed sample was 36% which would have increased to 48% had the entire population been exposed to the improved seeds. This study adds to the existing information by providing data on the impact of adoption on farmers' net income which is necessary for better understanding the effect of research intervention. Otieno *et al.* (2011) examined the importance of varietal qualities in influencing farmers' uptake of pigeon peas in the drylands of Taita District, Kenya. They reported drought and resistance to pest attacks, high yield, ease of cooking, taste, and price as the key pigeon pea varietal traits driving rapid adoption. They recommended that breeders of improved crop varieties should consider farmers' preferences to increase technology uptake.

Several studies have evaluated factors affecting the simultaneous uptake of several agricultural technologies. In Asia, the adoption of hybrid rice combined with inorganic fertilizers was assessed using the probit model by Jamal *et al.* (2014) in Malaysia and by Rahman (2008) in Bangladesh. Jamal found out that the educational level of the household head, farm credit, availability of labour, and vibrant agricultural extension services was critical to joint technology acceptance in Malaysia. In Bangladesh, Rahman reported that the availability of irrigation, farm assets, and the existence of well-developed infrastructure, the household's head farming experience, and the household's non-farm incomes influenced adoption.

In Sub-Saharan Africa, the adoption of hybrid maize and inorganic fertilizers was assessed by Nkonya *et al.* (2008) in Northern Tanzania and Chirwa (2005) in Malawi. Beshir *et al.* (2012) assessed the adoption of improved cereal seeds and inorganic fertilizers in Ethiopia using a double-hurdle model. The results showed that male and educated household heads, family and land size, number of livestock, non-farm income, and contact with agricultural extension service providers significantly influenced adoption. In Kenya, the contributing factors to growing hybrid maize and inorganic fertilizers were analyzed by Ouma *et al.* (2002) in Embu, Wekesa *et al*. (2003) in the coastal lowlands, and Ogada *et al*. (2014) in lowlands, midlands, and highlands in the country. Ouma *et al*. (2002) reported that labour input requirement, sex of the household head, and access to agricultural extension services significantly determined the adoption. Wekesa *et al.* (2003) found that the availability of the certified seed and its cost significantly influenced adoption. Doss *et al.* (2003) showed that age, gender, and wealth of household heads were key farmer characteristics that determined the uptake of agricultural innovations. These studies exhibit complementarity between hybrid seed and inorganic fertilizer use.

2.5 Assessment of the impact of technology adoption on farmers' wellbeing

A technological innovation generates more benefits than the previous practice that it is envisioned to replace especially when information about it is available and accessible to potential users (Anandajayasekeram and Martella, 1996). The contribution of agricultural technology to farmers' well-being can only be achieved when the technology is extensively used (Anandajayasekeram and Martella, 1996; Simtowe *et al.,* 2012b). At the farm level, the effects of adoption can be evaluated by the extent to which an intervention causes change in the well-being of target populations (Douthwaite *et al.*, 2002). The effects of an intervention can be felt by the beneficiaries a few years after the program and therefore termed short-term or have many years of relevance to be referred to as long-term. An intervention can have economic, social, institutional, or environmental effects on beneficiaries (Anandajayasekaram *et al.*, 2001). Assessment of the effect of an intervention can be undertaken before the commencement of the intervention (ex-ante) or after the intervention (ex-post), and the differences between outcomes for participants/adopters and non-participants/non-adopters (Anandajayasekeram and Martella, 1996).

An integration of quantitative and qualitative information has been used in assessing the effect of an intervention. Some of the quantitative methods used are comparisons of "with and without", "before and after" intervention, "target versus actual achievement" and "case study (La Rovere and Dixon, 2007). Estimation of a counterfactual situation about what would have happened had adoption never taken place has also been used in adoption impact analysis (Baker, 2000). The “with and without” counterfactuals can be reflected in adopters of improved pigeon pea varieties on *fanya juu* terraced plots versus non-adopters. However, outcome differences between the two groups could be caused by factors other than the adoption of a technology. This necessitates the need to determine whether a relationship exists between the adoption and outcome variables in terms of household income and food security.

This study sought to establish if a cause-effect relationship exists between the adoption of the technology and the difference in yield, net farm income, and household food consumption expenditure. The study sought to identify changes in household’s net farm income and food security from improved pigeon pea varieties produced on *fanya juu* terraced plots (for adopting households) compared to those of non-adopters and further establish that the changes emanated from the adoption of the technology rather than other factors. The establishment of appropriate counterfactual evidence was required in developing a correct causal relationship between the adoption of the technology and changes in outcomes. The outcomes were measured through productivity, net farm income, and food consumption expenditure at the household level and a further analysis was done to establish whether or not the changes in outcomes could have been influenced by other unmeasured factors.

2.6 Theories underpinning technology impact assessment

2.6.1 Theory of change

Theory of change is a representation of how a mediation is projected to function, by elucidating the several steps underlying the sequence from the interceding activities through to impacts (Douthwaite *et al*, 2008). A theory of change takes cognizance of the key actors along the chains of cause and the assumptions that intervene to work c A theory of change is developed during the program design stage, and is used as a guide in formulating the program’s evaluation tools such as surveys and interview guides that link the cause and effects of an intervention (Douthwaite *et al.*, 2008). An ex-ante theory of change assesses the probability of success of an intervention. The outcome pathway, impact pathway, and outcome logic model are some of the terminologies used to describe the theory of change (Douthwaite *et al.*, 2008).

2.6.2 The program theory

Program theory is defined as “the construction of a conceivable and workable model of a program” (Bickman, 1987). The theory simplifies coordinated cause-effect relationships in an intercession. The theory gives an explicit guide on how it is that the activities executed should derive the expected and desired outcomes and impacts (Bickman, 1987; Funnel et al., 2012).

2.6.3 Causation theory

The theory allows one to visualize the sequencing in the causal nexus (Shadish, Cook, & Campbell, 2002). Factual (or actual) cause and closer cause are the two elements of causation (Shadish, Cook, & Campbell, 2002). The factual cause is often created using the “but-for-test”. This test evaluates whether or not the event would have occurred without the actions or omissions of the defendant.

2.7 Past Studies on the impact of the adoption of agricultural technologies

Mignouna *et al.* (2011) analyzed the impact of combating *Striga sp.* weeds by taking up imazapyr-resistant maize technology and organic fertilizers on farm returns of smallholder maize producers in Western Kenya. The study used the tobit model to establish the determinants of the technology’s uptake. A gross margin analysis was used to estimate the difference in net returns in adopting and non-adopting households. The study found out that farming experience, risk-taking, education, the number of extension visits, the gap between maize production and consumption, availability of seeds, and membership in social groups influenced adoption. There was a significant difference in gross margins, adopters had gross margins of KES 51, 753 per hectare per year while non-adopters got KES 26, 566. The study concluded that the adoption of imazapyr-resistant maize technology and organic fertilizers was profitable for smallholder farmers and could have the potential to reduce food insecurity in striga-infested maize production areas in Kenya as climate change poses more threat of pest and disease incidence in crops.

Tesfaye *et al.* (2016) examined the impact of adopting better-quality wheat varieties and inorganic fertilizers on farmers' income in Ethiopia. The propensity score matching approach was applied in estimating the rate of uptake and its effect on farm households' income. Adopters increased production by 1.1 tons per hectare compared to the non-adopters and had an increase in farm income by a range of 35 to 50%. Hailu *et al*. (2014) assessed the impact of the adoption of yield-enhanced wheat varieties and inorganic fertilizers on farm income in Southern Tigray using cross-sectional data. They used the probit model to establish the predictors of the adoption of the technologies. The results showed that adopters generated 6,672 Ethiopian Birrs more than their non-adopter counterparts.

Propensity score matching method is broadly applied in technology impact analysis while addressing the self-selection problem (Amare *et al*., 2012; Hailu *et al*., 2014; Tesfaye *et al.,* 2016). The approach balances the distribution of observed covariates in the non-adopting and adopting groups (Rosenbaum and Rubin, 1983) and limits the logit/probit estimates to be interpreted as determinants of adoption (Abdullai and Huffman, 2014; Lee, 1982). The ESRM is a remedy used to address both the self-selection bias problem and the limitations in estimating the predictors of adoption while partitioning the farm outcomes into two categories (Abdullai and Huffman, 2014; Ojo *et al*., 2021; Wu, 2022).

CHAPTER 3: METHODOLOGY

3.1 Conceptual framework

Agriculture is a core sector in rural development in SEK. The predicted negative impacts of climate change are likely to destroy the indispensable agricultural activities that are essential for sustainable development. To redress these impacts, farmers have taken specific actions to strengthen their livelihoods against the anticipated or experienced risks of climate change. As shown in Figure 3.1, climate change causes negative effects on pigeon production systems in the form of reduced crop yields, reduced marketable surplus, and farm income to the household, and contributes to household food insecurity. Climate change adaptation measures such as growing improved pigeon pea varieties under fanya juu terraces (SWC). Farmer's perception of growing improved pigeon peas on *fanya juu* terraces as a strategy to enhance the farming system's resilience to climate change prompts its adoption. Farmers' perceptions about new farming practices are influenced by their knowledge which is reflected in the level of education and/or the experience they have about the technology. The perceptions emanate from a farmer's opinion and judgment about an innovation and prior experience with that technology. Socioeconomic factors like farmers' experience and level of education of the farmer and institutional factors like access to agricultural extension services influence their perception of the technology. Farmers' knowledge of the technology arises from the information and understanding of the technology and expected benefits (Meijer *et al.*, 2015). Farmer's perception of the technology influences adoption. Therefore, the adoption of improved pigeon peas on *fanya juu* terraces is posited to be influenced by socioeconomic and institutional factors. Adoption of the technology is expected to cause short-term (intermediate) outcomes in the form of increased yield/food income, and food consumption expenditure. The long-term impacts are enhanced food security.

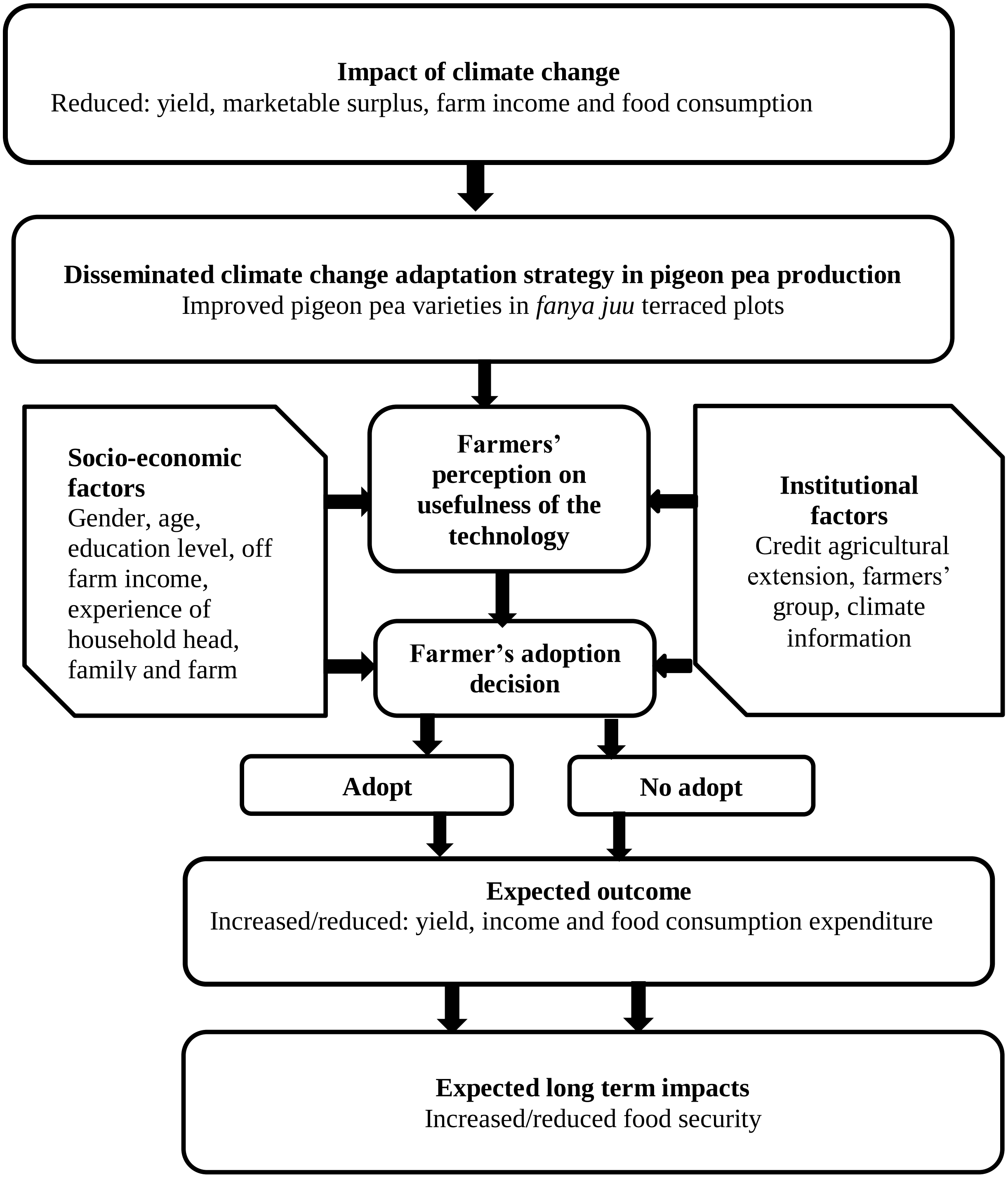

Figure 3. 2 Conceptual frameworks for assessing the impact of the adoption of integrating improved pigeon peas on *fanya juu* terraced plots

3.2 Theoretical framework

This study is anchored upon the random utility theory (RUT) that posits that people make choices based on utility maximization so that only the option that yields the highest utility is chosen (Fishburn, 1968). The random utility models an individual's behavior based on choices. According to Adesina & Baidu-Forson (1995), a farmer will adopt an innovation if the satisfaction attained from adopting (utility), U_1 is more than that of not adopting, U_0. The utility a farmer derives from a product encompasses two elements; the observed characteristics (deterministic element of utility) and the unobserved part (random element). The deterministic element is exogenous, it comprises farmers' and technology characteristics, some linearly-related parameters, and the random element that emanates from measurement errors (Fishburn, 1968). This function is specified as:

$$U_{ij} = X\beta + \epsilon \quad \text{(3.1).}$$

where $U_{ij}$is the maximum utility achievable when option j is selected by farmers I; $X\beta$ is the deterministic part of the utility function, X are observable socio-economic characteristics and technology-specific factors that affect the utility, β is a vector of parameters estimated and ϵ is the stochastic term.

Farmers are thus, assumed to select a technology that they perceive yields maximum net benefits. Individual's perception of a technology determines their intention and ultimate adoption of the technology (Fishbein and Ajzen, 1975). Following (Abdulai and Huffman, 2014; Manda *et al*., 2016; Shiferaw *et al.*, 2014), the study represents the net gains to farmers stemming from taking up the technology (Y_{1i}), and non-adopters are represented byY_{2i}. The net gains also represent the outcome variables (yield, income) of the two regimes of adopting and non-adopting (Abdulai and Huffman, 2014; Manda *et al*., 2016; Shiferaw *et al.*, 2014). Now the two regimes' net benefit equation can be specified as:

Regime 1: $Y_{1i} = \beta_1 X_{1i} + \varepsilon_{1i}$ if, A_{1i}=1 for adopters……………………………………… (3. 2a)

Regime 2: $Y_{2i} = \beta_2 X_2 + \varepsilon_{2i}$ if, A_{1i}= 0 for non-adopters ……………………………..... (3. 2b)

Where: X_i represents socio-economic, institutional factors, and locational factors; β_1 and β_2 are parameters to be estimated; and ε_{1i} and ε_{2i} are error terms that are identically and independently distributed (iid) (Greene, 2012).

The farmer will typically select an innovation if the net gains derived from the uptake are more than from not taking up the innovation (Abdulai and Huffman, 2014; Manda *et al*., 2016). Letting the difference between net gains from taking up and not taking up the innovation (Y_{1i} and Y_{2i}) be denoted by A such that the farm household *i* maximizing the net gains, will decide to take up the innovation if the benefits from adopting are greater than those of not adopting the technology that is represented by:

$$A^* = Y_{1i} - Y_{2i} > 0 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.\ 3)$$

The unobservable net gains (equation 3.3) can be described in terms of the observable elements in the latent variables:

$$A_i^* = \beta X_i + \mu_i,\ with\ A_i = \begin{cases} 1\ if\ A_i^* > 0 \\ 0, otherwise \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.\ 4)$$

where: A_i is a dummy variable (0 or 1) for adopting the technology; $A_i = 1$ for adopting and $A_i = 0$ otherwise, β are parameters computed by the model and X represents locational, institutional and household characteristics.

3.3 Empirical framework

3.3.1 Factors influencing farmers' perception of growing improved pigeon pea varieties as a climate change adaptation strategy

People tend to use technology if they have faith that it will help them improve their task execution (Davis, 1989). This belief is referred to as perceived usefulness (Davis, 1989; Hair *et al*., 2010). Perceived usefulness is defined as "the extent to which a person believes that using a particular technology would enhance their production" (Davis, 1989; Hair *et al*., 2010). Thus an agricultural technology highly rated in perceived usefulness, is the one believed to have a positive use-performance relationship (Davis, 1989; Meijer, *et al*., 2014).

Farmers will take up a technology if they perceive usefulness from adoption $(U_1)$is greater than for non-adoption (U_2) (Kassie *et al*., 2015). Therefore, if farmers perceive usefulness in terms of increased productivity to enhance their food security, which arises from integrating improved pigeon peas in fanya juu terraces, then it is expected that they adopt the technology.

Farmers' perception of agricultural technologies is determined by multiple attributes (Davis, 1989; Hair *et al*., 2010; Meijer, *et al*., 2014). Following Joshi *et al.* (2015), 5-point Likert-scaled questions were used to capture farmers' perceptions of the usefulness of agricultural technologies. The questions included if the farmers perceived that the technology: increases yields, produces yields in dry seasons, produces early maturity crop, enhances soil water retention, improves soil fertility, increases the harvesting duration, produce large pods, increases drought tolerance, increases disease tolerance, increases fodder production, increases fuel wood from stalk, easy to construct terraces, easy to maintain terraces.

Farmers' perception of agricultural technologies is determined by multiple variables (Adesina & Baidu-Forson, 1995; Meijer, *et al*., 2014). Davis, (1989); and Hair *et al.* (2014) recommend that the variables are summarized into joint perception factors by using factor analysis

(Davis, 1989, Hair et al., 2014). Factor analysis measures the interdependency between variables (Jolliffe, 2002). The perception of usefulness model is specified by a matrix equation (Maina *et al.*, 2021; Pennings & Leuthold, 2000) and expressed as:

$$G_i = \omega\Psi + \delta \text{ ……………………………………………………………….. } \quad (3.\,5)$$

Where: F_i are the usefulness perceptions of ith farmer, ω are the regression coefficients to be estimated (factor loadings); Ψ is the estimated effect of the factor loadings and δ are error terms in the variables.

The factors are derived through rotation factor loading using the varimax stata command to maximize the number of high factor loadings that enable suitable interpretation of the results (Steves, 2009; Streiner, 1994). Bartlett's test of sphericity was used to test the correlations among the variables used in analyzing farmers' perceptions of the usefulness of the technology (Bartlett, 1951, Stevens, 2009). The Kaiser-Meyer-Olkin (KMO) statistic, was used to test the extent to which each variable in the perception analysis was predicted without error by the other variables (Kaiser and Rice (1974).

The study expected to generate more than one factor to describe farmers' perception and therefore used a multivariate probit model to analyse predictors of farmers' perception of the usefulness of integrating improved pigeon peas in *fanya juu* terraces as an adaptation strategy to climate change.

Following (Greene, 2012; Lin *et al.*, 2005), we formulated the MVP model with four dependent variablesG_1, G_2, G_3, G_4, such that:

$$G_k^* = \begin{cases} 1, if\ X_k'\beta_k + \varepsilon_k > 0 \\ 0, if\ \beta_i X_i' + \varepsilon_i \leq 0, \\ k\ = 1,2,3,4 \end{cases} \text{ ……………………………………………………………… } (3.\,6)$$

$$E[\varepsilon_k | X_1, \dots, X_K] = 0$$

$$Var[\varepsilon_k|X_1, \dots, X_K] = 1$$

$$Cov\left[\varepsilon_j\varepsilon_k|X_1, \dots, X_K\right] = \rho_{jk}$$

$$(\varepsilon_1, \dots, \varepsilon_K) \sim N_K[0, R]$$

Where X_i is an array of explanatory variables that influence the perception of usefulness on the attribute of the technology; β_i and β_k are the estimated parameters in the model and ε_k are random errors in the multivariate normal distribution with mean zero, the variance of 1 and an n x n correlation matrix, R is the variance-covariance matrix. The values ρ_{jk} symbolize the unobserved correlation between the dependent variables examined (Arun and Yeo, 2020; Greene, 2019). The marginal effects were computed as:

$$\partial P_i/\partial X_i = \varphi(X'\beta)\beta_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.\ 7)$$

3.3.1.1. Variables used in the analysis of farmers' perception of growing improved pigeon pea varieties in fanya juu terraced fields as an adaptation strategy to climate change

The variables used in assessing factors influencing farmers' perception of growing improved pigeon peas in *fanya juu* terraces are presented in Table 3.1. The gender of the household head is a binary variable taking a value of 1 if the household head is male and 0 otherwise. Asfaw and Neka (2017); Ojo et al. (2021) Temesgen *et al.* (2009), found that being male had a positive effect on perceiving SWC practices as an adaptation to climate change. However, Abrham *et al*. (2017); and Nhemachena and Hassan (2007) found that female household heads were more likely to perceive beneficial attributes of SWC practices because they engage in more farm activities than males and have better judgment on the value of agricultural technologies. Therefore, this variable could either have a positive or negative influence on the perception of the technology as an adaptation strategy.

The education level of the farmer was coded as a discrete variable representing the years of formal education that the household head attained. Confirming to Abram *et al.* (2017); Moges *et al*. (2017); Solomon *et al*. (2016); and Temesgen *et al.* (2009), the level of education enhances farmers' understanding and perception of the positive attributes of an innovation. Moreover, farmers with higher levels of formal education often take the mantle as local communities' disseminators of technologies Moges *et al*. (2017). The level of education of the household head was anticipated to have a positive influence on the perception of the practice as a climate change adaptation strategy.

The age of the household head is a continuous variable that shows the number of years of the house head. According to Ojo *et al*. (2021); and Thinda *et al.* (2021) older farmers are likely to be aware of the benefits of technologies than younger ones and therefore are more likely to have a positive perception of an innovation with the potential to enhance resilience to climate change. The variable was postulated to have a positive effect on farmers' perception of the technology.

Farming's main source of income is a binary variable on whether or not the household has farming as the main source of income. Households with farming as the principal occupation are likely to have a positive perception of innovation. Kaliba *et al.* (2018); and Kamau *et al.*, (2020) reported a positive and significant relationship between households with farming as the main livelihood and perception of measures that can strengthen farmers' coping mechanisms to the vagaries of the changing climate.

Access to extension services is a yes, no-response variable on farmer's contact with the formal extension service provider. According to Abid *et al.* (2015); and Temesgen *et al.* (2009), the agriculture extension service provision is the main channel of information to the farmers, and their interaction is postulated to impart knowledge to farmers and influence their perception of agricultural technologies. The variable was hypothesized to significantly influence farmers' perception of the technology.

The slope of a plot is a dummy variable indicating whether the land was on a slope or not. In accord with Kidane, (2016); and Moges *et al*. (2017), plots located on higher slope relative to flat terrain have visible soil erosion that make the construction of terraces important to abate water runoff and soil erosion and enhance water percolation in soil, particularly in areas with low erratic rainfall. The variable was posited to significantly influence farmers' perception of the technology as an adaptation measure to climate change.

Table3. 1. Variables used in the analysis of the perception of the technology

Variable	**Description**	**Expected sign**
Gender	Gender of household head (0 = Female, 1= Male)	+
Age	Age of the household head in years	+
Education level	Years of formal education of household head	+
Farming occupation	Whether a household has farming as the main occupation (0= No, 1=Yes)	+
Owns land	Whether households own land they cultivated (0= No, 1=Yes)	+
Slope	Whether the slope of the land is steep (0= No, 1=Yes)	+
Agricultural Extension	Access to agricultural extension service provider (0= No, 1=Yes)	+
Location	The administrative county where the farm is situated (1 Machakos, 0 otherwise)	

3.3.2 Factors influencing adoption of improved pigeon pea under *fanya juu* terraces

A farming household will choose to grow improved pigeon pea varieties in *fanya juu* terraced plots if the expected utility of taking up the technology is greater than not adopting it (Adesina & Baidu-Forson, 1995). As previously mentioned, letting A^* represent the latent variable that denotes the expected gains emanating from choosing the technology compared to not adopting, then the selection equation is denoted by:

$$A_i^* = \beta X_i + \mu_i, \ with\ A_i = \begin{cases} 1\ if\ A_i^* > 0 \\ 0, otherwise \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.\ 8)$$

3.3.2.1 Specification of variables used to analyse the adoption of the technology

The variables used in estimating the adoption of improved pigeon peas in *fanya juu* terraces are presented in Table 3.2. The gender of the household head was coded as 0=female, 1= male. The study hypothesizes that male farmers were more likely to adopt the technology because of the masculine labour required to design and maintain the structure and the high cost of improved seed as was found by Asfaw and Neka (2017); Ojo *et al.* (2021) in Ethiopia and Ghana respectively.

The study considered the education level of the farm decision-maker as the household's human capital. The variable of education was measured in terms of years of formal education. Education is a proxy for literacy. It was hypothesized that literate farmers would be more likely to perceive the benefits of agricultural technologies and adopt them than farmers without any formal education. Education was anticipated to be positively associated with adoption of the technology as a higher level of education provides more knowledge and propels an individual to acquire and process information about the technology (Arun and Yeo, 2020; Mulwa *et al.*, 2017; Nhemachena *et al*., 2014).

The study postulates that farmers can make judgments on the merits and demerits of a technology based on their farming experience. The researchers also hypothesized that family size and ownership of livestock were positively related to the adoption of the technology. The large family size provides farm labour and also increases consumption which prompts the household to adopt strategies that use the family labour to increase food supply. More livestock is an indicator of wealth that farmers can use to acquire the resources required to adopt agricultural technologies (Kalele *et al*., 2021; Karienye and Macharia, 2020). The relationship between farm sizes and the adoption decision was hypothesized to be negatively related. It was also posited that farmers with small land parcels utilize their scarce resources more efficiently and therefore adopt technologies that are resilient to changes in climate and simultaneously increase farm productivity. This finding backs up the inverse association of farm size and productivity (Abdulai and Huffman, 2014; Zhuo *et al.*, 2011; Schultz, 1964) that hypothesizes that large farms are less productive relative to small farms.

Distance to input dealers is a continuous variable in kilometers that indicates how far the farmers source farm inputs. Long distance to the source of inputs increases transport costs, or/and the time taken to purchase the inputs. The study therefore postulates that long distance is expected to hurt input use and hence negative influence on the adoption of the technology. Teklewold *et al*. (2013); and Wossen *et al*. (2019) found that farmers abandoned technologies and continued with conventional farming practices due to long and time-consuming distance to the input dealers. The distance to the input market was chosen as an exclusion instrument because the short distance to the input dealers influences the adoption decision of the technology but does not directly affect the outcome (Radeny *et al.*, 2020; Teklewold *et al*.,2013); Wossen *et al*., 2019).

A farmer's perception of the technology is a continuous variable. The values on perception were derived from the perception model. The values range from 0 -1 and they indicate the probabilities of perceiving the usefulness of the technology. According to (Maina *et al*., 2020; Murage *et al.*, 2015) perceived attributes of innovations condition adoption behavior. The variable is predicted to have a positive effect on the adoption decision.

The study posited that farmers' membership in farmers' groups positively influenced the adoption of the technology. Farmers exchange ideas during their group meetings that influence their adoption decisions. Kaliba *et al.* (2018); Kamau *et al.*, (2020) reported a positive and significant association between membership in farmer groups and the adoption of climate change adaptation strategies. Establishing SWC structures on farms is labor-intensive and farmers use collective to catalyze adoption (Nyangena, 2008; Ojo and Baiyegunyhi, 2020; Omenda *et al*., 2022; Thinda *et al*., 2020; Toromo *et al.,* 2019).

The study hypothesized a positive relationship between technology adoption and farmers' access to agricultural extension services. Agricultural extension service providers influence farmers to adopt new technologies to increase farm productivity. Abdullai and Huffman (2014); and Darkwan *et al*. (2019) note that agriculture extension institution is a proxy for access to information and innovations.

Table3. 2. Specification of variables used in the analysis of factors influencing the adoption of the technology

Variable	Description	Expected sign
Gender	Gender of household head (0 = Female, 1= Male)	±
Experience	Years of experience in the farming of household head	+
Education level	Years of formal education of household head	+
Family size	Number of household members	+
Non-farm income	Whether a household earns non-farm income (0= No, 1=Yes)	+
Farm size	Farm size in acres (numbers)	-
Owns land	Whether households own land they cultivated (0= No, 1=Yes)	+
Distance input market	Distance to input market (Km)	-
Perception	Predicted values of perception of the technology (numbers 0-1)	+
Group membership	Membership in farmers' group (0= No, 1=Yes)	+
Agricultural Extension	Access to agricultural extension service provider (0= No, 1=Yes)	+
Owns livestock	Whether the household has livestock (0= No, 1=Yes)	+
Location	Base County Machakos, dummies for Makueni and Kitui counties	

3.3.3 The impact of adopting technology on farm income

Examination of the gains from adopting agricultural technologies based on non-random selection of participants and non-experimental observations entails estimation of the counterfactual of the intervention (Alene and Manyong, 2007). Farmers voluntarily choose to adopt. Apart from observed characteristics, there could be unobservable factors like farmer's motivation/attitude and skills that could potentially influence both the adoption decision and outcome variable (Abdulahi and Huffman, 2014). Estimating the impact of technology adoption without accounting for unobservable would cause endogeneity bias leading to inaccurate parameter estimates that cannot be used for policy prescription (Lockshen & Sajeia, 2004).

To account for unobserved household characteristics or those that could potentially influence both adoption decision and outcome variables, the study adopted the endogenous switching regression (ESR) approach by Lee (1982) with a two-stage framework. The first stage disaggregates farmers into the adopter and non-adopter categories through the selection equation. The second stage uses the probit model to evaluate the relationship between the adoption decision and outcome variable based on a set of explanatory variables while correcting for potential selectivity bias (Lockshen & Sajeia, 2004).

Following Lockshen & Sajeia, (2004), farmers face two regimes to adopt or not to adopt a given technology. The two regimes are defined as:

Regime 1: $Y_{1i} = \alpha_1 J_{1i} + \zeta A_i + \xi_{1i}$ if, A_{1i}=1 for adopters………………………………… (3. 9a)

Regime 2: $Y_{2i} = \alpha_2 J_{2i} + \zeta A_i + \xi_{2i}$ if, A_{1i}= 0 for non-adopters ……………………….….. (3. 9b)

where Y_{1i} and Y_{2i} are the outcome variables for adopting and non-adopting households respectively in regimes 1 and 2, J_i represents a vector of exogenous variables hypothesized to influence the outcome variables, α is a set of unknown parameters computed while ξ are identically distributed error terms.

Assume that the error terms, $\xi_{2i},$ and $have$ a trivariate normal distribution, with mean vector zero and covariance matrix (Lee et al., 1982) and following Maddala, (1983) are expressed as:

$$Cov\ (\xi_{1i}, \xi_{2i}, u_i\ ) = \begin{bmatrix} \sigma_{\xi 1}^2 & \sigma_{\xi 12} & \sigma_{\xi 1u} \\ \sigma_{\xi 12} & \sigma_{\xi 2}^2 & \sigma_{\xi 2u} \\ \sigma_{\xi 1u} & \sigma_{\xi 2u} & \sigma_u^2 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.10)$$

where σ_u^2 is the variance of the error term of the adoption choice equation, $\sigma_{\xi 1}^2$ and $\sigma_{\xi 2}^2$ are the variances of error terms of the outcome equations, and $\sigma_{\xi 1u}$and $\sigma_{\xi 2u}$ are the covariance of $\xi_1, \xi_2$and u. The covariance between $\xi_{1i}, and\ \xi_{2i}$, is not defined because Y_{1i} and Y_{2i} cannot be simultaneously observed (Maddala, 1983).

The expected values of the disturbance terms are non-zero and are estimated as (Maddala, 1983):

$$E(\xi_{1i}|A_i = 1) = \sigma_{\xi 1u} \frac{\phi(\beta X_i)}{\Phi((\beta X_i))} = \sigma_{\xi 1u}\lambda_{1i} \text{ and } (\xi_{2i}|A_i = 0) = -\sigma_{\xi 2u} \frac{\phi(\beta X_i)}{1-\Phi((\beta X_i))} = \sigma_{\xi 2u}\lambda_{2i}\ . \qquad \text{……………………………………………………………………………… (3.11)}$$

Following Lockshen & Sajeia (2004), the maximum likelihood estimation (FIMLE) approach was used to compute the ESRM. The FIML calculates the decision/ selection equation and the regime regression equation simultaneously (Lockshen and Sajeia, 2004). The logarithmic likelihood function for the two sets of equations in (3.09) is expressed as:

$$\ln L = \sum_{i=1}^{N} A_i \left[ln\phi\left(\frac{\xi_{1i}}{\delta_1}\right)\right] - ln\delta_1 + ln\phi(\gamma_{1i}) + (1 - A_i)\left[ln\phi\left(\frac{\xi_{2i}}{\delta_2}\right) - ln\delta_2 + ln\Phi(\gamma_{2i})\right]. \ .(3.12)$$

where $\gamma_{1j} =$, j= 1, 2; ρ_j is the correlation between ε_{1i} (the error term of the selection equation) and μ_{ji} (the error term of the outcome equation).

The study thought it probable that the perception of the usefulness of improved pigeon peas in *fanya juu* terraces as an adaptation measure was a likely determinant of the outcome equation (3.9) and was endogenous. We therefore integrated the perception variable in the outcome equation as a predicted value. Applying the treatment effect we generated $\rho_{1\mu}$ and $\rho_{2\mu}$ which are the correlation coefficients between the residual terms in the selection and outcomes equations (Lockshen & Sajeia, 2004). If either $\rho_{1\mu}$ or $\rho_{2\mu}$ is non-zero, then there is endogeneity in the assessed covariates that leads to selection bias if not accounted for (Di-Falco *et al.,* 2011; Maddala and Nelson, 1975). If $\rho_{1\mu} > 0$ it implies that there is a negative selection bias, meaning that farmers with below-average yields and income are more likely to integrate improved pigeon pea varieties in *fanya juu* terraced fields while $\rho_{1\mu} < 0$ denotes a positive selection bias (Di Falco *et al.* 2011; Maddala and Nelson, 1975).

The coefficient estimates of ESR enable the derivation of the average treatment effect on the treated (ATT) and of the effect of the treatment of the untreated (ATU) (Lockshen & Sajeia, 2004). The ATT is the effect of outcome variables on households that adopted the technology while ATU is the effect of the outcome variable on households that did not adopt the technology. The estimates are used to compare the results of the adoption aftermath between adopters and non-adopters in actual and counterfactual scenarios. Following Lockshen & Sajeia, (2004), the ATT and ATU are estimated as:

Among technology adopters

$E(Y_{1i}|A_i = 1) = \alpha_1 J_{1i} + \sigma_{1u}\lambda_{1i}$ ………………………………………………………… (3.13)

Among adopters had they not adopted (counterfactual case)

$E(Y_{2i}|A_i = 1) = \alpha_2 J_{1i} + \sigma_{2u}\lambda_{1i}$ ………………………………………………………… (3.14)

Among non-adopters had they adopted (counterfactual case)

$E(Y_{1i}|A_i = 0) = \alpha_1 J_{2i} + \sigma_{1u}\lambda_{2i}$……………………………………………………...... (3.15)

Among non-adopters as observed in the sample

$(Y_{2i}|A_i = 0) = \alpha_2 J_{2i} + \sigma_{2u}\lambda_{2i}$ ……………………………………………………….... (3.16)

The impact of technology adoption on the consequence of our interest is estimated as:

$ATT = E(Y_{1i}|A_i = 1) - E(Y_{2i}|A_i = 1) = J_{1i}(\alpha_1 - \alpha_2) + \lambda_{1i}(\sigma_{\xi 1u} - \sigma_{\xi 2u})$ ……….........(3.17)

The effect of the treatment of the untreated (TU) for households that do not adopt is:

$ATU = E(Y_{1i}|A_i = 0) - E(Y_{2i}|A_i = 0) = J_{2i}(\alpha_1 - \alpha_2) + \lambda_{2i}(\sigma_{\xi 1u} - \sigma_{\xi 2u})$ ………….. (3.18)

Following Carter and Milon (2005) to account for the heterogeneity (HE) among the the interviewed households, the effect of heterogeneity on those that decided to adopt (3.9-3.11) is estimated as:

$$HE_1 = E(Y_{1i}|A_i = 1) - E(Y_{1i}|A_i = 0) = \alpha_{1i}(J_{1i} - J_{2i}) + \sigma_{\xi 1u}(\lambda_{1i} - \lambda_{2i}) \text{ ……………. } (3.19)$$

The effect on households that decided not to adopt (3.10-3.12) was:

$$HE_2 = E(Y_{2i}|A_i = 1) - E(Y_{2i}|A_i = 0) = \alpha_{2i}(J_{1i} - J_{2i}) + \sigma_{\xi 2u}(\lambda_{1i} - \lambda_{2i}) \text{ ……………. } (3.20)$$

3.3.3.1. Variables used in analyzing the impact of adopting improved pigeon peas in *fanya juu* terraced plots in Machakos Makueni and Kitui counties

The variables used in estimating the impact of adopting improved pigeon peas in *fanya juu* terraces are presented in Table 3.3. The study hypothesized that male-headed households were more likely to get more income from technology than female-headed. According to (Abdullai and Huffman, 2014; and Manda *et al*., 2016) men get more income from agricultural technologies because they own and control resources that they use to enhance productivity.

Education was anticipated to be positively associated with income from adopting the technology as a higher level of education enhances understanding of agriculture marketing and the use of modern technologies to access markets of high margins (Manda *et al*., 2016; Wu, 2022)

The study postulates that farming experience affects the level of income from adopting a technology. Berhe *et al*. (2017); and Martey and Kuwornu (2021) found that farmers with more years of experience generated more income from knowledge of more lucrative markets.

Land size was expected to have a positive effect on income. Wordofa *et al.* (2021); and Verkaart *et al*. (2017) found out that technology adopting farming households with large holdings increased their marketable surplus and income.

The researchers also anticipated that family size and ownership of livestock positively affected income. The large family size provides farm labour to support production (Radney *et al.*, 2022). More livestock is an indicator of wealth that can be liquidated to enhance production and marketing of the produce (Kalele *et al*., 2021; Karienye and Macharia, 2020) in addition livestock produce manure is used to enhance soil fertility and augment yield and hence income.

The study predicted a positive association between farmers' access to agricultural extension services and income. According to Darkwan *et al*. (2019) and Manda et al. (2016), agricultural extension provides information on a whole value chain that enhances farmers' agribusiness skills that encompass marketing.

Table3. 3. Independent variables used in determining the impact of the technology on income

Variable	**Description**	**Expected sign**
Gender	Gender of household head (0 = Female, 1= Male)	+
Experience	Years of experience in the farming of household head	+
Education level	Years of formal education of household head	+
Family size	Number of household members	+
Non-farm income	Whether a household earns non-farm income (0= No, 1=Yes)	+
Farm size	Farm size in acres (numbers)	+
Owns land	Whether households own land they cultivated (0= No, 1=Yes)	+
Owns livestock	Whether the household has livestock (0= No, 1=Yes)	+
Agric. Extension	Access to agricultural extension service provider (0= No, 1=Yes)	+
Group membership	Household membership in farmer association (0= No, 1=Yes)	+
Location	Base County 1= Machakos, 0 = otherwise	

3.3.4 Diagnostic Tests

Diagnostic tests assist in verifying the nature of the data and aid in specifying the applicability of the model to the study in question to ensure unbiased, efficient, and consistent regression results. (Yihua, 2010). This study carried out the following tests before embarking on model estimation.

3.3.4.1 Detecting multicollinearity

Multicollinearity arises from a linear relationship between explanatory variables (Gujarati, 2004). The problem causes wrong signs and magnitude of the computed regression coefficients, smaller *t*-ratios for many variables, and high R^2 in the regression (Gujarati, 2004). It also causes the variances and standard errors to be high resulting in wide confidence intervals and therefore low *t* values (Gujarati, 2004; Greene, 2012). The variance-inflating factor (VIF) technique was used to test for multicollinearity. The Variance-inflating factor results on the variables used in the perception and adoption models are presented in Appendices 1.1 and 1.2.

3.3.4.2 Validity test of selection variables

A falsification test was used to test if the exclusion instrument used in the selection equation is binding. An instrument is valid if it affects the adoption decision but does not affect the outcome of non-adopters (Di-Falco et al., 2011). We suspected that perception of the usefulness of growing improved pigeon pea varieties in *fanya juu* terraces was an endogenous predictor of the outcome variable (income) and would therefore cause biased outcome values. The values of the variable were therefore predicted and incorporated in the outcome equation. Following (Kubitza and Krishna, 2020; Robinson, 1989) we used the distance to input the market as instrumental variables to address endogeneity. Following (Maddala and Nelson, 1975; Randey *et al*., 2022) we tested for the endogeneity of covariates and sample selection issues using post-estimation procedures on extended switching regression models in Stata.

3.3.5 Data types and sources

Primary data were used to address the objectives of the study. The data were collected from 400 households who were then surveyed using a semi-structured questionnaire. A pretested semi-structured questionnaire was used to collect information in the 2019 (March to May) cropping season. The questionnaire collected information on farm and farmer characteristics, types of crops grown, the types and amount of inputs in crop production, and the yields with a main focus on pigeon peas. Information on pigeon pea varieties grown, and the SWC practices adopted were also captured.

The data was collected by enumerators who had previous experience in data collection. The enumerators were trained by biometric experts from KALRO to strengthen their data collection skills and taken through the entire questionnaire. The questionnaire was pre-tested in the field with a small number of respondents outside the administrative wards where data were finally gathered to ensure that all questions were clearly understood for respondents to provide quality information. The questionnaire is in Appendix 1.4

3.3.6 Sampling

Following Kothari (2004) the sample size used in the study was computed as:

$N = \left({Z^2pq}/{d^2}\right)$ Where: N is the desired sample size; z was set at 1.96 representing the standard normal deviation corresponding to a 95 percent confidence interval; p is the proportion of the population estimated to have a particular characteristic of interest such as the proportion of households having *fanya juu* terraces in improved pigeon pea on their farms that were not known and therefore set at 50 percent in this study (0.5). q = 1- p, is the proportion of households that could not be growing improved pigeon peas on SWC on their farms (0.05), and d is the degree of accuracy.

$$N = \frac{1.96^2(0.5)(0.5)}{0.0025} = 385.$$

The study used multiple sampling designs. Machakos, Makueni, and Kitui counties were purposively chosen due to high pigeon pea production and the use of terraces on farms. (GoK, 2015; Simtowe *et al*., 2012a). Three sub-counties were selected from each county. Mutomo, Nguni/Masumba, and Masinga wards in Kitui, Makueni, and Machakos Counties respectively were purposively chosen due to semi-arid climatic conditions. Mutomo, Masinga, and Nguni/ Masimba wards had 5, 6, and 8 locations respectively. In the third stage, 3 sub-locations were selected from the Mutomo and Masinga wards and 4 from the Nguni/Masimba wards. In the fourth stage, 4 villages were randomly selected from each sub-location. In the fifth stage, 10 households were randomly selected from a sampling frame of the list of farming households in the villages provided by the agricultural extension staff. A total of 400 households were chosen for interview.

3.3.7 Study area

The study was carried out in Machakos, Makueni, and Kitui counties in SEK. The counties were selected because of high pigeon pea production (67%) of the Country's production (GoK, 2016; Kwena *et al.,* 2021). The region receives bimodal rainfall of short and long rains (Jaetzold *et al*., 2010). The region covers both sub-humid and semi-arid zones. The semi-arid zone is generally hot and dry receiving average annual rainfall of 630 mm (Gichangi *et al.,* 2015). The short rains seasons are more dependable than the long rains and therefore more important for crop production. The temperatures range from 17^0C and 34^0C, with lower temperatures during the short rain season compared to those of the long rain season (Jaetzold *et al*., 2010; Gichangi *et al.,* 2015). Low rainfall coupled with high evapotranspiration due to higher temperatures induces water stress on crop production (Jaetzold *et al*., 2010). The rainfall and temperature regime makes the integration of drought-tolerant crops in SWC suitable in the area.

The soil types in Southeastern Kenya vary from one county to the other. The dominant soils in Machakos and Makueni counties are Rhodic and Orthic ferralsols, while in Kitui, the Red soils (Lixisols) are the most common with isolated patches of Alluvial deposits along the rivers and on hillsides (Jaetzold *et al.,* 2010). Shallow, friable soils dominate the area and therefore require proper soil management practices for sustainable farming. The region has an undulating slope that ranges from 5- 45 % making the area prone to high rain-water runoff denudation of soil cover, and severe soil erosion during intense rainfall, which leaves inadequate water conserved for plant growth on farms with no SWC structures (Cooper *et al.*, 2008; Wambua and Mulei, 2014).

Semi-subsistence, crop, and livestock farming are dominant in Southeastern Kenya (Claessens *et al.,* 2012; GoK, 2015). Maize is one of the major staple crops grown albeit with frequent crop failure (Omoyo *et al.,* 2015). Other crops grown include pulses, cereals, leafy vegetables and tomatoes, fruit trees and roots, and tubers (Claessens *et al.,* 2012). Inadequate permanent river-water sources limit the production of high-value horticultural crops under irrigation (GoK, 2015). Cattle, goats, sheep, and chickens are the livestock kept by the majority of households. Other livestock like donkeys, pigs, rabbits, and bees are also kept by some farmers. Oxen and donkeys are kept for draught purposes.

The map of the study area is presented in Figure 3.2.

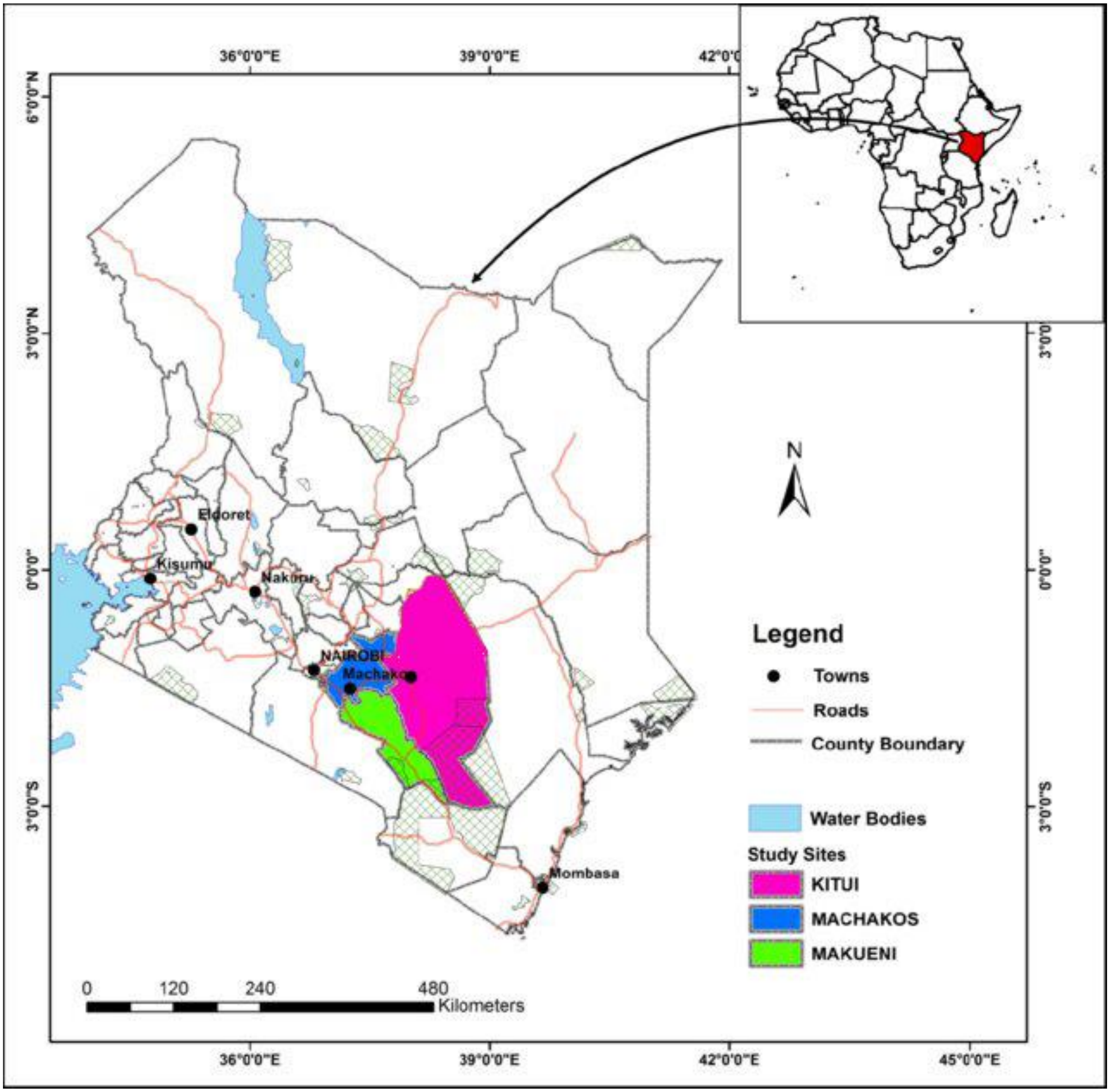

Figure 3. 3. Study area: Location of Machakos, Makueni, and Kitui Counties on the map of Kenya

Source: KALRO Natural Resource Management program (2019).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Farmers' socio-economic and demographic characteristics

Table 4.1 presents the socio-economic and demographic characteristics of the farming households surveyed. Out of the sample size, 34% were in Machakos, and Makueni and Kitui counties each had 33%. The average years of farming experience of the household heads were 33, 37, and 31 years in Machakos, Makueni, and Kitui counties respectively with corresponding standard deviations of 10.7, 8.4, and 9.8, indicating a large range of their duration of farming experience. The mean family size was 3.8, 4.6, and 5.1 in Machakos, Makueni, and Kitui counties respectively. The average farm size in Machakos County was 3.3 with 0.62 acres under pigeon peas with 0.40 acres under improved pigeon peas in *fanya juu* terraced fields. The mean farm size in Makueni County was 6.11 acres with 1.1 and 0.52 acres under pigeon peas and improved pigeon peas on *fanya juu* terraced plots respectively. Farmers in Kitui County had a mean farm size of 6.7 acres, pigeon peas grown on 1.5 acres, and 0.60 acres of improved pigeon peas in terraced fields. Improved pigeon peas had been grown in *fanya juu* terraced fields for an average of 3, 4.6, and 4 years among adopters in Machakos, Makueni, and Kitui counties respectively.

The average yield of improved pigeon peas (dry) from *fanya juu* terraced plots averaged 557 kg per acre per year compared to that of indigenous varieties which averaged 380 kg per acre. The results were similar to the green peas harvested, where improved pigeon peas yielded more than the indigenous varieties. The results mean that the production of improved pigeon peas on *fanya juu* terraces produced more yield for food and sale compared to the indigenous peas on non-terraced plots. Following Kwena (2018), the integration of pigeon peas in SWC has the potential to enhance food production in semi-arid Kenya.

Table 4. 1. Means of farmers' socio-demographic characteristics in Southeastern Kenya

	County						
	Machakos (n=120)		Makueni (n=160)		Kitui (n=120)		Pooled (n=400)
Characteristic	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**
Age he (Years)	53.2	13.1	52.45	16.3	53.15	13.2	53
Experience hhh (Years)	33.0	10.7	37.0	8.4	31.0	9.8	34
Education hhh (Years)	14.6	10.9	11.6	8.4	12.3	9.6	13
Livestock kept (No.)	24	10.4	47	9.6	43	12.3	38
Family size (No.)	3.8	2.5	4.6	3.7	5.1	3.4	4.4
Farm size (Acres)	3.3	2.4	6.11	2.9	6.7	2.7	5.4
Pp land size (Acres)	0.62	0.26	1.1	0.35	1.5	0.44	1.1
Ipp in terraces (Acres)	0.40	0.18	0.52	0.33	0.60	0.38	0.5
Years of adopting the package	3	3.7	4.6	2.1	4	3.2	4
Yield dry ipp (kg/acre/yr)	552	45	571	56	545	61	556
Yield green ipp (kg/acre/yr)	364	67	343	75	350	59	352
Yield indigenous pp (kg/acre/yr)	361	54	386	90	392	83	380
Yield green indigenous pp(kg/acre/year)	248	72	273	68	251	51	257
Distance to input mkt (Km)	12	4.1	18	9.7	16	10.3	15
Distance to output market	5	2.7	8	3.9	9	4.3	8

Note: hhh is household head; pp is pigeon pea, ipp is improved pigeon pea varieties, adoption package is adopting improved pigeon peas in *fanya juu* terraces.

The average distance to the input market was 15km in the study area, while the distance to the output market was 8km. This could mean that the output market was closer to most homesteads compared to the input market. This is probable in the case where most farmers sell their commodities at the farm gate but have to get inputs farther away from their farm gates as was found in Mergeai *et al*. (2001); and Musyoka *et al.* (2022). The distance to input dealers/market implies the cost of production. Farmers need improved seed and agro-chemicals to grow improved pigeon peas and therefore long distance to the input dealers if coupled with increases in the cost of acquiring the inputs. Madison (2006); Teklewold *et al*.(2013); Wossen *et al*. (2019) observed that long distances to input markets reduce the farmers' ability to adopt agricultural technologies in Africa. While the short distance to the output market could mean low transport costs and generally market transaction costs, it also implies the marketing margin generated especially from selling at the farm gate with poor price negotiating skills that are common to rural smallholder farmers (Habiyaremye, 2017, Jama *et al*., 2019; Olwade *et al*., 2015).

The results for discrete socio-demographic characteristics are presented in Table 4.2. The sample was 72% male-headed households pointing to a largely patriarchal farming society in Ukambani (SEK) where the study was undertaken. The proportion of male-headed households in the sample was higher than the national average of 64% (KNBS, 2020). Between 65 to 76% of the farmers owned the land they tilled and 71-78% had constructed *fanya juu* terraces on their farms. The establishment of terraces on farms entails high costs and takes more than 3 years to recover the cost invested depending on the crops grown (Atampugre, 2014; Posthumus and Stroosnijder, 2010). Land ownership is therefore important factor in influencing whether or not farmers would establish terraces on leased land, especially when returns to investment are not short-term.

About 90% of the households kept livestock which portrays a mixed farming system. About 60% had non-farm income, a common strategy for minimizing the risk of climate-induced crop failure in semi-arid areas. For instance, Claessens *et al*. (2012) and Kalele *et al.* (2021) noted that diversification of the farming portfolio was used in smallholder farming systems in dry areas to spread the risk of climate-induced production failure.

An average of 68% of households had access to agricultural extension services over the previous 5 years before the survey of this study and about 67% of the households had accessed climate information over the same period. The results show that the proportion of the interviewed who got agricultural extension services was similar to those who accessed climate information, which is plausible because agricultural extension is instrumental in the dissemination of climate information in the region (Muema *et al*., 2018; Kalele *et al*., 2021) Access to climate change information is helpful to the farmers if it is accompanied by the advisories on appropriate adjustment in farming activities to match the forecast to enhance the farmers' resilience to climate change (Tall *et al.,* 2013). The experts from the Ministry of Agriculture, the Kenya Meteorological Department, and some other stakeholders participate in Participatory Scenario Planning (PSP) to develop localized adaptation strategies that are communicated to the farmers through extension service providers to enable farmers to apply the information.

Table 4. 2. Frequencies of farmers' sociodemographic characteristics in Machakos Makueni and Kitui counties

		County		
Characteristic (%)	**Machakos (n=120)**	**Makueni (n=160)**	**Kitui (n=120)**	**Pooled (n= 400)**
Gender hhh (1=Male)	71	75	68	72
Owns land (1=Yes)	56	50	55	52
F*anya juu* terraces on the farm (1=Yes)	78	75	71	75
Grows pigeon peas (1=Yes)	81	86	75	81
Grow improved peas past 5 years (1=Yes)	44	47	46	46
Grows improved peas on terraces (adoption package) (1=Yes)	36	32	34	34
Ever discontinued adoption package (1= Yes)	10	12	15	12
Sells peas grown on own farm (1=Yes)	70	63	52	62
Got non-farm income (1=Yes)	64	57	60	60
Keeps livestock (1=Yes)	89	93	90	91
Contacted agric extension past 5yrs (1=Yes)	74	63	67	68
Access climate info. (1= Yes)	71	64	67	67
Gets market info. (1=Yes)	76	67	63	69
Group member (1=Yes)	70	73	77	70
Credit access over the past 5 years (1=Yes)	25	28	40	31

Access to credit services for agricultural development amongst the farmers was low at 25%, 28%, and 40% in Machakos, Makueni, and Kitui counties respectively. According to Kiplimo *et al*., (2015), farmers' access to credit in Eastern Kenya was 31%, the low access rate was ascribed lack of awareness of and availability of the finance products. Most farmers obtain loans from farmer associations (informal sector) relative to the formal credit facilities due to the latter's strict repayment terms that are often tough for most resource-constraint farmers and low awareness of rural finance products on the market (Kiplimo *et al*., 2015; Njeru *et al*., 2016).

4.1.1 Adoption of improved pigeon pea varieties in Southeastern Kenya

All farmers who grew the improved varieties also grew the indigenous varieties. About 44% of the households in Machakos County, 47% in Makueni, and 46% in Kitui counties had grown Mituki variety as presented in Figure 4.1. An average of 38% had grown the Kajani variety, and 27% grew the KARI Mbaazi1 variety. An average of 12% grew KAT60/8 and 9%, 8%, and 5% grew Kari Mbaazi 2, ICEAP 00557, and ICEAP 00554 varieties respectively. About 46% of the farmers grew the improved varieties and all farmers grew indigenous types. The results confirm the low adoption of improved pigeon peas in semi-arid Kenya (Otieno *et al*., 2011; Simtowe *et al*., 2012).

Mituki and Kajani varieties were preferred more than the other improved varieties that were ascribed to the mineral iron-richness that has high demand in urban markets (Karimi *et al*., 2018). The KARI Mbaazi1 was preferred for its early maturing and drought escaping and high-yielding attributes. Esilaba *et al.* (2021) and Kwena *et al.* (2018) reported three-fold yields of improved peas relative to the indigenous varieties. The KAT60/8, ICEAP 00557, and ICEAP 00554 are medium-maturing varieties, favoured for drought and disease tolerance.

The early and medium maturing varieties are favoured because their green peas are normally harvested in the months of February and April typically for food. Maturing of the short-and medium-duration varieties coincides with cereal shortage that is embraced by women as a strategy to improve households' food security (Kwena *et al*., 2021). The KARI Mbaazi2 is a long maturing variety that takes 8-9 months. The late-maturing varieties are ordinarily harvested in June to July at the time of maize harvesting and therefore complement the cereal diet. Most farmers grew more than one improved variety for comparison of varietal performance. Farmers reported the easy access to seed from the previous harvest or from friends and the desire to maintain indigenous varieties in case the improved varieties fail as the motivation to grow the local landraces.

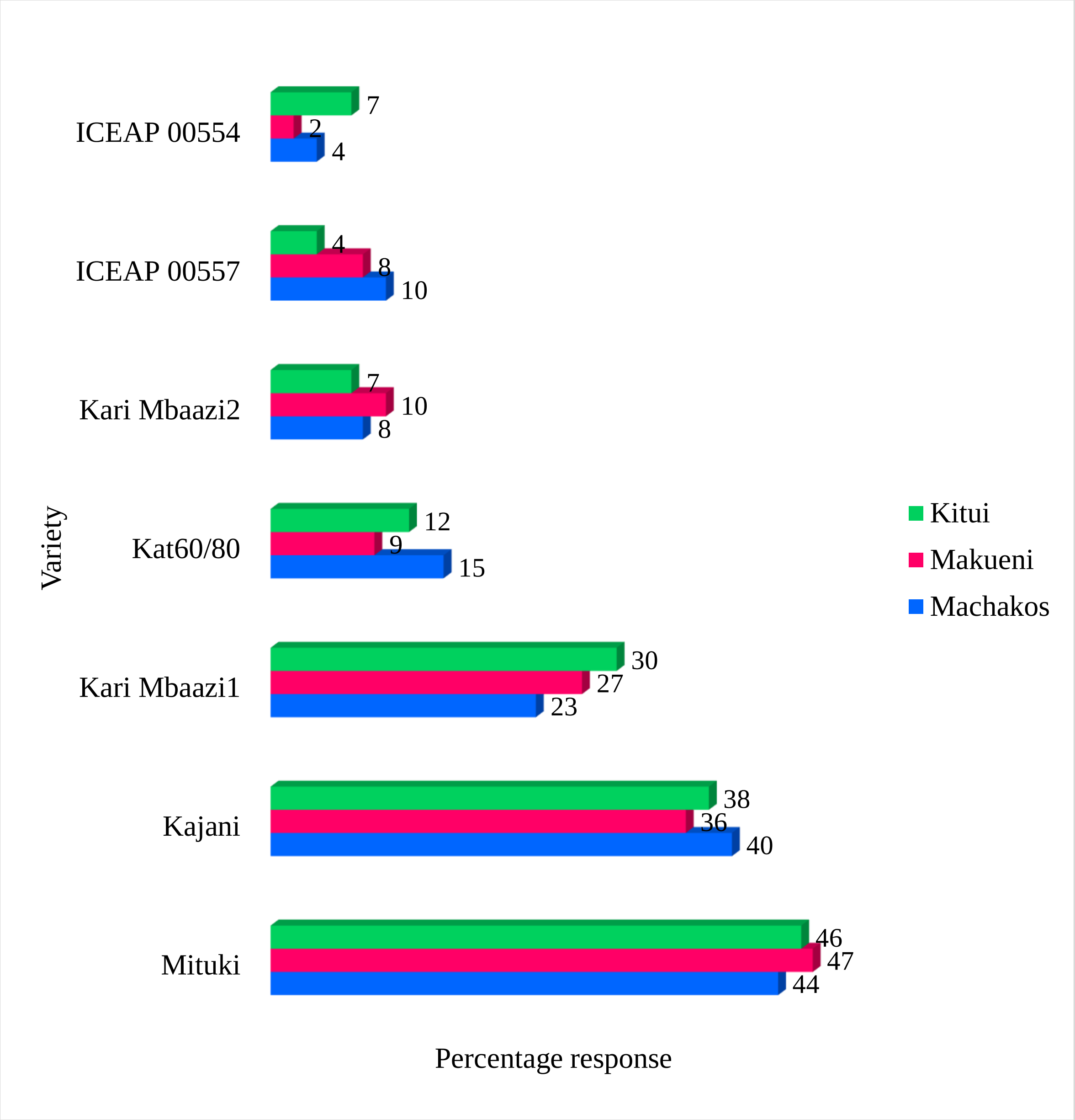

Figure 4. 1. Improved pigeon pea varieties adopted in Machakos, Makueni and Kitui counties

The results on the proportion of the interviewed that had adopted the technology package are presented in Table 4.3. Approximately 36%, 32% and 34% of the households in Machakos, Makueni and Kitui counties respectively had integrated improved pigeon pea varieties in *fanya juu* terraced plots. The results show a low adoption of the technology.

Table 4. 3 Frequency of adopters and non-adopters of improved pigeon pea in *fanya juu* terraced plots in Southeastern Kenya

County	Adopters		Non-adopters	
	n	%	n	%
Machakos	43	36	77	64
Makueni	51	32	109	68
Kitui	42	35	78	65
Total/average	136	34	264	66

4.2 Farmer perception of the usefulness of integrating improved pigeon peas in *fanya juu* terraces as an adaptation strategy

4.2.1 Factor analysis on farmers' perception of the usefulness of integrating improved pigeon peas in *fanya juu* terraces in Machakos, Makueni, and Kitui counties

The results in Table 4.4 portray the association between the variables assessed and the factors that describe farmers' perception of the usefulness of growing improved pigeon pea varieties in *fanya juu* terraced fields in adapting to variability in climate. The perceptions were described by 4 factors namely: increase resilience to climate change, boost crop productivity, ease of use/setting up terraces on farms, and increase in plant residue. The variables on perceptions that integrating improved pigeon pea in *fanya juu* terraced plots: increases retention of soil moisture, produces early maturing peas, enhances drought and disease tolerance in the crop, and improves soil fertility had high factor loading ranging from 0.8 and 0.5. Factor 2 had a high loading on increases in crop yield (0.87), produced large podded peas (0.82), and increased the duration of harvesting peas (0.78). Factor 2 variables described the increase in crop productivity. Factor 3 loaded highly on ease to maintain terraces and encourage collective farming. Factor 4 had high loading on increase in fodder from foliage, and fuel wood from stalks. The factor loadings meet the minimum requirement of loading criteria of > 0.4 (Kaiser and Rice, 1974). The Eigenvalue of factor 1 was 2.87 which was the highest of the three factors, indicating that the factor accounts for the largest percentage of variance (24%) in the variables measured as shown in the row on eigenvalue contribution. All three factors met the threshold of 1.0 as the minimum requirement in factor analysis (Streiner, 1994).

All three factors combined accounted explained 68% of the variation in the measured variables. The Kaiser Meiyer-Olkin (KMO) statistic gave a sampling suitability of 0.8 which was above the minimum requirement of 0.6 (Stevens, 2009). Bartlett's test of sphericity showed significant correlations (1%) among variables measured and thus justifies the application of factor analysis on the data evaluated (Bartlett, 1957).

Table 4. 4. Factor analysis of farmers' perception of the usefulness of growing improved pigeon pea varieties in *fanya juu* terraced plots in Southeastern Kenya

Farmers' perception of growing improved pigeon peas in *fanya juu* terraced plots	Factor 1	Factor 2	Factor 3	Factor 4
Early maturing crop	0.791	0.387	0.028	0.246
Enhances drought tolerance	0.767	0.286	0.369	-0.094
Increases soil water retention	0.804	0.297	0.316	0.159
Improves soil fertility	0.592	-0.145	-0.331	0. 212
Increases pest tolerance	0.516	0.192	-0.067	0.403
Increases yields	0.306	0.868	0.214	0.115
Large pods	-0.263	0.819	-0.055	0. 314
Long harvest period	0.372	0.783	-0.276	0.068
Easy to establish structures on a farm	-0.213	0.241	0.309	-0.125
Require specialized skills to set up	-0.197	0.069	0.152	-0.013
Requires low initial capital	0.258	0.341	0.496	0.307
Takes a lot of family labour to set up	0.223	-0.207	0.417	0.384
Easy to maintain structures	0.296	-0.153	-0.723	0.265
Encourages collective action	0.198	0.367	0.692	0.274
Increases fodder produced	-0.091	0.104	0.265	0.673
Increases firewood from stalk	0.187	0.326	-0.114	0.703
Eigenvalues	2.867	1.302	1.154	1.094
Eigenvalues contribution	0.243	0.187	0.131	0.116
Cumulative variance explained	0.243	0.43	0.561	0.677
KMO statistic	0.802			
Bartlett's test of sphericity	705.92***(25)			

Note: Factors 1, 2, 3, and 4 represent high factor loading on variables related to pigeon pea's resilience to climate change; an increase in pigeon pea productivity, ease of use and maintenance, increase in crop residue.

KMO is Kaiser Meyer-Olkin measure of sampling adequacy, *** represents a 1% level of significance; degrees of freedom in brackets.

The results on mean scores on farmers' perception of the technology (Table 4.5) reveal a higher mean score in the adopting households (4.07) relative to the non-adopting ones (3.22). The scores in the two categories were significantly different at the 1% level. Similarly, the mean scores on perceiving an increase in crop productivity from using the technology were significantly different between the adopters and non-adopters. The scores on the perception that the technology is easy to use and maintain were statistically different between the adopters and non-adopters at a 1% level. The perception statement with the highest mean score represents the variable that most respondents selected among other perceptions. The Likert scale results are in Appendix 1.5.

Table 4. 5 Mean scores on farmers' perception of growing improved pigeon pea varieties in *fanya juu* terraced plots amongst adopters and non-adopters in Southeastern Kenya

Perception	Adopters (n=165) mean	Non-adopters (n=285) Mean	t-test
Perception of enhancing resilience to climate change	4.073 (0.592)	3.218 (0.675)	8.065***
Perception of increasing crop productivity	3.872 (0.784)	3.042 (0.694)	7.111***
Perception of ease of use	3.395 (0.655)	2.854 (0.879)	2.276*
Perception of increase in crop residues	3.085 (0.247)	2.741 (0.764)	1.795

***, **, * show statistical significance at 10%, 5% and 1% level respectively. Std deviations in parenthesis

Farmers perceived that the technology increases crop productivity which could be linked to an increase in yield resulting from the increased number of pods from improved genetic characteristics and improved access to water (Makello, 2017; Ojwang *et al*., 2016) and the seasonal harvest (twice a year) relative to the once-a-year harvest from the long-maturing indigenous varieties. These results agree with ICRISAT (2011) that farmers in dry lands perceive the production of early maturing and drought-escaping pigeon pea varieties as an adaptation to climate change because they produce high yields even under low soil moisture and mature within a short period, which enables households to reduce the time between exhausting the previous year‘s grain supplies and the new harvest. According to (Njiru *et al*., 2021; Miriti *et al*., 2012) legume crop production under *fanya juu* terraces improves yields. The results on the economic attributes of growing improved pigeon peas in terraced fields are consistent with Rogers (2003), Smale and Mason (2014), and Walton (2008) that farmers’ opinion on the relative benefits of new technologies influences their positive perception about the technology. Realistically and perceptibly, rational farmers do not want losses in their investments.

The perception of the usefulness of the technology in enhancing the resilience of pigeon pea production to climate change was higher when farmers expected benefits of adoption in terms of drought-escaping, early-maturing, disease-tolerant crop, and increased yield. Climate change is projected to increase temperatures, reduce rainfall, and shorten the crop’s growth period in semi-arid areas which is likely to reduce crop yields (Gichangi *et al.,* 2015; Høgh-Jensen *et al*., 2007; Kimani *et al.,* 2015; Kwena *et al.,* 2021; Niang *et al.,* 2014). Early maturing varieties are therefore suitable for the short crop growth period and escape the effects of drought while drought tolerance enhances the crop’s ability to withstand the dry spell and therefore likely to be perceived as a useful measure to cope with climate variability.

Farmers perceived that terraces were easy to maintain once they were established on the farm. Most farmers (61%) disagreed that terraces were easy to set up on farms (Appendix 1.5). Laying out terraces is labour intensive and particularly farmers’ constraints in labour and technical know-how have difficulties in constructing them on their farms. According to Binyam and

Asmamaw, (2015); Njiru *et al*. (2022); knowledge of different crop's performance in terraces is crucial in the appropriate designing of the terraces to enhance productivity in the ASALs. In addition those with inadequate technical knowledge face difficulties in properly designing and laying out the farm structures. Gachene *et al.* (2019); and Karuku *et al*. (2018) attest that *fanya juu* terracing is a structural measure of SWC that is undertaken to change the gradient of the land to regulate surface runoff and abate soil erosion that typically requires considerable capital or labour resources to start with. Collective action is a remedy for household labour strain because farmers in groups take turns working on members' farms to ease the strain on labour. Kyalo and Holm-Mueller (2013); and Gathaara *et al.* (2009) found that collective action initiatives influence individual farmers' perception and adoption of SWC practices in Kenya.

The quantity of fodder and fuel wood from pigeon pea production was not significantly different between the adopters and non-adopters of improved pigeon pea under *fanya juu* terraces. This could be because the height of the stalks and foliage from the technology is not different from the indigenous varieties (Ojwang *et al.*, 2016; Saxena *et al*., 2018).

4.2.2 Factors influencing the perception of integrating improved pigeon pea varieties in *fanya juu* terraced plots as an adaptation strategy to climate change

To analyse the factors that influence farmers' perception of the usefulness of integrating improved pigeon pea varieties in *fanya juu* terraces as an adaptation strategy, the dependent variables were generated through a rotation factor loading on farmers' perception of the technology. Following (Steven, 2009), the factors with values greater than 0.4 were retained and chosen as dependent variables in the perception model. Three factors had values greater than 0.4 and therefore a multivariate probit model was used to assess the factors influencing farmers' perception of the usefulness of the technology in adapting to climate change. The results presented in Table 4.6, show a Wald test $chi^2(21)$ =102.98***, $Prob > chi^2$ = 0.000 that is significant at the 1% level which means the model fitted the data well. The results also indicate that the set of coefficients in the model was jointly significant and in agreement with the predictor power of factors included in the model (Greene, 2012). The LR test of the null hypothesis of independence between the perceived attributes of the technology viewed in the (rhos = 0) was significant at 5%. The null hypothesis that the degree of correlation between values on perceived usefulness of the technology (rho) are jointly equal to 0 is therefore rejected, demonstrating that the model has goodness-of-fit (Greene, 2012) and thus supports the hypothesis of interdependence between the perceptions of usefulness of the technology in adapting to climate change.

The results of the significant value of rho21 mean there was a positive correlation between farmers' perception that integrating improved pigeon peas in *fanya juu* terraces increases the resilience of pigeon pea production to climate change and the perception of increasing productivity that was significant at 1% level. This is plausible because drought-tolerant varieties limit crop failure, and disease tolerance reduces crop damage and loss which increases yield (FAO, 2015; Muriithi *et al.,* 2021). Integration of improved crop varieties in SWC practices is a climate-smart technology anchored on the pillars of increased productivity while simultaneously adapting to climate change.

The results in Table 4.6 also show that females had a positive and significant effect on household's perception that growing improved pigeon peas in *fanya juu* terraces increases pigeon pea production's resilience to climate change and increases farm productivity ($P< 0.05$) and increase crop residue (fodder and fuel wood) ($P<0.01$). Having farming as the main source of livelihood had a significant effect on perceiving that the technology is useful in the form of strengthening farming's resilience to variability in climate ($P<0.01$), increasing productivity and ease of practice on a farm. The steep slope of the cultivated land had a positive and significant effect on the perception of the usefulness of the technology in enhancing resilience to climate change ($P<0.01$), increasing productivity ($P<0.01$), and being easy to use ($P<0.05$). The coefficients on the location of the study sites Makueni and Kitui were positive and significant ($P<0.01$) on the perception that the technology increases farm practice's resilience to climate change, productivity ($P<0.05$), and ease of use/application.

The female farmers were more likely to perceive that growing improved pigeon peas in *fanya juu* terraces increases the resilience of pigeon pea production to climate change increases farm productivity and increases fuel wood and fodder than their male counterparts. This is plausible as most women carry out farm activities and therefore have knowledge of the performance of various varieties. Women perceived that the technology increases fuel wood and fodder because the responsibility to collect firewood for fuel and to feed the small stocks (sheep and goats) is mainly bestowed upon them (Gathaara *et al*., 2019). According to (Doss *et al*., 2020; Malapit and Quisumbing, 2015) women are in charge of household food production and utilization and are therefore keen on any innovations that increase yield and make preparation for use easy.

The slope of the land had a significant effect on farmers' perception of growing improved pigeon peas in *fanya juu* terraced plots to increase productivity and ease of establishing the terraces. The terrain of the land influences the conservation decision for the reason that soil erosion is more intense on steep slopes than on flat land. The velocity of rainwater runoff denudes the soil and reduces the productivity of the land on steep slopes more than on flat terrain. According to (Katema and Bauer; 2012; Marenya and Barret, 2007; and Moge *et al*., 2017), farmers on steep slopes have the urge to get remedies that abate soil erosion and are likely to have a positive perception of SWC techniques.

Table 4. 6 Factors influencing farmers' perception of growing improved pigeon peas in *fanya juu* terraces as an adaptation strategy to climate change in Southeastern Kenya region

Variable	Increase resilience to climate change		Increase productivity		Easy to use		Increase crop residue	
	Coef	Std. error	Coef	Std. error	Coef	Std. error	Coef	Std. error
Male head	-0.675**	0.043	-0.158**	0.094	0.565	0.351	-0.811***	0.094
Age	0.148	0.087	0.224	0.103	0.368	0.197	0.092	0.081
Education	0.572	0.381	0.176	0.194	0.325	0.240	0.083	0.212
Farming main	0.525***	0.116	0.194***	0.008	0.672*	0.226	0.164	0.198
Own land	0.023	0.082	0. 015	0.057	0.062	0.065	0.071	0.061
Slope	035***	0.011	0.374***	0.089	0.397**	0.145	0.008	0.091
Agric. extns	0.337***	0.164	0.506***	0.148	0.382***	0.114	0.199**	0.057
Makueni	0.498***	0.118	0.603***	0.269	0.342*	0.153	0.456*	0.218
Kitui	0.731***	0.142	0.507**	0.268	0.197**	0.087	0.028	0.064
Constant	-3.224***		-6.203***		-6.109***			
	Rho1		Rho2		Rho3		Rho4	
Rho2	0.372**							
Rho3	0.413*		0.092**					
Rho4	0.325		0.051***		0.269***			
Observations	400							
Loglikelihod	-1372.59							
Wald χ^2(27)	102.95							
Prob $> \chi^2$	0.0001							

Likelihood ratio test of rho21 = rho31 =rho 41= rho32 = rho 42=rho 43= 0: chi2 (36) = 91.9367 Prob > chi2 = 0.000. ***, **, * denote $p < 0.01$, $p < 0.05$ and $p < 0.1$ respectively. Machakos is the reference county.

Access to agricultural extension services significantly influenced farmers' perception of the usefulness of growing improved pigeon peas in *fanya juu* terraces on increasing resilience to climate change, increasing crop productivity, ease of establishing terraces on the farm, and enhanced production of fodder and firewood. Agriculture extension institution is mandated to reassure farmers of the positivity of agricultural innovations on their well-being and influence their perception of the technology. The agriculture extension is mandated to catalyze the uptake of climate-smart agricultural technologies to enhance productivity and cope with climate variability.

The result is consistent with (Cheruyiot, 2010; Moges *et al*., 2017; Omenda *et al*., 2022; Toromo et al., 2019) that farmers who interact with agricultural extension agents have a positive perception of SWC practices and tend to look for long-term benefits through land management practices that enhance soil quality.

The results on the marginal effect of the independent variable on the explained variables in the perception model (Table 4.7) show that a shift from being a female to a male household head would increase the probability of positively perceiving the usefulness of the technology in adapting to climate change by 1.9%. The result is plausible as women perform most of the tasks in pigeon pea production and therefore understand the production cycle. Women contribute the largest proportion of household labour, especially from resource-poor households that have a low ability to hire supplementary labour to avert any household labour constraint. The lengthy hours that women devote to land preparation, sowing, weeding, harvesting, drying, threshing, and winnowing enable them to have more knowledge about pigeon pea production and hence the perception of the crop on adaptation to climate change. This finding corroborates that of Me-Nsope and Larkins (2016); Namuyinga *et al*. (2022) who reported women provided more than half of the labour requirement at the lower node of the pigeon pea value chain and were more concerned about pest and disease-resistant varieties to limit the loss production less than the men.

A switch from farming on flat land to sloppy land would increase the probability of positively perceiving the usefulness of the technology by 3%. The fanya juu terraces are designed to minimize soil water loss through runoff by shortening the length of the slope (Gachene *et al*., 2019, Rashid *et al*., 20116; Njiru *et al*., 2022). Barungi *et al.* (2013) found that the possibility of implementing terraces on farms was 25% higher in households that perceived that their land was on a steep slope than those whose land was on a gentle gradient.

A shift from non-access to agricultural extension services to accessing would increase the probability of positively perceiving the usefulness of the technology in adapting to climate change by 8.4%. Laying out the terraces entails knowledge of contour, ditch depth, and slope positioning to ensure *in situ* water conservation and enhanced yield (Gachene *et al.*, 2019; Njiru *et al*., 2022). They acknowledge the role of agriculture extension in empowering farmers to construct technically appropriate SWC structures with the capacity to control runoff. According to (Abdullai and Huffman, 2014; Karuku, 2018; Moges *et al.*, 2017) contact with agricultural extension staff inculcates a positive perception of agricultural technologies.

Table 4. 7 Marginal effects factors hypothesized to influence farmers' perception of the usefulness of integrating improved pigeon pea varieties in *fanya juu* terraces in Southeastern Kenya

Variable	**Marginal effects**	**Standard error**
Gender (0= Female,1= Male)	-0.019**	0.007
Age (Years)	0.036	0.020
Education (Years)	0.019	0.019
Farming main occupation ((0= No, 1 = Yes)	0.107***	0.034
Own land (0= No, 1 = Yes)	0.021	0.024
Slope (0 = Flat, 1= Steep)	0.063**	0.022
Access to agricultural extension (0= No, 1=Yes)	0.084**	0.029

Note: $p < 0.01$, $p < 0.05$ and $p < 0.1$ respectively.

4.3 Factors influencing adoption of improved pigeon pea varieties in *fanya juu* terraced plots in Machakos Makueni and Kitui counties

4.3.1 Descriptive statistics of adopters and non-adopters of improved pigeon peas in fanya juu terraces

Adopters were defined as households that had adopted at least one of the improved pigeon pea varieties in *fanya juu* terraced plots during the cropping years of 2018-2019. About 34% of the farmers were in the adoption category and 66% were non-adopters. From the results presented in Table 4.8, the male house heads comprised 84% of the adopters and 83% of non-adopters. The average age of adopters was about 61 years while the non-adopters were 12 years younger. The average age of adopters was significantly different from non-adopters (1% level). The adopters had an average of 40 years of farming experience while non-adopters had 27 years, the difference in years of farming experience of the two groups was significantly different (1% level). The adopters had smaller land sizes and owned the parcel of land they cultivated compared to non-adopters. The average land size of adopters was 3.9 acres while non-adopters owned 5.6 acres, the difference in land sizes of the two groups was statistically significant at a 5% level. The average land size apportioned for pigeon pea production was 0.91 acres in adopting households while 1.3 acres in the non-adopting ones, the difference was statistically different at a 5% significant level.

The adopters were on average 18km away from the input dealers compared to 11km for the non-adopters. The adopter got 552kg/acre/year of dried peas and 364kg of green peas compared to 361kg/acre of dry peas and 248kg/acre in non-adopting households. The difference in yield of the two categories was significantly different at the 1% level. Both adopters (85%) and non-adopters (72%) sold part of the peas produced which was an indication that the pigeon pea production enterprise has the potential of increasing farm income under good management practices. However, the difference between the adopters and non-adopters was statistically significant at a 5% level.

About 72% of the adopters had contact with agricultural extension service providers compared to 43% of the non-adopters. The difference between the 2 groups was significantly different at 5% level. About 37% of the household heads had membership in farmers' associations compared to 51% of non-adopting households. The difference in farmers’ association of the two groups was statistically significant (1% level). The average family size of adopters was 4 while non-adopters was 6. Access to financial services of the adopting and non-adopting households was significantly different at a 10% statistical level.

Table 4. 8 Descriptive statistics of adopters and non-adopters of improved pigeon pea in *fanya juu* terraced plots

Variable	Adopters (n=136)	Non-adopter (n=264	Full sample (n=400)
Gender head male (%)^{a}	84 (0.033)	83 (0.027)	83 (0.022)
Age head (yrs)^{b***}	60.7(0.093)	44.8(0.096)	53.2(0.067)
Education	10.5(0.341)	14.6(0.425)	13.2 (0.367)
Experience head (yrs)^{b,***}	39.5 (0.006)	26.5 (0.061)	34.1(0.021)
Family size (no.) ^{b,*}	4(0.021)	6(0.008)	5(0.005)
Farm size (acres) ^{b,**}	3.9(0.121)	5.6(0.060)	5.4(0.062)
Own land (%)^{a}	56(0.008)	50(0.009)	52(0.011)
Land under pp(acres) ^{b,**}	0.91(0.003)	1.3(0.002)	1.1(0.002)
No. livestock (no.) ^{b,*}	28 (0.045)	42(0.097)	38(0.182)
Distance input mkt (km) ^{b,**}	18 (0.104)	11 (0.218)	15(0.096)
Credit facilities (%)^{a,*}	39(0.055)	20(0.033)	31(0.032)
Group member (%)^{a,***}	78(0.003)	51(0.027)	70(0.022)
Agric. Extension (%)^{a,**}	72(0.059)	43(0.025)	68(0.034)
Market information (%)^{a}	71(0.218)	69(0.219)	70(0.154)
Peas yield (kg/acre)^{b***}	552(0.042)	361(0.067)	439(0,097)
Sold peas (%)^{a,**}	85(0.182)	72(0.175)	79(0.175)
Income peas (Ksh) ^{b,***}	79,700(0.067)	55,000(0.193)	64,570(0.087)

Notes: ***. ** and * indicate that differences between adopters and non-adopters are significantly different at 1%, 5%, and 10% levels, respectively based on Chi-square test ^{a} and t-test ^{b}. Standard errors in brackets.

4.3.2 Marginal effects of factors influencing adoption of improved pigeon pea varieties in *fanya juu* terraces in the three study sites

The results on the marginal effects of explanatory variables on the explained variables influencing the adoption of improved pigeon peas in *fanya juu* terraced plots are presented in Table 4.9. A one-year increase in farming experience increased the probability of adopting the growing of improved pigeon peas in *fanya juu* terraced plots by 5.2% which was significant at a 1% level. A shift from not owning land and livestock to owning them would increase the probability of adopting the technology by 3.7% and 4.1% respectively, both significant at the 5% level. An increase in a kilometer of the distance to the input dealers would decrease the probability of adopting the technology by 3.8%, significant at the 5% level. A unit increase in the chance of perceiving the usefulness of the technology in adapting to climate change would increase the likelihood of adoption by 6% which was significant at a 1% level. A switch from not accessing agricultural extension services to accessing them would increase the probability of adopting the technology by 2.6%. A change from non-membership in a farmer's group to membership would increase the likelihood of adopting the technology by 10%.

Table 4. 9 Marginal effects of factors hypothesized to influence the integration of improved pigeon pea varieties in *fanya juu* terraced plots in South-eastern Kenya

Variable	Marginal effects	Standard error
Gender (0= Female, 1= Male)	0.053	0.029
Experience (Years)	0.052***	0.004
Education (No of years)	-0.029	0.028
Family size (No)	0.39	0.43
Farm size (No. acres)	-0.046	0.087
Non-farm income (0= No, 1=Yes)	0.081	0.092
Owns land (0= No, 1= Yes)	0.037**	0.013
Owns livestock (0= No, 1= Yes)	0.041**	0.014
Distance to input dealers (No. Km)	-0.038**	0.0062
Perception (predicted values 0-1)	0.061***	0.006
Group membership (0= No, 1= Yes)	0.101***	0.019
Access to agricultural extension (0= No, 1= Yes)	0.026***	0.003
County:		
Makueni	0.087***	0.007
Kitui	0.033**	0.000
Constant	-2.245	0.548
Observations = 400, LR chi2(13) = 167.92		
Log likelihood = -209.596***, Pseudo R^2 = 0.5882		

***, **, * denote statistical significance at the one %, five % and ten % levels, respectively.

The years of farming experience of household's head coefficient was positive and significantly influenced adoption as was expected. These findings were appropriate for *fanya juu* terraces that had been promoted in SEK for many years since colonial times which meant that those who had farmed for years knew the benefits of establishing terraces on land in addition to improved crop varieties especially those that are drought tolerant, early maturing. More experienced farmers seem to have better information and accumulated knowledge over time about climate variability and the possible crop production technologies that can cope with climate change climate change. The results concur with (Gebrezgabher *et al.,* 2015; Lambert *et al*., 2015; Musafiri *et al.,* 2022), who found that more years of farming experience help farmers evaluate the advantages of agricultural technology and influence adoption.

Farmer's ownership of the land they tilled positively influenced the adoption of the technology. This is mainly because land tenure arrangements make investments in terraces worthwhile as the owners are assured of accessing and controlling the benefits resulting from it, which forms a great basis of motivation to take up the venture. Ownership of land is an important factor in any long-term investment. Benefits from terraces are not realized immediately and therefore anybody leasing land and not certain of utilizing the land for a long period would be apprehensive of investing in terraces especially when not sure of recovering the capital invested within the period they are allowed to cultivate the land. The results imply that the informal land tenure system as pertains to those conferred through customary laws could impede farmers' decision to adopt the technology. Doss (2004); and Kabubo-Mariara and Mulwa, (2019) reported that secure land tenure influences the adoption of agricultural technologies. Bett (2004); Barungi *et al*. (2013); Mati (2010) found out that formal land ownership by farmers influenced the household's adoption of soil and water conservation practices especially those that involved constructing farm structures.

The coefficient on household keeping livestock was positive and significant in determining the adoption of the technology as expected. This is attributed to livestock being a source of income as they are easily liquidated to cash (Kabubo-Mariara and Mulwa, 2019; Radney *et al*., 2022). Farmers have the option of selling their livestock to raise funds to invest in improved pigeon peas and *fanya juu* terraces. Ox-drawn carts are also used in land preparation and manure from livestock is used to enrich soil fertility. (Moges *et al.,* 2017; Muriithi *et al*., 2021; Musafiri *et al.*, 2022) noted that livestock is a form of wealth associated with farmers' adoption of improved technologies.

Farmers who perceive the usefulness of the technology in enhancing pigeon pea production to the adverse effects of the changing climate are prompted to adopt the technology to enable them to minimize and manage the risks of climate change. According to (Kichamu *et al*., 2018; Lencsés *et al.,* 2014; Meijer *et al*., 2015; Ndambiri *et al*., 2014; and Ntshangase *et al*., 2018) positive perception of technology is a prerequisite to the adoption of a technology with a positive perception are likely to increase adoption and sustain the practice in future.

Farmers' access to agricultural extension services positively influenced adoption as had been postulated. The agricultural extension staff provides farmers with information on soil water and health management, seeds suited to the various agroecological zones, availability of farm inputs, and good crop husbandry. The results indicate that public agricultural extension service provision is a strong conduit for providing both information and technical skills on improved agricultural production. Access to agricultural extension services reduces farmers' ignorance of improved technology and catalyzes adoption instead. The results agree with (Bryan *et al.*, 2011;

Maina *et al*., 2020; Miriithi, 2021) that farmers' regular contact with agricultural experts in Semi-arid areas of Kenya prompted their adoption of adaptation measures. Similarly, Ajewole (2010), Kaliba *et al.* (2018) and Mwangi and Kariuki (2015) reported that the frequency of extension visits increased the possibility of adoption of soil fertility enhancing technologies in Nigeria and improved sorghum in Tanzania respectively. The Agriculture extension staff provides information on available improved seeds and how to access them. Leggesse *et al.* (2004) and Nhemachena *et al*. (2014) argue that access to information without the requisite inputs stifles farmers' efforts to adopt the technology. Simtowe *et al.* (2012) also reported farmers' adoption of improved pigeon pea varieties in SEK was contingent on access to improved seed that was distributed by agriculture extension. In SEK the recurrent drought and resultant crop failure (GoK, 2015) is a likely precursor to exhaustion of seed stock in most resource-poor households. This is due to the tendency of the households to convert the seed into food whenever there is drought and hunger. Limited replenishment of seed stock which is common in remote parts of the country is likely to constrain adoption (Kabunga et al., 2012, Muriithi *et al.*, 2021).

The study posited that farmers' membership in associations positively influenced the adoption of the technology. Farmers exchange ideas during their group meetings that influence their adoption decisions. Establishing SWC structures on farms is labour intensive and farmers use collective action to catalyze adoption. A positive and significant relationship between farmers' membership in associations and the decision to adopt soil and water conservation measures was reported by (Kaliba *et al.*, 2018; Kamau *et al.,* 2020; Nyangena, 2008; Omenda *et al*., 2022; Toromo *et al.,* 2019). Laying out terraces on a farm requires high initial capital and labour investment and therefore farmer group loans enable the members to acquire the required inputs that enable them to adopt the technology (Gachene *et al.,* 2021; Karuku *et al*., 2018; Njiru *et al.*, 2021).

4.4 Impact of growing improved pigeon pea varieties in *fanya juu* terraces as a climate change adaptation strategy on farmers' income

4.4.1 Gross margins of adopters and non-adopters of pigeon pea technology across the three study areas

The results in Table 4.10 portray the gross margins of adopters and non-adopters of improved pigeon peas grown in *fanya juu* terraced plots in an acre of land over two rain seasons in a year. The adopters planted improved pigeon pea varieties in *fanya juu* terraced plots while non-adopters were those with indigenous peas on un-terraced plots. The total variable costs of adopters in Machakos, Makueni, and Kitui counties were KES 52,300, KES 45,040, and KES 41640 per acre per year respectively, while for non-adopters were KES 30,900, KES 27620, and KES 2530 correspondingly. The adopters incurred an additional cost of KES 3,600, KES 2,800, and KES 2,400 per acre per year in Machakos, Makueni, and Kitui counties respectively on harvesting grass on the terrace embankment relative to non-adopters.

The adopters had total revenue of KES 84, 040, KES 77, 201 and KES 73,300 per acre per year in Machakos, Makueni, and Kitui counties respectively relative to non-adopter who correspondingly got KES 52,940, KES 49, 590 and KES 47390 per acre per year. The adopters had gross margins of KES 31,740 per acre per year in Machakos, KES 32,170 in Makueni, and KES 31,660 in Kitui counties while the non-adopters had KES 22,040 in Machakos County, 21,970 and 22,040 in Makueni and Kitui counties respectively. More detailed results on gross margins in different pigeon pea production practices are in Appendices 1.6, 1.7, and 1.78

The results indicate that the cost of land preparation for planting was on average 16% of the total variable cost of production in adopting households and 20% in non-adopting households.

Table 4. 10 Mean gross margins of adopters and non-adopters of improved pigeon pea

			County			
	Machakos		Makueni		Kitui	
Cost/revenue item (KES/acre/year)	**Adopters**	**Non-adopter**	**Adopter**	**Non-adopter**	**Adopter**	**Nonadopter**
Ploughing	6000	3600	4500	4250	4200	3600
Furrowing	2400	1800	2000	1750	2600	2000
Pigeon pea seed	4500	2400	5040	3120	6000	2500
Manure	2000	800	2100	1750	2200	1600
Planting	3600	2700	3500	2500	1600	1200
Weeding	9000	7200	5000	4000	4600	3200
Terrace maintenance	4500		4250		4000	
Pesticides	6000	6000	7000	5500	7940	7000
Spraying	1200	1200	1000	750	800	600
Harvesting	5400	3000	4000	3000	1200	800
Transportation	2000	1000	1600	1000	2000	1500
Drying Pigeon pea	900	600	1000	1000	1200	600
Threshing	1200	600	1250	1000	900	750
Grass harvesting	3600		2800		2400	
Total variable cost	**52300**	**30900**	**45040**	**27620**	**41640**	**25350**
Yield dry	55200	36000	51660	34740	43600	31360
Yield green	21840	14940	17150	13650	21000	15030
Crop residue	2000	2000	1200	1000	1500	1000
Grass	5000		7200		7200	
Total Revenue	**84040**	**52940**	**77210**	**49590**	**73300**	**47390**
Gross margin/acre/yr	**31740**	**22040**	**32170**	**21970**	**31660**	**22040**

The cost of pesticides made up 15% of the total variable cost in adopters and 19% in non-adopting households. Pigeon peas are infested by pests during dry spells, which if not contained affects the plant's floral development and stem with a resultant damaging effect on yields. The result is a pointer to the need for a remedy that would enhance pest resistance in both improved and indigenous varieties. The results depict higher gross margins for adopters relative to non-adopters. The results imply that the integration of improved pigeon peas in *fanya juu* terraces had more benefits in terms of increased crop yields, more crop residues, and hence more net farm returns compared to those of non-adopters. The production of grass on the terraces' embankment has twin benefits of trapping the soil mitigating soil erosion and providing fodder for livestock.

4.4.2 Impact of adopting improved pigeon pea varieties in *fanya juu* terraced plots on gross margins

Table 4.11 represents the determinants of variation in adoption decision (selection) and outcome equations of adopters and non-adopters of improved pigeon pea varieties in *fanya juu* terraced plots. The selection equation in column 2 in Table 4.11 displays the determinants of adopting the technologies that were discussed in the previous section 4.3.2. The same determining variables were used in computing the Full Information Likelihood (FIML) estimates of the outcome equation.

The male household head variable was significant (10% level) and positive in explaining increased gross margins from the production of improved pigeon peas amongst the adopting households. The finding indicates that male-headed households had a higher probability of having more income from pigeon peas compared to their female counterparts. The result supports the notion that men access and control resources required in adopting improved technologies and selling farm produce that female household heads are constraints. Adzawla *et al.* (2019); Matere *et al*. (2022); Me-Nsope and Larkins (2016) and Ojo and Baiyegunhi, (2020) argue that gender-associated differences in benefiting from agricultural technologies are actually attributed to the differences in access to resource-based opportunities in the value chain from production to marketing and therefore should not be directly adduced to a farmer being male or female. This is a pointer to the fact that male-headed households generally have opportunities that enable them to exploit the benefits of adopting agricultural technologies more than most female-headed households and therefore interventions should be cognizant of this fact.

More years of farming experience of the farmer increased the chances of amplified income from adopting the adaptation measures in pigeon pea production (1% significance level). Years of farming experience enhance the farmers' capability to carry out good management practices that increase yields and net returns. This suggests that those with many years of experience in farming have better information and knowledge amassed over time that strengthen their productive potential and enhance their capacity to improve productivity and increase marketable surplus. The result is consistent with Berhe *et al*. (2017); Martey and Kuwornu (2021); Tufaa *et al.* (2019); and Wu (2022) who found that years of farming experience had an affirmative and significant impact on the income from adopting agricultural technologies.

Land size was negatively but significantly associated with increased gross margins amongst adopters (significant at 10% level). This could mean that those with small farm sizes focus on increasing productivity from the adaptation strategies from the limited land resources compared to those with large farm sizes. This finding corroborates Varma (2019), who reported that smallholders had a higher probability of taking up sustainable rice intensification technologies and were likely to have more farm productivity and income compared to those with large farms in India. Our finding is in contrast with Wordofa *et al.* (2021); and Verkaart *et al*. (2017) who concluded that adopters of agricultural technologies who had large farm sizes, had more crop productivity than those of small land sizes, which was attributed to high-risk aversion of those with small land sizes.

Livestock was used as a measure of household wealth. The number of livestock owned was an important factor in explaining high net farm income amongst adopters that emanate from increased yields. Adoption of agricultural technologies requires financial resources and therefore farmers who own more livestock are more likely to obtain resources to carry out the required agronomic practices that increase farm revenue compared to households with a low resource base. Improved pigeon peas in *fanya juu* terraces require financial resources to acquire inputs and pay the farm for labour therefore farmers with more livestock and thus wealth have the resources and are less risk-averse and therefore likely to take up new technologies than the limited-resource farmers. Farmers with livestock have an additional benefit of accessing manure to use in soil fertility enhancement. The results uphold the findings of (Abdulai and Jumpah, 2021; Awotide *et al.,* 2012; and Jama *et al*., 2019) that households' ability to benefit from technology is often positively related to its wealth of which livestock is one form of wealth in farming communities.

Membership in farmers' group/s positively influenced the increase in the gross margins in improved pigeon pea production. Producer marketing groups pool resources to increase productivity and use their bargaining power to sell their produce at better prices. Wu (2022); Kamau *et al.,* (2020) reported a positive and significant relationship between farmers' membership in associations and farm income. Most smallholder farmers face financial constraints in attempting to adopt technologies, they, therefore, resort to informal credit organizations like the farmer group-based village saving and lending associations (VSLA) to be able to purchase inputs such as improved seed, and agro-chemicals and pay labour charges for the timely undertaking of the farm operations to improve productivity. The result is aligned with (Namboka et al., 2017; Wordofa *et al.,* 2021) participation in farmer groups strengthens members' ability to access credit, and increases production and farm income relative to individual activities, especially in resource-limited households.

Table 4. 11 Determinants of variation in pigeon pea gross margin among adopters and non-adopters of improved pigeon pea varieties in *fanya juu* terraced plots in Southeastern Kenya

	Selection (adoption equation)	Outcome (Gross margins) equation	
Variable		Adopters	Non-adopters
Male head	0.521 (0.349)	39.576* (19.348)	23.141 (20.632)
Education	0.236 (0.191)	-2.694 (2.758)	2.754*** (0.946)
Farm experience	0.478***(0.092)	3.118**(1.063)	1.849(1.619)
Household size	0.175(0.123)	1.129(0.726)	1.338*(0.641)
Farm size	0.319(0.267)	-36.752 (19.278)	18.725** (7.312)
Own land	0.265**(0.096)	15.935**(6.117)	20.489(11.461)
Own livestock	0.869**(0.342)	57.071**(20.312)	50.509*(21.143)
Off-farm income	0.075 (0.049)	1. 113 (1.096)	3.926(2.108)
Group membership	0.364***(0.103)	12.189**(4.237)	9.765(4.053)
Agric. extension	0.293***(0.087)	10.839***(3.456)	13.184*(5.902)
Makueni	0.544** (0.196)	71.867***(20.648)	76.101**(30.154)
Kitui	0.666***(0.214)	67.639***(20.081)	69.471*(40.128)
Perceive the usefulness of tech	0.658***(0.218)		
Distance to input market	0.496*** (0.165)		
$ln\sigma_1$.	1.571*** (0.459)		
$\rho_{1\mu}$		-0.524***(0.162)	
$ln\sigma_2$.			1.389*** (0.487)
$\rho_{2\mu}$			-0.086 (0.052)
Wald χ^2	29.23***		
Log-likelihood	-607.58		
LR test of independent equations χ^2 (1)	58.91***		

Notes: *,**, ***, represent statistical significance at the ten %, five %, and one % levels, respectively; standard errors (in parentheses).

Farmers' contact with agricultural extension service providers increased the probability of increasing income from both categories of farmers regardless of their adoption decisions. Agricultural extension staff provide information on the benefits of agriculture that contribute to enhanced household yield, food supply, and income. Similarly (Archie *et al.*, 2018; Kaliba *et al.*,

2018) found that farmers' agricultural extension plays a critical role in rural communities' well-being.

Following (Teklewold *et al*., 2013; Wossen *et al*., 2019) the distance to the farm input market only affected the adoption decision and was therefore omitted from the outcome equation as the exclusion restriction variable. The variation in the coefficients of the independent variables in the outcome equations of adopting and non-adopting households illustrates the existence of heterogeneity in the data (Di Falco *et al*., 2013).

The econometric results on the choice and outcomes equations are displayed in Table 4.11. The likelihood ratio test for the independent equations $\chi^2(1)$ = 58.91 indicates that the Endogenous switching regression (ESR) estimates were statistically significant at a 1% level. This suggests that the vector of independent variables considered in the model simultaneously influenced the adoption decision and the effect on net income from pigeon pea production of adopters and non-adopters of the technology. The values of $\rho_{1\mu}$ represent the correlation coefficient of the selection and outcome equations for adopters that were significantly correlated (1% level) revealing that self-selection took place in the adoption decision and therefore imply that adoption of improved pigeon pea in *fanya juu* terraced fields may not have similar effects on the non-adopting category if they choose to adopt (Di Falco *et al*., 2013; Lockshen & Sajeia, 2004). This means that if we fail to consider unobserved variables, then the model estimates would be biased (Di Falco *et al*., 2013; Lockshen & Sajeia, 2004). The negative sign of $\rho_{1\mu}$ points to a positive selection bias, which evinces that households that had above-the-average net farm returns had a higher chance of adopting the technology. Furthermore, $\rho_{2\mu}$was greater than$\rho_{1\mu}$, meaning adopters of improved pigeon peas in *fanya juu* terraced plots obtain higher gross margins than they would have if they had not adopted (Lokshin and Sajaia, 2004).

A falsification test approved the relevance of the exclusion restriction and confirmed that distance to input markets was a valid selection instrument, the variable was significantly correlated with growing improved pigeon pea varieties in *fanya juu* terraced fields at 1% level, but was not correlated with the outcomes in the non-adopting households (Di Falco *et al.*, 2013).

Table 4.12 presents the expected gross margin per acre per year from pigeon pea production under actual and counterfactual conditions. The households that adopted improved pigeon peas in *fanya juu* terraced plots on average obtained KES 31,852 while non-adopters got KES 22,028 per acre per year. In the counterfactual case, that had farmers who adopted, or did not adopt, would have earned KES 27, 792(14.6%) less income. Conversely, had non-adopters, adopted, they would have earned KShs 29, 484 (33.8%) more than their previous status of not adopting. These results imply that adopting improved pigeon pea varieties in *fanya juu* terraced plots had benefits relative to not adopting the technology. The heterogeneity effect of adopting (HE_1) was KES– 3,396. The negative sign means that the effect is smaller for the households that adopted relative to those that did not adopt. Without controlling for selection bias through the treatment effect model, the effect of adopting would have been KES 9,824 (1a -1b), that is, 45% more relative to the case of non-adopting, which could be misleading. The results further suggest that farmers who decided to adopt the technology would have above-average gross margins whether or not they adopted it, which indicates a positive selection bias. Nonetheless, the adopting households were better off adopting than not adopting. The results provide evidence that the adoption of integrated improved pigeon pea varieties in *fanya juu* terraced field increases farm income. This finding is consistent with those of Abdulai and Huffman (2014), Jaleta *et al*. (2018), Marteyet *al.* (2021), and Shiferaw *et al.*

(2014) on the positive impact of adopting agricultural technology on income. The positive impact of integrating improved pigeon pea varieties in *fanya juu* terraces on pigeon pea production's gross margin is expected because improved varieties are yield-increasing and therefore increase the marketable surplus leading to high farm income.

Table 4. 12 Average expected gross margins from and treatment and heterogeneity effects among adopters and non-adopters of improved pigeon peas in *fanya juu* terraces in Southeastern Kenya

	Decision		
Subsample	**Adoption**	**Non-adoption**	**Treatment effects**
Gross margin of households that adopted (KES)	(1a)31,852	(1c)27,792	TT= 4,060**
Gross margin of households that did not adopt	(1d)29,484	(1b)22,028	TU=7,456**
Heterogeneity effects	2,368	5,764	HE_1 = -3.396

Note: ** denote statistical significance at the five percent level.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The adoption of improved agricultural technologies in agricultural-based economies particularly in developing countries is expected to improve farmers' well-being directly by increasing productivity, and farm income and contributing towards food security in the majority of resource-poor rural households. For a long time, improved pigeon pea varieties have been promoted in semi-arid areas of Kenya to increase food production and farm income. An integrated crop and soil and water management technology in the production of improved pigeon pea varieties in *fanya juu* terraces were disseminated in the area to enhance food production and be mutually reinforcing in reducing household food security and strengthening farmers' resilience to climate change. However, farmers' perception of the usefulness of the technology as an adaptation has not been assessed and the adoption of the technology is not known and the impact of adoption on farm income was not documented. This study set out to investigate the effect of adopting improved pigeon peas on *fanya juu* terraced farms using three objectives. The first objective assessed the factors influencing farmers' perception of the usefulness of integration of improved pigeon pea varieties in *fanya juu* terraces as an adaptation strategy to climate change using factor analysis and multivariate probit model. The second objective was to examine factors influencing the adoption of improved pigeon peas grown in *fanya juu* terraced plots and the third objective was to analyse the impact of adopting the package on farm income was assessed jointly using an endogenous switching regression that accounted for endogeneity and sample selection.

The results showed the farmers perceived that growing improved pigeon pea varieties in *fanya juu* terraced plots was useful to: increase the resilience of pigeon pea production to climate change, increase pigeon pea productivity, be easy to apply/ use technology, and increase crop residue fodder and fuel wood. Adopters improved pigeon pea varieties in *fanya juu* terraced plots had a mean score of 4.1 out of the possible 5 points that the technology increased resilience of pigeon pea production to the deleterious effects of climate change compared to a 3.2 mean score in the non-adopting households. The difference in the mean scores was statistically significant. Adopting households had higher scores than the non-adopting ones and were statistically different in perceiving usefulness in terms of increase in productivity and ease of using the technology.

The results on factors influencing farmers' perception of the usefulness of the technology in adapting to climate change showed that female household heads had positive and significant effects on household's perception that the technology increases pigeon pea production's resilience to climate change, increases farm productivity and increases crop residue (fodder and fuel wood). Years of experience in the farming of the household head and the slope of the cultivated land had positive and significant effects on the perception that the technology increases resilience to climate change, increases productivity, and is easy to use. Farmers' membership in farmer groups and access to agricultural extension services significantly influenced the perception of the technology as a measure of adapting to variability in the changing climate.

The results suggest that researchers and disseminators of technologies should take cognizance of farmers' perceptions of technologies to increase adoption.

About 34% of the households sampled were growing improved pigeon peas in *fanya juu* terraces. The years of experience in farming, ownership of land and livestock, positive perception of the usefulness of the technology in adapting to climate change, membership in farmers' groups, and contact with agricultural extension services providers of the household head significantly influenced the adoption.

The results on the impact of adopting improved pigeon peas in *fanya juu* terraced plots on farming households' income showed that adopters of the technology got an average of KES 31,852 per acre per year compared to KES 22,028 in non-adopting households. In a hypothetical case that farmers who adopted, did not adopt, they would have earned 14.6% less income. In another case that non-adopters, actually adopted, they would have earned 33.8% more than their previous status. The study concludes that farmers had a positive perception of the usefulness of growing improved pigeons in *fanya juu* terraces to increase their resilience to climate change, increase productivity, ease in application of technology, and increase fodder and fuel wood production from the crop residues. And that farmers' perception of the usefulness of integrating improved pigeon peas in *fanya juu* terraces and adoption of the technology was influenced by socio-economic factors. Adoption of the technology significantly increases gross margins.

5.2 Recommendations

An individual cannot be brought out of food insecurity unless the quality and productivity of the resources on that livelihood depends are addressed. Interventions to promote the adoption of improved pigeon pea production on *fanya juu* terraced farms should take advantage of the available opportunities and strengthen conditions under which resource-limiting farmers' decisions are made. The specific recommendations are:

(a) Policy at the county level should strengthen and leverage government extension services to promote and create awareness about the existing improved pigeon pea varieties and soil and water management practices to enhance farmers' resilience to climate change. The county governments should create an enabling environment for farmers to access input that strengthens production pigeon pea production.

(b) To obtain a high impact on income from integrating improved pigeon peas in *fanya juu* terraces, promotion efforts should also target farmer groups, households that own the land they cultivate, own livestock, and are more experienced in farming to ensure increased adoption of the technology. Female-headed households should also be targeted as they carry out most activities in pigeon pea production.

(c) The County government should advocate for farmers to legally own land so that they have an incentive to invest in long-term soil water management practices like terraces that require high capital investment but a long payback period.

(d) A more detailed study on the impact of adoption that integrates more drought-tolerant crops like pearl millet, sorghum, and livestock keeping that is typical in smallholder, mixed farming systems should be carried out by researchers and academia.

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7.0 APPENDICES

Appendix 1.1 Variable inflation factor for multicollinearity test in variables in the perception model

Variable	**VIF**	**1/VIF**
Gender	2.43	0.41
Age	2.71	0.37
Education	1.64	0.61
Own land	1.36	0.74
Slope of land	1.28	0.78
Access to agricultural extension	2.09	0.49
Mean VIF	2.16	

Appendix 1.2 Variable inflation factor for multicollinearity test in variables in the adoption model

Variable	**VIF**	**1/VIF**
Gender	1.89	0.59
Experience	1.21	0.83
Education level	1.74	0.69
Family size	1.48	0.73
Non-farm income	2.01	0.67
Farm size	1.15	0.81
Owns land	1.65	0.96
C	1.43	0.68
Group membership	1.59	0.87
Agricultural Extension	1.27	0.54
Owns livestock	1.05	0.92
Mean VIF	1.78	

Appendix 1.3. Test of validity of selection instruments

Selection variable	Adoption IPP/FJT	Gross margins Pigeon pea production
Perception usefulness of technology	0.451***(0. 139)	0.070(0.059)
Distance to market	-0.656***(0.206)	0.054(0.102)
Constant	2.742***	3.199**
Wald test on perception on usefulness of technology and distance to input market variable	$\chi 2$ = 31.43*** P = 0.000	F. Stat = 0.53 P= 0.221
Observations	400	

Appendix 1.4 Farmer's Questionnaire

Instructions:

This questionnaire is divided into 7sections (1-7) that should be completed. Some of the questions need specific answers (are pre-coded) while others are open-ended. For the pre-coded questions, select the most appropriate answer. For the open-ended questions please write clearly and briefly.

This information is solely for research. The information gathered will be confidential and will not be disclosed to any other party apart from the researcher.

Enumerator's Name ……………………………………Telephone no …………………….

Date of interview …………………………………………

Name of Respondent ……………………………………Telephone no……………………

GPS coordinates and altitude (elevation):

GPS: Longitude …………………………..Latitude …………………………………..

Elevation …………………………………….Meters

No.	Variable label	Variable value	Instructions
1.01	County		
1.02	Sub-County		
1.03	Ward		
1.04	Village		
1.05	Are you the household head?	0 =No, 1= Yes	
1.06	What is your relationship with household head?	1= Wife 2=Husband 3= Son 4=Daughter 5= Farm manager 6= Relative 7= other (specify) ……	
1.07	Are you involved in decision making on farm activities?	1= Yes, 2=No	
1.08	Gender of the household head	1=Male, 2=Female	
1.09	Age of the household head	……………. Years	
1.10	Level of education of household head	1=None 2= Adult education 3= Primary 4=Secondary 5=College/University	Tick

1.11	For how many years has the household head been farming?	……………… years	Fill in
1.12	Household size	Total …………………… Under 18 years………. Over 70 years ………….	
1.13	What is the household's main source of income?	1= Salaried employment[ ] 2= Farming [ ] 3= Business [ ] 4= Casual labour [ ] 5= other (specify)……. [ ]	
1.14	How much does the household earn per month per year?	KES ………………………	Give most appropriate
1.15	Do you get any remittances from relatives, friends etc?	0 =No, 1= Yes	
1.16	Approximately how much do you receive in a year?	KES ………………….	
1.17	Age of respondent	………………… years	
1.18	What is your level of education?	1=None 2= Adult education 3= Primary 4=Secondary 5=College/University	
1.19	For how many years have you been involved in farming in this household?	………….. years	

Section 2: Farm characteristics and enterprises

<table>
<tr><td>2.01</td><td>What is the household's farm size?</td><td>……………… acres</td><td></td></tr>
<tr><td>2.02</td><td>Does the household own the land cultivated?</td><td>0=No, 1=Yes</td><td></td></tr>
<tr><td>2.03</td><td>Does the household have title deed for the land owned?</td><td>0=No, 1=Yes</td><td></td></tr>
<tr><td>2.04</td><td>Crops grown on land</td><td><table>
<tr><th>Crop</th><th>Acreage</th></tr>
<tr><td></td><td></td></tr>
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</table></td><td>Fill</td></tr>
</table>

2.05	Which livestock do you keep?	1= Cattle [ ] 2= Sheep [ ] 3= Goats [ ] 4= Chicken [ ] 5= Rabbits [ ] 6= Donkeys [ ] 7= Bees [ ] Other (specify)………………… ……………………………........	Response can be more than one
2.06	Is soil and water conservation (SWC) practiced on this farm?	0=No, 1=Yes	If No, skip to 4.01
2.07	What is the slope of your land?	0=Not steep, 1= Steep	
2.08	Which SWC practices are adopted on this farm	1= *Fanya juu* terraces 2= Bench Terraces 3= Water retention ditches 4= *Zai* pits 5= Tied ridges 6= Check dams 7= other (specify) ……………………………….. …………………………………. ………………………………….	Response can be more than one. If you don't have *fanya juu* terraces skip to 4.01

Section 3: ***Fanya juu*** **terraces on farm**			
3.01	For how long have the terraces been on this farm?	……………………. years	Only those with *fanya juu* terraces
3.02	Which crops have you grown in *fanya juu* terraced plots	…………………………………… …………………………………… …………………………………… ……………………………………	
3.03	From where did you get the technical knowhow on constructing terraces?	1= Agric. extension officers 2= Farmer group 3= neighbour 4= None	
3.04	What is the main source of labour for terraces construction?	1= Family labour 2= Hired labour 3= farmers group labour. 4= Other (specify)	

3.05What was the cost of establishing the terraces?

Activity/Item	No. of units	Unit cost	Total cost

Pegs			
Measuring &pegging			
Digging trenches			
Manure			
Planting grass			
Others (specify)			

3.06 Do you carry out maintenance of the terraces Yes [ ] No [ ]. If yes, fill the table.

3.07

Activity	Units	no units	Unit cost	Total cost	How regular
Deepen the trench					
Harvest grass					
Plant grass					
Plant trees in trench					
Others(specify)					

Section 4: Pigeon pea production			
4.01	Do you grow pigeon pea?	0= No, 1= Yes	
4.02	Which varieties do you grow?	Indigenous 1 2 3 4 5 6 Improved 1 2 3 4 5 6	
4.03	Do you grow some improved pigeon pea varieties in *fanya juu* terraced plots?	0= No, 1= yes	
4.04	If yes, how many acres?		

4.05	For how many years have you been growing improved pigeon pea varieties in *fanya juu* terraces?		
4.06	Do you grow some improved pigeon pea varieties in un-terraced plots *fanya juu* terraced plots?		
4.07	If yes, how many acres?		
4.08	Have you ever discontinued growing improved pigeon pea varieties in terraced plots *fanya juu* terraced plots		
4.09	If yes, why?		
4.10	Do you grow some improved pigeon pea varieties peas in un-terraced plots?	0= No, 1= yes	
4.11	If yes, how many acres?		
4.12	Do you grow some indigenous peas in *fanya juu* terraced plots?	0= No, 1= yes	
4.13	If yes, how many acres?		
4.14	Do you grow some indigenous peas in un-terraced plots?	0= No, 1= yes	
4.15	If yes, how many acres?		
4.16	Have you ever grown improved pigeon peas in *fanya juu* terraces?		
4.17	If yes, for how many years?		
4.18	What is the source of your improved pigeon pea seed?	1.Research Centre 2.Dry Land seed company 3. Local retail market 4. Other farmers 5. Own produce	
4.19	What is the source of your indigenous pigeon pea seed?	1. Local retail market 2. Other farmers 3. Own produce	
4.20	What is the approximate distance to the input market for your pigeon pea production?	Km	
4.21	How many times do you harvest the improved peas in a year	1= Once 2= Seasonally (twice) 3= other (specify) ………………………….. …………………………… …………………	
4.22	How many times do you harvest the indigenous peas in a year	1= Once 2= Seasonally (twice) 3= other (specify) …………………………..	

		…………………………… …………………	
4.23	When do you harvest peas from improved varieties	Green peas …………………………… …… Dry grain…………………………… …………..	Specific months
4.24	How much did you harvest last year?	Green peas …………… kg Dry grain ……………… kg	
4.25	How much of the harvest was consumed?	Green peas …………… kg Dry grain ……………… kg	
4.26	How much of the harvest is sold?	Green peas …………… kg Dry grain ……………… kg	
4.27	Was the harvest and consumption different from the previous years?	0= No, 1= Yes	
4.28	If yes why?	…………………………… …………………………… …………………………… …………………………… …………………………	
4.29	When do you harvest green peas from indigenous varieties	Green peas …………………………… …… Dry grain…………………………… …………..	Specific months
4.30	How much did you harvest last year?	Green peas …………… kg Dry grain ……………… kg	
4.31	How much of the harvest was consumed?	Green peas …………… kg Dry grain ……………… kg	
4.32	How much of the harvest was sold?	Green peas …………… kg Dry grain ……………… kg	
4.33	Was the harvest and consumption different from the previous years?	0= No, 1= Yes	
4.34	If yes, why	…………………………… …………………………… …………………………… …………………………… …………………………	

5.0 Costs and benefits in production

Description of item	Improved in Terraces	Improved no terrace	Indigenous in Terraces	Indigenous no terraces
Land preparation				
Seed				

Manure
Planting
Weeding
T. Maintenance
Pesticides
Spraying
Harvesting
Transportation
Dry &thresh
Other cost

Grass harvest
Yield dry
Yield green
Crop residue
Grass
Other revenue streams

6.0. Marketing

Do you sell the peas 0 = No, 1= Yes

Variety	Units	No. of units	Average unit price
Green peas			
Dry peas			

Do you sell any peas for seed?	0= No, 1= Yes	
What is the price of for improved peas for seed?	KES ………………	
What is the price of indigenous peas for seed?	KES ………………	
Where do you sell your pigeon peas?	1= Farm gate 2= Nearest market centre (distance)…….Km 3= Nearest urban centre (distance) ……..Km 4= In the city (distance)………..Km Other (specify)………………… …………………… ………………………… ………………………… …	
How do you sell the peas?	1= Individually 2= Farmer group Other (specify) ………………………. ………………………… …………………………	
When do you sell your peas	1=immediately after harvest 2= Store sell later	

Section 7: Perception on usefulness of integrating improved pigeon peas in *fanya juu* terraced plots

7.01	Which adaptation measures do you undertake in pigeon pea production?	…………………………… …………………………… ……………………………	
7.02	Do you think integration of improved pigeon peas in *fanya juu* terraces is an adaptation strategy to climate change?	0 = No, 1= Yes	Tick one
7.03	Likert scale for perception on usefulness of Integrating improved pigeon peas in *fanya juu* terraces.	Scale 1= Strongly disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly disagree	Write one scale in questions below

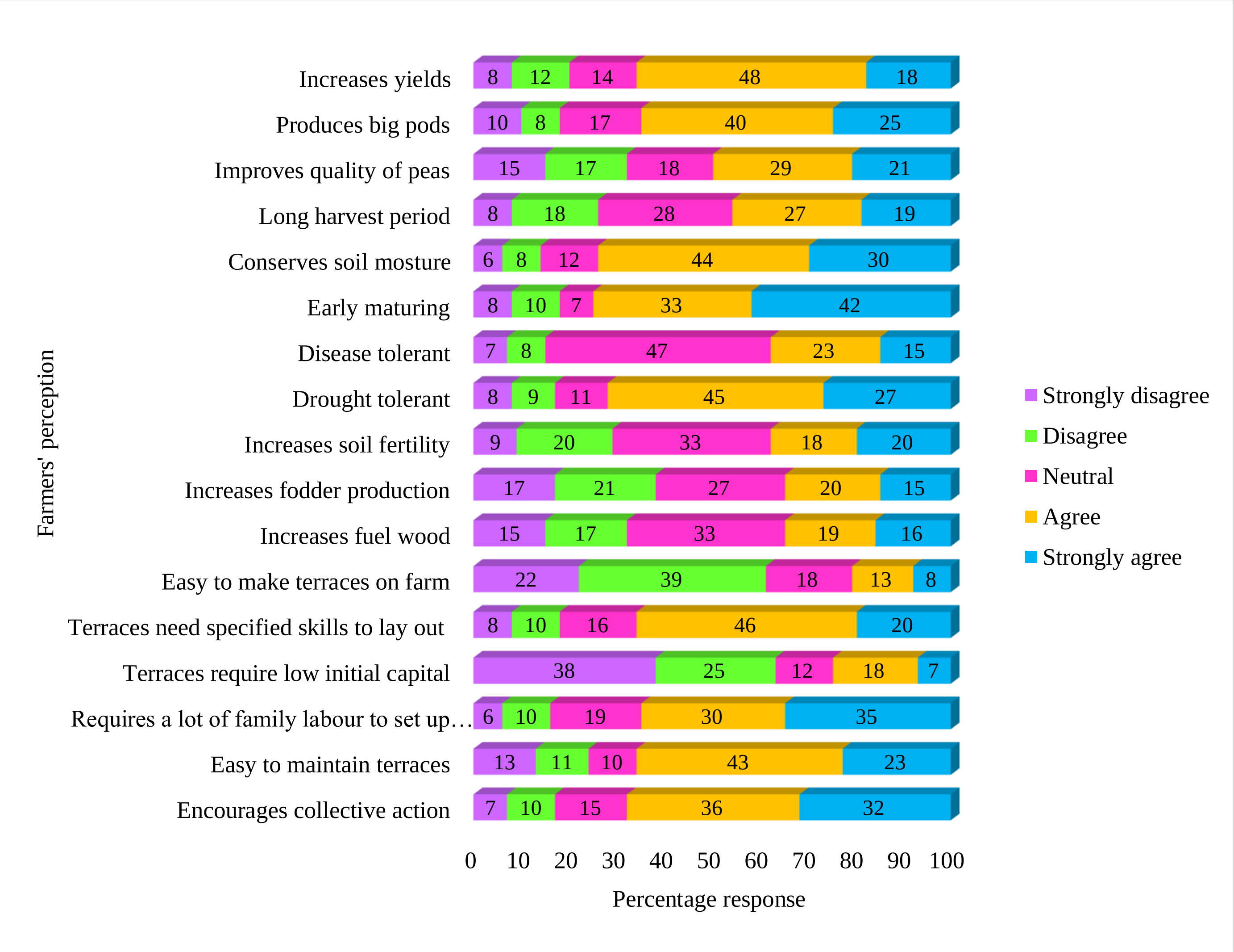
7.04	Variable	Likert scale	Choose one
.1	It increases yields.		
.2	Produces yields in dry seasons		
.3	Increases soil water retention		
.4	Improves soil fertility		
.5	Long harvest period		
.6	Large pods		
.7	Better quality pods		
.8	Increases fodder production		
.9	Increases fuel wood from stalk		
.10	Early maturity crop		
.11	Increases drought tolerance		
.1	Increases disease tolerance, no pesticides required		

Section 8: Formal and informal networks and institutions supporting agriculture

8.01	Do you access agricultural extension services?	0= No, 1= Yes
8.02	Do you access credit services for agricultural development	0= No, 1= Yes
8.03	If yes, from where?	……………………… ……………………… ………………………
8.04	Are you a members of a farmers' association?	0= No, 1= Yes
8.05	Do you access climate change information?	0= No, 1= Yes
8.06	If yes, from where?	……………………… ……………………
8.07	Which climate information do you access?	……………………… ……………………… ………………………
8.08	Do you access market information?	0= No, 1= Yes
8.09	If yes, what specific information do you receive	
8.10	If yes, from where?	……………………… ……………………….

Thank you very much for taking time to respond to my questions

Appendix 1.5. Likert Scale on farmers' perception on growing improved pigeon pea in *fanya juu* terraced plots as an adaptation strategy to climate change



Farmers' perception on usefulness of integrating improved pigeon pea in *fanya juu* terraces in Southeastern Kenya

Appendix 1.6. Gross margin analysis of pigeon pea production in Machakos County

		Improved pp on terraces			Indigenous seed no terraces			Indigenous seed on terraces			Improved seed no terraces		
Description	**Units**	**No of unit**	**unit cost**	**Total cost (KES)**	**No. of units**	**Unit cost**	**Total cost (KES)**	**No. of units**	**Unit cost**	**Total cost (KES)**	**No of unit**	**unit cost**	**Total cost (KES)**
Ploughing	Md	20	300	6000	12	300	3600	18	300	5400	16	250	4000
Furrowing	Md	8	300	2400	6	300	1800	8	300	2400	8	300	2400
Seed	Kg	18	250	4500	20	120	2400	20	120	2400	18	250	4500
Manure	W/burro	10	200	2000	4	200	800	8	200	1600	9.5	200	1900
Planting	Md	12	300	3600	9	300	2700	12	300	3600	9.5	300	2850
Weeding	Md	30	300	9000	24	300	7200	27	300	8100	20.5	300	6150
Terraces maintenance	Md	15	300	4500	0	0	0	15	300	4500	0	0	0
Pesticides	litres	4	1500	6000	4	1500	6000	4	1500	6000	3.5	1500	5250
Spraying	Md	4	300	1200	4	300	1200	4	300	1200	4	300	1200
Harvesting	Md	18	300	5400	10	300	3000	12	300	3600	14.5	300	4350
Transportation	Ksh	2	1000	2000	1	1000	1000	1	1450	1450	1	1500	1500
Drying Pigeon pea	Md	3	300	900	2	300	600	4.2	300	1260	4.5	300	1350
Threshing	Md	4	300	1200	2	300	600	2	300	600	3	300	900
Grass harvest	Md	12	300	3600	0	0	0	10	300	3000	0	0	0
Total cost	**Ksh**			**52300**			**30900**	**145.2**	**6270**	**45110**	**112**	**5800**	**36350**
Yield dry	Kg	552	100	55200	360	100	36000	470	100	47000	455	100	45500
Yield green	Kg	364	60	21840	249	60	14940	308	60	18480	314	60	18840
Crop residue	Donkey cart	4	500	2000	4	500	2000	3	500	1500	2	500	1000
Grass	Bags	20	250	5000	0	0	0	24	250	6000	0	0	0
Total Revenue				**84040**			**52940**			**72980**			**65340**
Gross margin/acre/yr				**31740**			**22040**			**27870**			**28990**

Appendix 1.7. Gross margin analysis of pigeon pea production in Makueni County

		Improved pp on terraces			Indigenous seed no terraces			Indigenous seed on terraces			Improved seed no terraces		
Description	**Units**	**No of unit**	**unit cost**	**Total cost (KES)**	**No. of units**	**Unit cost**	**Total cost (KES)**	**No. of units**	**Unit cost**	**Total cost (KES)**	**No of unit**	**unit cost**	**Total cost (KES)**
Land preparation	Md	18	250	4500	17	250	4250	20	250	5000	18	250	4500
Furrowing	Md	8	250	2000	7	250	1750	8	250	2000	8	250	2000
Seed	Kg	18	280	5040	26	120	3120	25	125	3125	17	275	4675
Manure	W/burrow	12	175	2100	7	250	1750	8	250	2000	8	250	2000
Planting	Md	14	250	3500	10	250	2500	13	250	3250	13	250	3250
Weeding	Md	20	250	5000	16	250	4000	16	250	4000	16	250	4000
Maintenance	Md	17	250	4250	0	0	0	15.5	250	3875	0	0	0
Pesticides	litres	4	1750	7000	2	1750	3500	4	1750	7000	4	1750	7000
Spraying	Md	4	250	1000	3	250	750	4	250	1000	4	250	1000
Harvesting	Md	16	250	4000	12	250	3000	14	250	3500	14	250	3500
Transportation		1	1600	1600	1	1000	1000	1	1200	1200	1	1280	1280
Drying peas	Md	4	250	1000	4	250	1000	4	250	1000	4	250	1000
Threshing	Md	5	250	1250	4	250	1000	4	250	1000	4	250	1000
Grass harvesting	Md	14	200	2800	0	0	0	13	250	3250	0	0	0
Total cost				**45040**			**27620**			**41200**			**35205**
Yield dry	Kg	574	90	51660	386	90	34740	479	90	43110	504	90	45360
Yield green	Kg	343	50	17150	273	50	13650	353	50	17650	349	50	17450
Crop residue	Donkey cart	3	400	1200	3	400	1200	4	400	1600	4	400	1600
Grass	Bags	24	300	7200	0	0	0	22	300	6600	0	0	0
Total Revenue				**77210**			**49590**			**68960**			**64410**
Gross margin/acre/yr				**32170**			**21970**			**27760**			**29205**

Appendix 1.8. Gross margin analysis of pigeon pea production in Kitui County

		Improved pp on terraces			**Indigenous seed no terraces**			**Indigenous seed on terraces**			**Improved seed no terraces**		
Description	**Units**	**No of unit**	**unit cost**	**Total cost (KES)**	**No. of units**	**Unit cost**	**Total cost (KES)**	**No. of units**	**Unit cost**	**Total cost (KES)**	**No of unit**	**unit cost**	**Total cost (KES)**
Land preparation	Md	18	250	4500	17	250	4250	20	250	5000	20	200	4000
Furrowing	Md	8	250	2000	7	250	1750	8	250	2000	11	200	2200
Seed	Kg	18	280	5040	26	120	3120	25	125	3125	19	300	5700
Manure	W/burrow	12	175	2100	7	250	1750	8	250	2000	10	200	2000
Planting	Md	14	250	3500	10	250	2500	13	250	3250	9	200	1800
Weeding	Md	20	250	5000	16	250	4000	16	250	4000	19	200	3800
Maintenance	Md	17	250	4250				15.5	250	3875	0		0
Pesticides	litres	4	1750	7000	2	1750	3500	4	1750	7000	3	2000	6000
Spraying	Md	4	250	1000	3	250	750	4	250	1000	4	200	800
Harvesting	Md	16	250	4000	12	250	3000	14	250	3500	5	200	1000
Transportation		1	1600	1600	1	1000	1000	1	1200	1200	1	2000	2000
Drying peas	Md	4	250	1000	4	250	1000	4	250	1000	5	200	1000
Threshing	Md	5	250	1250	4	250	1000	4	250	1000	4	220	880
Grass harvesting	Md	14	200	2800	0	0	0	13	250	3250			0
Total cost				**45040**			**27620**			**41200**		**6120**	**31180**
Yield dry	Kg	574	90	51660	386	90	34740	479	90	43110	480	80	38400
Yield green	Kg	343	50	17150	273	50	13650	353	50	17650	341	60	20460
Crop residue	Donkey cart	3	400	1200	3	400	1200	4	400	1600	3.25	500	1625
Grass	Bags	24	300	7200	0	0	0	22	300	6600			
Total Revenue				**77210**			**49590**			**68960**		**640**	**60485**
Gross margin/acre/yr				**32170**			**21970**			**27760**			29305