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Revisiting Climate Change Mitigation Potential in Smallholder Farming Systems in Kenya

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Abstract

In a country where Agriculture fuels both livelihoods and economic growth, understanding the dynamics of smallholder farming systems is essential for addressing Kenya's food security challenges. This study, carried out in the Nyando region of Kisumu County in Western Kenya, intends to explore the potential of smallholder farming systems to mitigate climate change by analyzing extensive data collected in 2012. As a first step, agricultural management was investigated in the area. Field surveys and interviews were used to gain information on agricultural management and establish a farm typology; the variables here are the crop type, the use of fertilizer, the location of the household with reference to the farm, other vegetation as well as different management practices such as intercropping. The majority of crops grown in the (lowlands) KK1 are woodlots whereas in the slopes (KK2), the most common crops are sugarcane. On the other hand, in KK3, the highlands, bananas are most common. Additionally, the use of fertilizers is high in KK3 and lowest in KK1. A lot of erosion is observed in the lowlands,(KK1), as compared to in the highlands, of KK3, where it is less. Various grazing management techniques are used such as rotational grazing. Burning, as a farm practice, was only utilized by 0.73% of farmers to control weeds, suggesting a move towards more sustainable methods. Intercropping was also used such as sorghum and maize. The study emphasizes the significance of organic soil amendments, improved land tenure security, and sustainable land management.

Keywords: Smallholder Farming, Climate Change Mitigation, Agricultural Management, Soil Fertility, Carbon Sequestration, Sustainable Farming Practices.

List of abbreviations

- **CH4**-Methane
- **CO2**-Carbon dioxide
- **CSA**-Climate-Smart Agriculture
- **DAP**- Diammonium phosphate
- **FAO**- Food and Agriculture Organization
- **GHG**-Greenhouse gas
- **N2O**… Nitrous oxide
- **pH**… potential of hydrogen
- **SAMPLE**- Standard Assessment of Agricultural Mitigation Potential and Livelihoods

Introduction

Agriculture is the foundation of human civilization, providing basic resources like food, fiber, and raw materials. It is a key sector for millions of people's livelihoods around the world, particularly in underdeveloped nations where smallholder farming practices are common. However, agriculture is inextricably related to climate change, both as a driver and as a victim.

Climate change, caused by the accumulation of greenhouse gases (GHGs) such as carbon dioxide, methane, and nitrous oxide in the atmosphere, offers significant difficulties to agricultural systems worldwide. These gases come from a variety of sources such as deforestation, animal production, and soil management practices. As a result, agriculture accounts for a large share of global GHG emissions.

In contrast, climate change has far-reaching and varied consequences for agriculture. Rising temperatures, changing precipitation patterns, an increase in the frequency and severity of extreme weather events all have a direct impact on crop yields, soil health, and water availability. These developments jeopardize food security, particularly in communities that rely primarily on agriculture for economic stability and survival.

Within this framework, smallholder farming systems play a dual role in contributing to and mitigating climate change, as explored by the RECLIK (Revisiting Climate Change Mitigation Potential in Smallholder Farming Systems in Kenya) study. In the Nyando region of Kisumu County, Western Kenya, the RECLIK initiative seeks to evaluate the efficacy of climate-smart agricultural practices. It builds on the findings of the SAMPLES (Standard Assessment of Agricultural Mitigation Potential and Livelihoods) project, which was completed in November 2012. This study focuses on the three production systems (lowland, slopes, and highlands) of Nyando Region, providing relevant information on the management practices as well.

Despite the critical role of smallholder farmers in Kenya's agricultural sector, and the significant challenges they face such as droughts, and floods leading to low productivity and food insecurity, the analysis of lowland, slopes, and highlands in the Nyando region aims to identify the agricultural potential and limitations of each zone, guiding effective resource allocation and sustainable practices tailored to local conditions. It also seeks to enhance the economic viability of smallholder agriculture by informing targeted policies and investment strategies that address specific community needs.

Small-Scale Farming

Global agriculture, especially in developing nations, depends heavily on small-scale farmers. According to the Food and Agriculture Organization (FAO), there are approximately 570 million farms worldwide, with more than 90% classified as small-scale farms [22]. Run by individual families, these farms are usually smaller than two hectares.

The distribution of small-scale farms exhibits notable regional variations. The agricultural landscape in Asia and Africa is dominated by small-scale farms. For example, in sub-Saharan Africa, smallholder farms account for about 80% of all farms and produce up to 90% of the region's food supply (Alliance for a Green Revolution in Africa, 2017). In India, small and marginal farmers constitute around 86% of the farming community [13].

A vital component of regional and global food security is small-scale farming. They generate a large amount of the food in the globe, especially staples like wheat, rice, and maize. In many developing countries, smallholder farms are the primary source of food for local populations, ensuring a stable food supply and contributing to rural economies [29].

However, while small-scale farms are common and essential for rural economies and food security, large scale farms are also important to global agriculture. High degrees of mechanization, large capital investments, and cutting-edge technical applications are characteristics of large-scale farms, which frequently span hundreds of hectares. Concentrating on high-value crops or livestock for commercial markets, these farms typically specialize in monoculture production.

The economies of scale that large-scale farms have allow them to outperform small-scale farms in terms of production and cost per unit. They are more integrated into global supply chains and are better positioned to access markets, credit, and advanced agricultural technologies (Collier & Dercon, 2014). However, this model of farming also has its drawbacks, including environmental degradation, loss of biodiversity, and social issues related to land ownership and labor practices (Pretty, 2008).

Small-scale farmers not only produce food but also help preserve agricultural biodiversity. They frequently employ agricultural techniques that encourage genetic diversity and raise a broad range of crops. This diversity is crucial for the resilience of agricultural systems, allowing them to adapt to changing environmental conditions and pests (Altieri, 2004).

For the people living in rural areas, small-scale farming provides a significant source of revenue and jobs that is now available in other sectors. Agriculture is the main economic activity in many developing nations, and small farms are essential to maintaining rural livelihoods. They provide income for millions of families, helping to reduce poverty and enhance economic stability (IFAD, 2013).

Small-scale farms continue to be essential for food security, biodiversity preservation, and rural livelihoods even while large-scale farms provide a substantial economic and food production contribution to the world. Because of the difficulties smallholder farmers confront, especially in light of climate change, specific interventions are required to increase their resilience and production. The RECLIK project intends to investigate these issues and possible fixes in light of Kenya's smallholder agricultural systems.

Challenges Faced by Small-Scale Farmers

Numerous obstacles that small-scale farmers must overcome have a big impact on their means of subsistence and agricultural output.

Food Security

Across the globe, one of the biggest issues small-scale farmers confront is compromised food security. The Food and Agriculture Organization (FAO) projects that by 2050, food production will need to increase by approximately 70% to meet the demands of a growing global population, particularly in developing countries where population growth is most rapid [9]. Numerous challenges impede the productivity and ability of small-scale farmers, who play a crucial role in guaranteeing the local food supply, to fulfill the growing needs.

Low productivity is one of the main issues, and it is caused by a lack of access to vital resources including markets, credit, and technology. It is challenging for smallholder farmers to access larger marketplaces where they may sell their produce at reasonable rates since they frequently work in remote, undeveloped rural areas with poor infrastructure. Additionally, financial constraints limit their ability to invest in modern farming equipment, quality seeds, and other inputs that could enhance their productivity (IFAD, 2013). In addition, non-adequate agricultural management has also contributed to lack of access to vital resources.

Credit availability is still another major obstacle. Insufficient financial services prevent small-scale farmers from purchasing the inputs they need to advance their farming techniques. This lack of investment perpetuates a cycle of low productivity and poverty, making it difficult for farmers to break free from subsistence farming and transition to more commercialized agricultural activities [34].

Climate Change and the Need for Adaptation

Small-scale farming operations are seriously threatened by climate change. Due mostly to human activity, the concentration of greenhouse gases (GHGs) in the atmosphere is rising, which has resulted in global warming and notable modifications to weather patterns. For smallholder farmers, who depend on predictable weather conditions for planting and harvesting, these changes can be devastating [16].

Temperature and precipitation changes are the most obvious effects of climate change on agriculture. Smallholder farmers in Sub Saharan Africa are especially susceptible to these changes since they usually depend on rain-fed agriculture. Raising temperatures can cause crops to experience heat stress, which lowers yields and quality. For instance, many staple crops such as maize and wheat have optimal growing temperature ranges, and temperatures exceeding these ranges can lead to substantial yield losses [8].

Modifications in the patterns of precipitation can also be harmful. Small-scale farmers experience irregular rains, protracted droughts, and unforeseen floods that interfere with their planting and harvesting schedules. Water shortages brought on by droughts lower soil moisture levels and impede agricultural development. Conversely, excessive rainfall can cause water logging, soil erosion, and loss of nutrients, all of which adversely affect crop productivity (World Bank, 2013).

A sustainable agricultural production depends on the fertility and health of the soil, both of which are impacted by climate change. A soil's capacity to sustain healthy crop development can be diminished by soil degradation brought on by temperature increases and variations in precipitation. For instance, poor soil quality can result from flooding and excessive rains, which can wash away the organic matter and nutrient-rich topsoil. On the other hand, drought conditions can lead to soil compaction and reduced microbial activity, further diminishing soil fertility (Lal, 2004).

The distribution and frequency of illnesses and pests are also impacted by temperature rise and altered precipitation patterns. Increased infestations and crop damage can result from several agricultural pests' habitat range being expanded by warmer temperatures. Similarly, changes in humidity and rainfall patterns can create favorable conditions for the proliferation of plant diseases, further threatening crop yields (Rosenzweig et al., 2001).

Adopting climate-smart agriculture methods are crucial to addressing climate change challenges. Climate-smart agriculture (CSA) aims to increase agricultural productivity sustainably, enhance resilience to climate change, and reduce GHG emissions where possible (Lipper et al., 2014).

Varieties and Farming Techniques

An essential element of CSA is efficient water management. Even in dry spells, crops can receive enough water thanks to strategies like drip irrigation, rainwater collection, and economical water usage. These practices not only enhance water use efficiency but also improve crop resilience to drought conditions [2].

Using ecological principles in agricultural production is the focus of agro-ecological techniques, which have the potential to improve resilience. These methods include incorporating livestock into farming systems, diversifying crops, and intercropping in order to preserve biodiversity. By promoting a diverse and balanced ecosystem, agro-ecological practices can help manage pests, improve soil health, and increase the overall resilience of farming systems to climate change (Altieri, 2004).

It's critical to increase small-scale farmers' ability to adapt to climate change. This entails giving farmers access to extension services, climate information services, and training courses that include the best methods for preparing for climate change. Knowledge sharing platforms and farmer field schools can facilitate the exchange of information and experiences, helping farmers adopt and implement CSA practices effectively [7].

Mitigating GHG Emissions from Agricultural Systems and use of Fertilizers

In order to effectively combat climate change, mitigation of greenhouse gas emissions from agricultural systems is also necessary. GHGs are mostly found in agriculture, especially nitrous oxide from synthetic fertilizers and manure, and methane from rice paddies and cattle. Thus, putting into practice strategies that lower these emissions is crucial for the development of sustainable agriculture.

Enhancing manure management to lower methane emissions, implementing no-till farming techniques to improve soil carbon absorption, and making the most use of fertilizers to reduce nitrous oxide emissions are some strategies to reduce greenhouse gas emissions in agriculture. Additionally, integrating livestock and crop production systems can enhance nutrient cycling and reduce the overall carbon footprint of farming activities [30].

The integration of adaptation and mitigation tactics can significantly contribute to the mitigation of climate change by small-scale farmers. Initiatives like RECLIK seek to investigate and advance these methods, assisting farmers in strengthening their resilience and supporting international efforts to cut greenhouse gas emissions. The results of these kinds of studies offer important new information on how smallholder farming systems might reduce climate change while maintaining agricultural productivity and raising living standards.

East Africa, Kenya and Nyando Region

East Africa, which includes nations like Kenya, Ethiopia, Tanzania, and Uganda, is distinguished by a variety of topographies, societal configurations and cultural traditions but they also share points in common. These countries' economies rely heavily on agriculture, which also creates jobs and ensures food security. Agriculture is the foundation of their socioeconomic progress. The agricultural sector in East Africa is predominantly made up of small-scale farmers who rely heavily on rain-fed agriculture and traditional farming methods [17].

In Kenya, agriculture is a vital sector, accounting for about 33% of the Gross Domestic Product and employing over 70% of the rural population [19]. The agricultural operations of the nation are dispersed among many regions, each with unique farming practices and climatic conditions. A broad variety of crops, including maize, tea, coffee, sugarcane, and horticulture goods, can be grown in Kenya due to its varied climate. Thanks to their rich soils and ideal climate, the Rift Valley and Central Highlands are two of the most prolific agricultural regions.

There are almost 54 million people living in Kenya, most of them reside in rural areas where agriculture is the main source of income. Subsistence farming on small parcels of land is practiced by small-scale farmers who are widely dispersed throughout the nation. In contrast, large-scale farmers, though fewer in number, operate on extensive land areas and primarily engage in commercial farming, focusing on cash crops like tea, coffee, and horticultural products for export markets [34].

In western Kenya, the county of Kisumu is a significant agricultural area. The county covers an area of about 2,085 square kilometers and is home to a population of approximately 1.2 million people [18]. Kisumu County is well-suited for a variety of agricultural pursuits due to its tropical environment and moderate to heavy rainfall. Agriculture is the main driver of the county's economy, and smallholder farmers are important to both the local economy and food production [20].

The Nyando region, located in Kisumu County, is a thriving agricultural area renowned for its many crop options and farming methods. The rainfall pattern in the Nyando region is bimodal, peaking in March–May and October–December. This distribution of rainfall makes it possible to grow a variety of crops, such as beans, cassava, sorghum, and maize. The region's soils, predominantly composed of black cotton soils and alluvial deposits, are fertile but require proper management to maintain productivity [11].

The majority of people living in the Nyando region are small-scale farmers who engage in mixed farming, which combines the raising of cattle and crops. For managing soil fertility and nutrient cycle, this integration is essential. Cattle, goats, and chickens are common livestock in the area and give farming households extra income and food security.

Based on their economic value and capacity to adapt to the local climate, crops are preferred by farmers in the Nyando region. Beans, sorghum, and maize are common staple crops farmed in the area. Since most households utilize maize as their main source of staple food, it is especially significant. Known for its ability to withstand drought, sorghum is an essential crop, particularly in dry seasons. Beans provide essential protein and are often intercropped with maize to optimize land use and improve soil fertility through nitrogen fixation [8].

Agricultural Management and Development in Nyando Region

Agricultural Management and Development in the Nyando Region of Kenya, encompasses various strategies and practices aimed at enhancing agricultural productivity, sustainability, and economic development. The Nyando Region experiences a tropical climate with seasonal rainfall, which influences agricultural practices. The area is characterized by fertile soils, making it suitable for diverse crop production, including maize, sugarcane, and various fruits and vegetables. Farmers in Nyando are encouraged to diversify their crops to reduce reliance on a single crop and enhance food security. This includes growing traditional crops like millet and sorghum alongside cash crops. Sustainable agricultural practices, such as agroforestry, and mixed farming practices help improve soil health, increase biodiversity, and reduce environmental degradation.

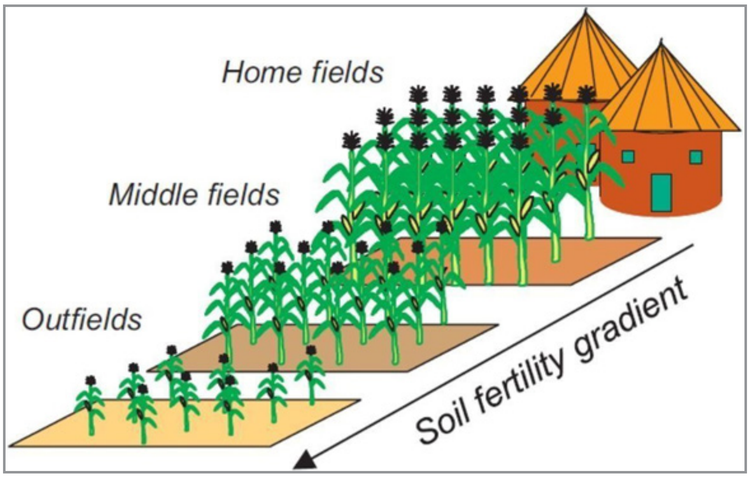

Figure 1: Soil fertility gradients in smallholder farming systems (Tittonell Und Giller - 2013 - When Yield Gaps Are Poverty Traps the Paradigm of.Pdf - BOKUdrive, n.d.) [1]

The SAMPLES Project
Smallholder agricultural systems' potential to mitigate climate change can be assessed using the SAMPLES project, which stands for "Standard Assessment of Agricultural Mitigation Potential and Livelihoods." The SAMPLES project sought to comprehend how smallholder farming methods interact with the environment, especially with regard to carbon sequestration and greenhouse gas (GHG) emissions. The goal of the RECLIK (Revisiting Climate Change Mitigation Potential in Smallholder Farming Systems in Kenya) project is to better investigate and improve these interactions in the Nyando region of Kisumu County by building on the approaches and discoveries of the SAMPLES project.

The SAMPLES project used a variety of methods, including field surveys, soil sampling, farmer interviews, and the utilization of cutting-edge technology like remote sensing and GIS for landscape stratification, to meet its goals. Comprehensive data on the different elements impacting greenhouse gas emissions and carbon sequestration in smallholder farming systems were made available by these approaches. A thorough investigation of the potential for mitigating climate change in these systems was made possible by the combination of scientific methods and traditional wisdom.

A number of studies were carried out within the framework of the SAMPLES project in order to collect information on the previously listed elements. Different field ratings were offered to characterize fields based on this research. These scores were useful in determining mitigation plans, analyzing land management techniques, and evaluating soil quality.

The primary goal is to obtain an overall picture of the agricultural production and its relation with climate change in small-farming systems in Nyando and how a new scoring system can be formulated.

Objectives and Hypothesis
The primary goal is to obtain an overall picture of the agricultural production and its relation with climate change in small-farming systems in Nyando. We further aim at investigating whether the management practices have an influence on the relevant soil and environmental properties.

Research Objectives
The primary aims of this research are:

- To analyze the relationship between crop yields and farm productivity in the three distinct production systems (KK1, KK2, and KK3). This paper intends to do this by assessing the crop yields from the three production systems. The research also seeks to quantify the output of smallholder farms. This measurement will provide a concrete basis for comparing productivity across the different systems.
- To investigate the crop diversity in the Nyando region of Kenya with reference to the production systems. This paper aims at analysing the different types of crops within the three production systems, as well as the contributing factors such as rainfall, soil fertility etc.
- To compare the use of agricultural inputs (fertilizers) across the three production systems and investigate if certain systems have higher rates of input usage. This paper aims to understand whether the use of fertilizers is higher in the highlands and slopes, compared to the lowlands.

The overall goal of the project is to assess smallholder farming practices in the Nyando region of Kenya by analyzing the interrelationships between crop yields, farm productivity, crop diversity, and agricultural input usage across distinct production systems (KK1, KK2, and KK3). This research aims to provide insights into management strategies and contributing factors affecting productivity, thereby enhancing the understanding of smallholder farming dynamics in this region.

Hypothesis
Hypothesis 1
The productivity of smallholder farms in the Nyando region varies significantly across the three production systems (lowlands, slopes, and highlands) due to differences in land management practices, crop choice and diversity, access to agricultural inputs, and farm size and land tenure.

This hypothesis posits that the productivity of smallholder farms in the Nyando region exhibits significant variation across three distinct production systems—lowlands, slopes, and highlands. This variation can be attributed to several key factors: the land management practices employed by farmers, which influence soil health and crop yields; the selection and diversity of crops, which can enhance resilience against pests and diseases; the accessibility and affordability of agricultural inputs such as fertilizers and quality seeds, which are crucial for optimizing production; and the size of the farms coupled with the security of land tenure, which can determine farmers' willingness to invest resources and adopt improved agricultural practices. Collectively, these elements contribute to the differential productivity observed in each production system within the region.

Hypothesis 2
Crop diversity and agricultural management in the Nyando region varies significantly across the three production systems.

This hypothesis aims to test if there are environmental and farming differences that lead to significant differences in the kinds of crops being grown in different systems. It suggests that different types of crops grow in different parts of the Nyando region depending on a few important factors such as the amount of annual rainfall, soil fertility, and how farmers manage their land.

For instance, highland areas that get more rain may be better suited to grow certain types of crops like tea, while lowland areas with less rain might grow more drought-resistant crops like sorghum and cassava. Similarly, if the soil is rich and fertile in one area, it might support a wider variety of crops compared to an area where the soil is poor, exemplified by the highlands that have a variety of crops such onions, tomatoes, bananas, maize etc. whereas lowland regions which are less fertile are characterized by woodlots and bananas

Hypothesis 3
The use of fertilizers is higher in the slopes (KK2) and highlands (KK3) compared to the lowlands (KK1) in smallholder farming systems.

The hypothesis posits that the utilization of agricultural inputs, specifically fertilizers, is greater in the slopes (KK2) and highlands (KK3) compared to the lowlands (KK1). The objective is to compare fertilizer usage across these three production systems to determine whether specific systems exhibit higher rates of fertilizer application. By analyzing data from these varying topographies, the research aims to identify patterns in fertilizer use that may correlate with the geographical and environmental factors of each production system, ultimately shedding light on the relationship between location and fertilizer application practices in smallholder farming systems.

Justification for the Study

This study is crucial for improving small-scale farming in the Nyando region of Kenya, addressing key challenges like low productivity, soil degradation, and environmental stress. By exploring tailored management strategies, it aims to offer practical solutions to enhance agricultural productivity and sustainability. Sustainable practices are essential to ensure farmers can continue farming without degrading the land for future generations.

Additionally, the study will investigate crop diversity across different production systems, focusing on factors such as rainfall, soil fertility, and farming practices. Understanding the relationship between these factors and crop diversity is vital for optimizing land use and enhancing food security in the region.

Furthermore, this research will evaluate sustainable agricultural methods like agroforestry, crop rotation, and intercropping, which are believed to improve soil health and crop yields. By assessing these techniques within the Nyando context, the study provides evidence-based recommendations for farmers looking to adopt more environmentally friendly practices.

The research is particularly important in helping farmers adapt to climate change and manage their resources—such as water and soil—more effectively. Ultimately, this study will empower local farmers with the knowledge and tools needed to improve their livelihoods, increase food security, and promote long-term sustainability, contributing to broader goals of poverty reduction and climate resilience in the region.

Materials and Methods

This chapter outlines the materials and methodologies applied to achieve the research objectives within the Nyando region of Western Kenya. The study region is predominantly agricultural, characterized by smallholder farming with crops such as maize, beans, and sorghum, alongside livestock farming. The diverse terrain, ranging from low-lying plains to hilly areas, combined with varying soil types, creates unique agricultural challenges and opportunities. By analyzing key environmental factors such as rainfall, soil fertility, and farming practices, the research aims to provide insights into sustainable agricultural techniques and their impact on soil health and productivity.

To conduct this analysis, quantitative method was used. The research involved systematic soil surveys, and comprehensive surveys of nearly 400 small-scale farmers. The stratified sampling method ensured a representative selection of farms based on factors such as land size, crop diversity, and management techniques. Soil samples from several farms had several plots and subplots investigated were analyzed in laboratory settings, and data was processed using statistical tools such as regression models and Excel for evaluating relationships between farming practices and environmental outcomes. Additionally, questionnaires collected detailed information on agricultural practices, land use, and socioeconomic factors, offering both numerical and qualitative insights into farming systems in the region.

General Information about the Study Region - Nyando

The Nyando region, located in western Kenya, is characterized by a primarily rural terrain with agriculture as the primary economic activity. The region experiences a tropical environment with distinct wet and dry seasons, which has a considerable impact on agricultural productivity. Nyando's main crops are maize, beans, sorghum, and a variety of horticulture crops. Livestock farming, particularly cattle, goats, and poultry, is also widespread.

Figure 2: Aerial view of the agricultural landscape in the Nyando region, Kisumu County, Western Kenya, showing diverse smallholder farming plots.

Nyando is part of Kisumu County, which borders Lake Victoria. The region's terrain varies from low-lying plains around the lake to undulating hills inland. Nyando's soils are diverse, ranging from fertile loamy soils on the plains to more degraded sandy soils in the hills. These soil changes influence agricultural potential and output.

In general, farmers in Nyando have a low socioeconomic position; smallholder farms in the area often cover less than two hectares. Both rain-fed and irrigated agriculture are vital to farmers; however, the importance of irrigated agriculture is growing as a result of altered rainfall patterns linked to climate change. Improving agricultural production and sustainability is hampered by the lack of access to markets, extension services, and agricultural inputs.

Since Nyando is a representative example of smallholder farming systems in sub-Saharan Africa, where issues like low productivity, soil degradation, and climate change are common, Nyando is the focus of this study. Through an understanding of the region's agricultural practices, GHG fluxes, and soil qualities, the study seeks to offer insights that are transferable to other similar contexts inside and outside of the region.

This geographic selection provided a wide range of farming practices and environmental factors, which is crucial for assessing how various agricultural practices affect soil health and greenhouse gas emissions. Through meticulous sampling, almost 400 small-scale farmers were chosen, guaranteeing representation of a range of farm sizes, crop kinds, and farming practices common in the area.

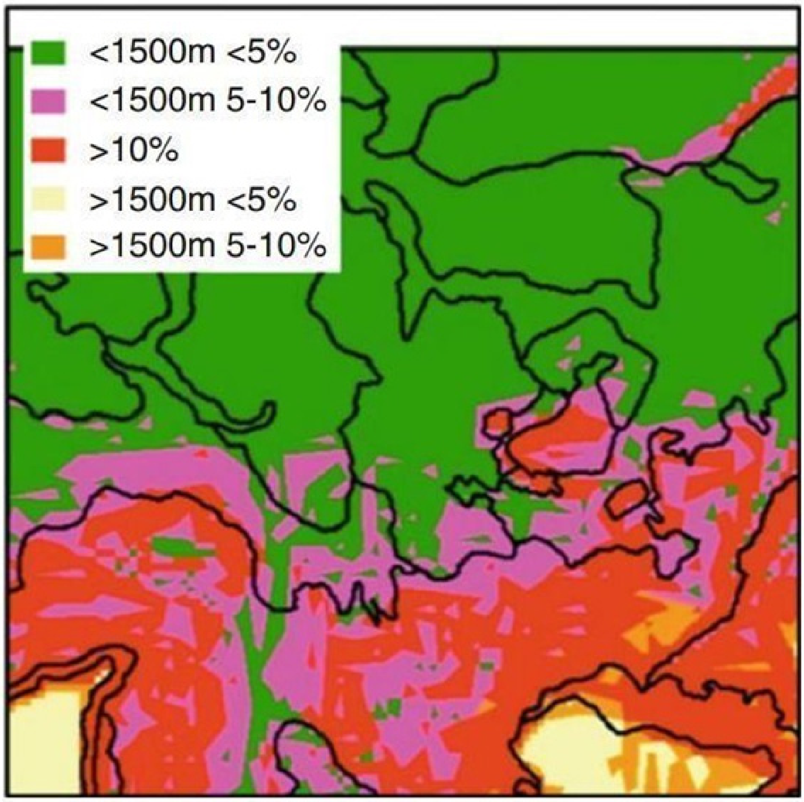

Figure 3: Topographic characteristics of Nyando region. Altitude (m a.s.l.) and slope (expressed as percentage) came from the Shuttle Radar Topography Mission (SRTM) digital elevation model (USGS 2004)

Research Methodology

The three types of research methods are qualitative, quantitative, and mixed-method research (Eriksson and Kovalainen, 2015). A qualitative study design is the first type, and it can take various forms based on the particular research techniques employed, such as surveys and focus groups. On the other hand, focus groups are the technique used in qualitative research studies. According to Morgan (2018), one reason for performing qualitative research is to gain as much knowledge as possible about a subject from personalized perspectives. A smaller, more representative sample is utilized since collecting qualitative data takes a larger amount of time. According to Queirós et al. (2017), detailed explanations of the data are valued more highly than numerical summaries in qualitative research. The basic objective of a qualitative investigation is to provide light on the "why" and "how" of a phenomenon. Because qualitative investigations are done in language rather than statistics, they depend more on stories and anecdotal evidence than quantitative studies do. However, it was crucial that objective facts prevail over subjective information in the current research issue.

The current study adopted a quantitative research approach to collect and analyze numerical data at each stage of the investigation. Measurements, percentages, ratios, and rankings are all examples of quantitative information. Quantitative research design is preferable over the qualitative method since qualitative techniques only allow thorough and subjective investigation of social processes from different perspectives (Kyngas, 2020). On the other hand, according to Aspers and Corte (2019), the effectiveness of quantitative research designs depends on how the data are presented. Design is all about investigating how people respond, think, or feel in a certain environment. Quantitative research, in contrast to qualitative research, aims to collect numerical knowledge; therefore, it uses large samples and prioritizes the volume of responses. The quantitative design's structure guarantees that the same types of questions are asked of every respondent, allowing for a more precise examination of the data gathered. After that, the data are numerically and statistically analyzed and demonstrated using statistical tools and methodologies (Bloomfield & Fisher, 2019). According to Apuke (2017), closed-ended questionnaires are often used in quantitative investigations to give the respondent a variety of choices. The quantitative approach is more productive and efficient as compared to qualitative research, as its structure does not allow for freeform queries; hence, time is saved. This technique is thought to be more successful since qualitative design inherently requires more time. Quantitative design, which is easier to apply than qualitative design, is characterized by closed-ended questions. Furthermore, it is also commonly acknowledged that any deduction-based research procedures must be conducted using quantitative methodologies (Silverman, 2016).

Thus, the current research found it suitable to use a quantitative research design. The quantitative approach will facilitate the collection and analysis of numerical data related to the different production systems and the impacts of different agricultural practices. This structured approach ensures that the research findings are objective, reliable, and can be generalized to similar contexts.

Data Collection and Analysis

The Nyando sentinel region is a 10 km x 10 km area located in Western Kenya, characterised by a range of altitudes between 1184 and 1743 meters. This region has been differentiated into three distinct "Production systems": Lowlands (KK1), Slopes (KK2), and Highlands (KK3). In the lowlands, eight villages were investigated, whereas in both the slopes and highlands, six villages per production system were examined. Within each village, 10 households were investigated, providing a comprehensive overview of the region's agricultural practices and environ-mental conditions. This segmentation allowed for detailed analysis of various agricultural practices and their impact on soil health, greenhouse gas emissions, and overall agricultural productivity.

In the frame of the RECLIK project, we want to take advantage of information generated during the SAMPLES project in the Nyando region. The Standard Assessment of Agricultural Mitigation Potential and Livelihoods (SAMPLES) project was launched in 2013, motivated by the need to understand the effect of smallholder farming on the Earth's climate [28]. The Nyando sentinel region was chosen as a site for a pilot project. Data gathered can be structured in the following aspects- The researchers used a stratified sampling technique to group farms. This method involves dividing the population (in this case, farms) into smaller subgroups or "strata" based on specific characteristics before sampling. The key factors used for stratification were: a) Land size b) Crop diversity d) Management techniques the stratification allowed for a comprehensive examination of how these factors influence sustainable farming practices.

Data Collection through Soil Surveys

A thorough structure for gathering data was created in order to record a variety of agricultural parameters:

- Thorough soil surveys were carried out, with measurements made of important parameters such as pH levels, nutritional profiles (nitrogen), and soil organic matter content. Each farm's soil samples were painstakingly taken from several plots in order to account for spatial heterogeneity and guarantee reliable data correctness.
- A vast amount of information about agricultural techniques was acquired, including crop kinds, crop rotation schemes, methods for managing the soil, and the application of fertilizers (both organic and inorganic). In order to comprehend their effects on soil health and greenhouse gas emissions, information on pest control techniques and irrigation strategies was also documented.

Soil surveys involved systematic sampling from different depths and locations within each farm. These soil samples were analyzed in laboratory settings to assess physical and chemical properties critical for understanding soil health dynamics and their relationship with agricultural practices.

Concurrently, GHG flux measurements were carried out using advanced techniques such as gas chromatography, ensuring precise quantification of emissions over time and under varying management scenarios.

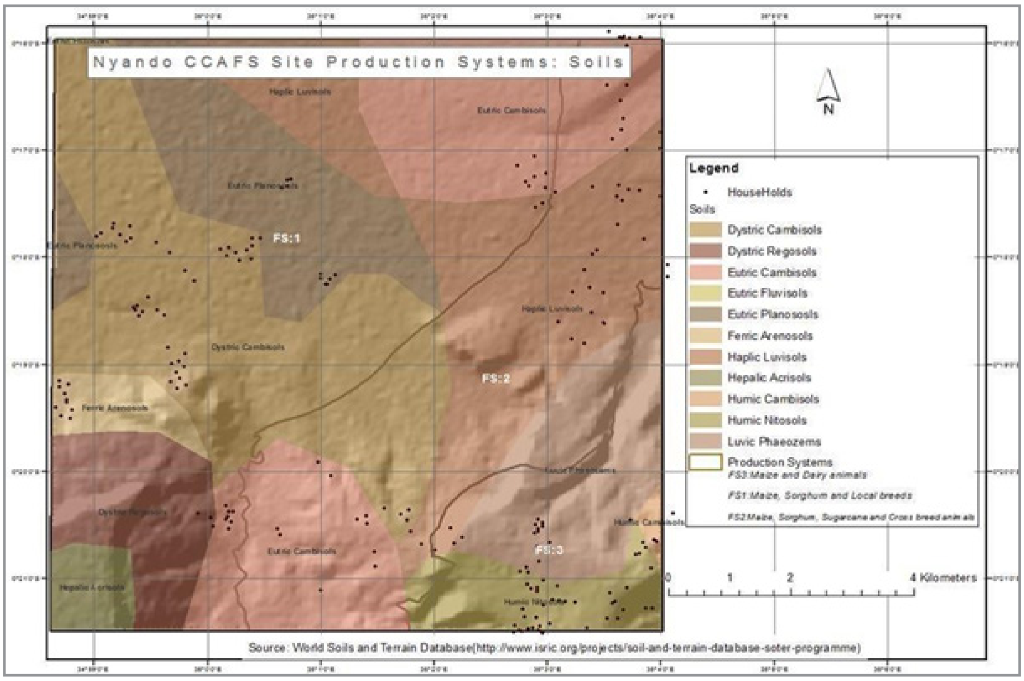

Figure 4: Overview on soil types in the Nyando CCAFS Sentinel site. The black symbols indicate the location of the investigated households

Questionnaire Details

Participants were asked about the range of crops grown, including staples that are essential for both market-driven agriculture and local sustenance. Together with fruits like mangoes and bananas, these also included groundnuts, cowpeas, beans, cassava, and maize. A thorough picture of the agricultural environment was given by including grains like millet, fodder crops like Napier grass, and a wide variety of vegetables, including soybeans, onions, sorghum, sugarcane, green grammes, sweet potatoes, tea, and tomatoes. Assessing food security, economic sustainability, and the ecological impact of farming practices are facilitated by an understanding of the range of crops farmed.

The homestead status of the farmers was disclosed in relation to their agricultural holdings. This inquiry sought to comprehend how decisions about land use and resource allocation are influenced by the combination of farming and residential activities. Evaluating the existence of homesteads aids in determining the extent of land use, any conflicts between agricultural and residential demands, and the general sustainability of farming methods.

The most common crops planted and their highest yields, expressed in kilos per hectare, were described in detail by the participants. This information provided insights on crop preferences, productivity levels, and the efficiency of farming methods. It is possible to evaluate agricultural productivity, the effect of soil and climate on crop performance, and the possibility of increasing farming efficiency by being aware of the regularly planted crops and their yields.

Vegetative cover was classified as either herbaceous or woody in the questionnaire. The potential for land rehabilitation and conservation initiatives, the provision of ecosystem services, and the biodiversity within farming systems were all evaluated with the use of this classification. Comprehending the nature of vegetative cover offers valuable perspectives on soil stabilization, carbon sequestration, habitat variety, and environmental change resilience—all essential elements of sustainable land management.

Farmers reported on whether visible signs of erosion were on their land. This question aimed to highlight soil conserve Farmers discovered evident signs of erosion on their farm. This question aims to emphasize soil conservation difficulties, erosion control measures, and the overall effectiveness of land management strategies. Identifying erosion aids in assessing soil health, the efficacy of conservation measures, and the susceptibility of agricultural land to deterioration, all of which guide activities to limit environmental impacts.

Participants disclosed whether their farming practices involved grazing livestock or burning fields. Land tenure data gave insights into how ownership patterns influence farming decisions, land use practices, and community dynamics. Understanding land tenure clarifies property rights, resource availability, investment incentives, and potential hurdles to long-term land management and agricultural development.

Information on land tenure arrangements provided insights into ownership structures influencing farming decisions, land use practices, and community dynamics. Understanding land tenure clarifies property rights, resource availability, investment incentives, and potential hurdles to longterm land management and agricultural development.

Historical perspectives on land cover prior to agricultural use were gathered. This data indicated changes in environmental conditions, land use legacies, and adjustments in ecosystem services across time. Understanding previous land cover helps analyze habitat loss, ecosystem alterations, biodiversity decrease, and the cumulative effects of land use change on environmental sustainability.

Detailed information on fertilizer types and their distribution across sub-plots was collected. This was crucial for assessing nitrogen management strategies, soil fertility impacts, and potential environmental issues related to fertilizer application. Assessing fertilizer use helps optimize nutrient delivery, decrease environmental pollution, increase crop output, and encourage sustainable agricultural intensification methods.

Table 1: Questions asked during the survey

Question	Choices
1. What types of crops do you cultivate on your farm? (select all that apply)	Maize, beans, cassava, cow peas, ground nuts, mangoes, millet, Napier grass, bananas, vegetables, soya, onions, sorghum, sugarcane, green grams, sweet potatoes, tea, tomatoes, or indicate "no cover" if no crops are grown.
2. Do you have a homestead located within your agricultural plot?	Yes, or No
3. Which crops do you commonly plant, and what is the highest yield you have achieved for each crop (measured in kilograms per hectare)?	Example: Maize (5000 kg/ha), beans (3000 kg/ha), cassava (8000 kg/ha), etc.
4. What is the predominant vegetative cover on your farm?	Woody cover (<4%, 4-15%, 15-40%, 40-65%,
>65%), Herbaceous cover (<4%, 4-15%, 15-	
40%, 40-65%, >65%)	
5. Do you observe visible evidence of erosion on your land?	None, Sheet, Rill, Gully
6. Do you employ grazing or burning as part of your farming system?	Grazed, Burned, Not applicable
7. What is your land tenure status?	Owned, Rented, Leased, Other
8. What was the predominant land cover type prior to converting it to agricultural use?	Forest, Grassland, Wetland, Other
9. If you apply fertilizers, please specify the type used and indicate which sub-plots receive each type:	Organic (e.g., compost, manure), Inorganic (e.g., urea, DAP), Mixed (both organic and inorganic), Not applied
10. How many years ago was it covered with Agriculture?	0-2, 2-5, 5-10, >10, unknown
11. Type of fertilizer	DAP, Manure, CAN, NPK2323, Urea, MEA
(specify amount and crop on which fertilizer is applied)	
12. Information about the plot	Best plot? Why? Additional info?

Source: Own personal questions, 2024

After a substantial volume of data had been gathered, it was transformed into Microsoft Excel for analysis.

The available data is compiled in the excel file which contains 427 rows of data from 196 households. The survey was conducted from November 2nd to November 30th, 2012, by seven different surveyors.

Each household, identified by unique HH IDs (e.g., KE01 for Nyando), belongs to one of three production systems: Lowlands (KK1), Slopes (KK2), or Highlands (KK3). The survey covered eight villages in KK1 and six villages each in KK2 and KK3, with ten households investigated per village. The respondents included 198 individuals, providing detailed information on coordinates (south and east), GPS error metrics, plot IDs, plot areas, land cover types, and photo IDs.

Results

This chapter explores the key agricultural management practices employed by smallholder farmers in the Nyando region. It examines the integration of crop and livestock farming, soil fertility management through the use of organic and inorganic inputs, and the adoption of homesteading as a land management strategy. Additionally, the chapter discusses grazing management techniques, land use dynamics, and the tenure systems that influence agricultural decision-making. Furthermore, it highlights the diversity of crops grown in the region and the strategies employed for weed control and erosion management. Through this comprehensive analysis, the chapter seeks to provide insights into how smallholder farmers in Nyando are adapting to modern challenges while maintaining sustainable agricultural practices.

Techniques for Agricultural Management

Smallholder farmers in the Nyando region use a range of agricultural management techniques to increase yield and maintain sustainability. Crop-livestock farming, the application of manure and fertilizers, and intensive agricultural methods involving the placement of homesteads inside farmed plots are some of these practices.

The merging of livestock raising and crop cultivation is a major agricultural technique in the Nyando region. With this method, an effective cycle of nutrients is made possible, with crop leftovers feeding the animals and livestock producing manure that improves soil fertility. This symbiotic relationship not only improves soil health but also boosts overall farm productivity [23]. Farmers use a combination of organic and inorganic inputs to enhance soil productivity. Organic supplements such as compost and manure are increasingly utilized alongside synthetic fertilizers to maintain soil health and fertility [24]. By supplying both plant and animal products, the incorporation of livestock into the farming system contributes to food security and revenue source diversification.

In the Nyando region, where farmers use a combination of organic and inorganic inputs to maintain and boost soil production, soil fertility management is essential. Farmers use a range of practices, such as crop rotation, intercropping, and agroforestry, to improve soil fertility. These methods enhance crop nutrient availability, minimize erosion, and preserve soil structure. The use of organic additions, including manure and compost, is growing, indicating a move towards more environmentally friendly methods. These organic inputs help improve soil structure, enhance microbial activity, and increase nutrient availability [24]. Although inorganic fertilizers are also utilized, their application must be carefully controlled to prevent pollution of the environment and damage of the soil. Additionally, the use of legumes in crop rotations and intercropping systems contributes to soil nitrogen enrichment, benefiting subsequent crops [23].

Another popular method among Nyando farmers is homesteading, which integrates a variety of plant species, livestock, and waste management systems into one property. By improving resource efficiency, income diversification, and food security, this strategy fosters climate resilience. Livestock integration creates a sustainable and self-sufficient farming system by providing manure for soil fertility and using crop leftovers and byproducts as animal feed. Farmers grow a variety of crops and rear different types of livestock within the same space, ensuring efficient use of land and resources [8].

To support the health of the ecosystem and the cycling of carbon, grazing management strategies vary throughout the Nyando region. Changes in pasture areas are made possible by rotational grazing, which keeps pasture productivity high while allowing grazed regions to recuperate. This practice not only improves soil health but also enhances carbon sequestration, contributing to climate change mitigation [10].

The Nyando region's agricultural techniques demonstrate a dedication to climate resilience and sustainability. Smallholder farmers in Nyando are able to increase output, improve soil health, and adjust to changing climatic conditions by fusing scientific knowledge with traditional farming methods. Sustainable land management practices, such as the use of organic amendments, proper grazing management, and diversified cropping systems, help mitigate the impacts of climate change and ensure long-term food security and resilience [32].

Land Use and Land Tenure

Understanding land use dynamics and tenure systems is crucial for assessing the sustainability and resilience of agricultural landscapes. This study analyzed the duration of land use practices among smallholding farmers, revealing that approximately 20% of land parcels were under a specific land use during an unknown duration, suggesting gaps in historical data or uncertainties regarding land use history. The findings indicate a significant proportion of land under medium-term use, with 17.91% and 15.12% of parcels having durations ranging from 2-5 years and 5-10 years, respectively. Long-term land use (>10 years) may reflect established agricultural systems, permanent land cover types such as forests or perennial crops.

In Nyando, very few farmers (0.73%) employ burning to suppress weeds. This indicates that fire is not a common tool for land management. This indicates a shift towards more sustainable land management practices that minimize environmental degradation [33].

Land Usage Before Agriculture

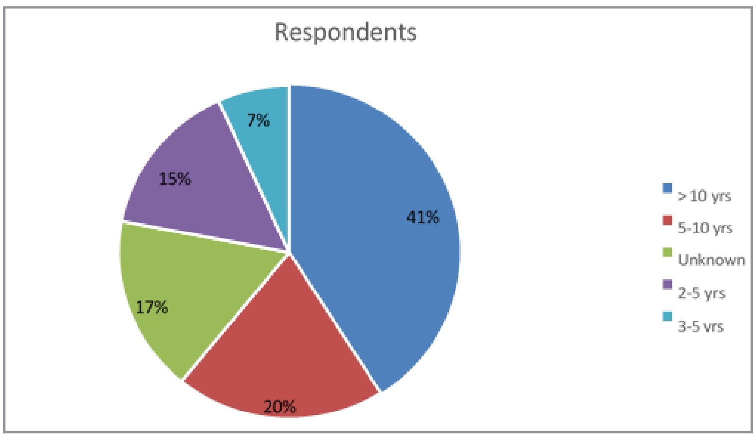

Figure 5: Responses of smallholder farmers to the question “how many years ago was the land converted into agriculture?” in the Nyando region.

In the figure above, the sample population was 200 respondents. Out of this, 82 had their land converted for agricultural use more than ten years ago, 39 fit the bracket of 5 to 10 years ago, whereas 34 did not know the answer. Additionally, 30 respondents answered between 2 to 5 years whereas 14 of them fit the 3 to 5 brackets.

The analysis unveils a diverse tenure system, with the majority (95.18%) of farmers owning their land, followed by a smaller proportion renting (4.10%) and a minimal share having communal land tenure (0.72%). This distribution reflects the varied ownership structures within the agricultural landscape, which can profoundly influence land management practices and environmental outcomes. Land tenure arrangements are often associated with ownership rights and provide farmers with long-term incentives to invest in sustainable land management practices [3]. Landowners are more likely to adopt conservation measures, such as agroforestry, soil conservation, and reforestation, that enhance carbon sequestration and mitigate greenhouse gas emissions. Conversely, farmers with rental or communal land tenure may face challenges accessing credit, technical support, and tenure security, limiting their ability to implement sustainable land management practices [5].

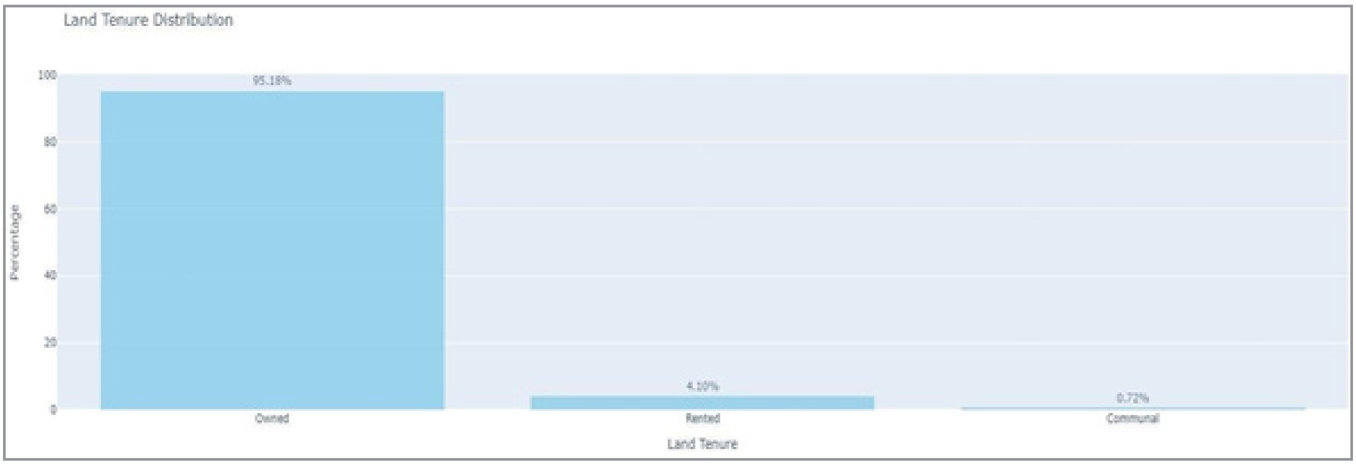

Figure 6: A representation of the Land Tenure ownership

Vegetation Cover

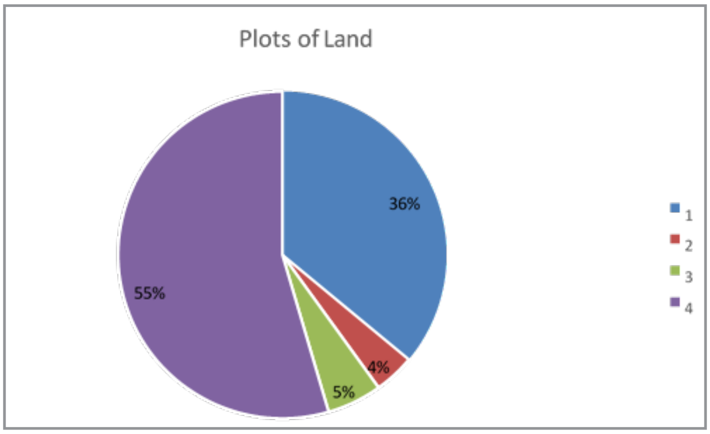

Figure 7: A Representation of Established land cover

Accordingly, out of a total of 388 plots of land, 79.3 % of the vegetation cover is grass or shrubland, forests account for 8.84% and 11.9% is unknown.

The study reveals that the predominant land cover type is grassland or shrub land (79.30%), followed by unknown (11.86%) and forest (8.84%) categories. Grassland and shrub land ecosystems can play a crucial role in carbon sequestration and soil carbon storage, especially when managed sustainably through practices such as rotational grazing, reforestation, and agroforestry [4]. The presence of a significant proportion of land parcels categorized as "Unknown" underscores the importance of improving land cover classification methods and monitoring systems to better understand landscape dynamics and inform land management decisions. Addressing data gaps and uncertainties in land cover classification is essential for accurately assessing land-use changes, habitat fragmentation, and ecosystem services provision [6].

Crops Grown

The analysis unveils a diverse range of crops cultivated by smallholding farmers, including maize (67.13%), beans, cassava, groundnuts, and others. This diversity reflects the varied agroecological conditions and farming practices employed by farmers. The rotation of crops, as evidenced by the prevalence of multiple crops in the smallholding farming systems, disrupts pest and disease cycles, reduces nutrient depletion, and promotes natural pest control mechanisms, thereby enhancing soil health and productivity.

Additionally, each production system has a different range of products grown, dependent on contributing factors such as soil fertility. The lowlands (KK1), have a range of crops that can resist harsher climate such as drought as is evidenced by the presence of sorghum and cassava. The slopes (KK2) have moderate fertility and can grow a wider variety of crops such as sweet potatoes, sugarcane, maize, cowpeas etc. The highlands however (KK3) are characterized by rich volcanic soils that support an even wider variety of crops such as tea, beans, bananas, maize, mango trees, etc. The farmers were able to provide a total of their crop yields in Kilograms.

The figure below is a representation of this data;

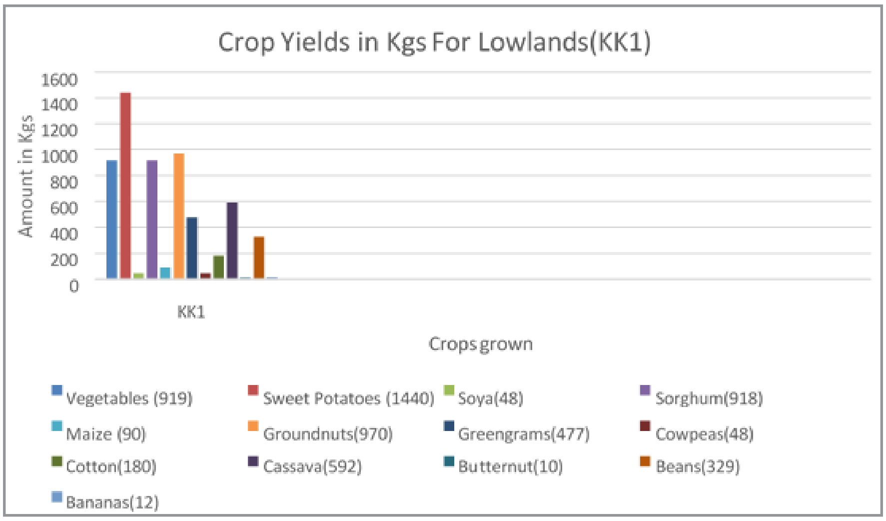

Figure 8: A Representation of Crop Yields in Kgs for KK1

In the figure above, 919kgs of vegetables were grown, 1440kgs of sweet potatoes, 48kgs of soya, 918 kgs of sorghum, 90kgs of maize, 970kgs of groundnuts, 477 kgs of greengrams, 48kgs of cowpeas, 180kgs of cotton, 592 kgs of cassava, 10kgs of butternuts, 329kgs of beans and 12kgs of bananas.

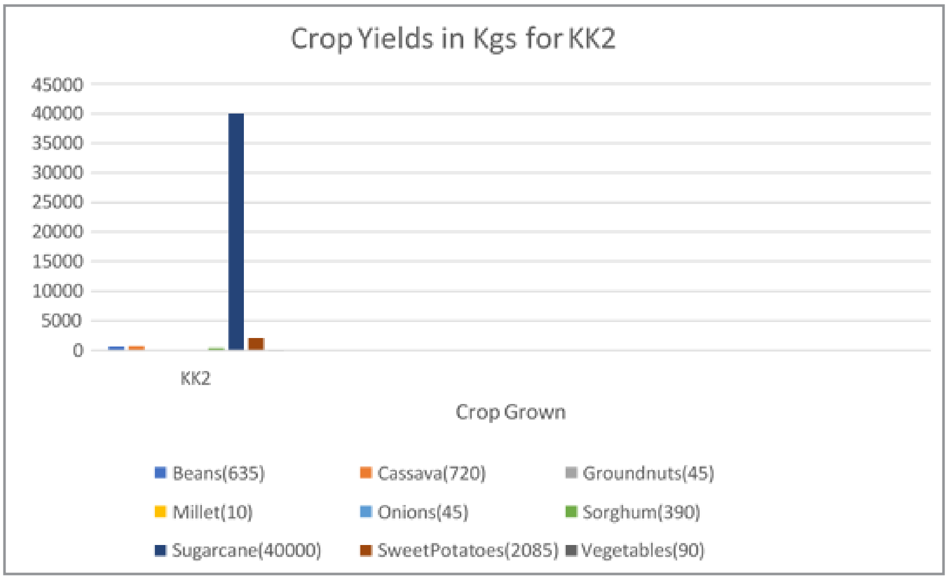

Figure 9: A Representation of Crop Yields in Kgs for KK2

In the figure above, 635 kgs of beans, 720 kgs of cassava, 45 kgs of groundnuts, 10kgs of millet, 45kgs of onions, 390kgs of sorghum, 40tonnes of sugarcane, and 2025kgs of sweet potatoes were gotten from the slopes of Nyando region.

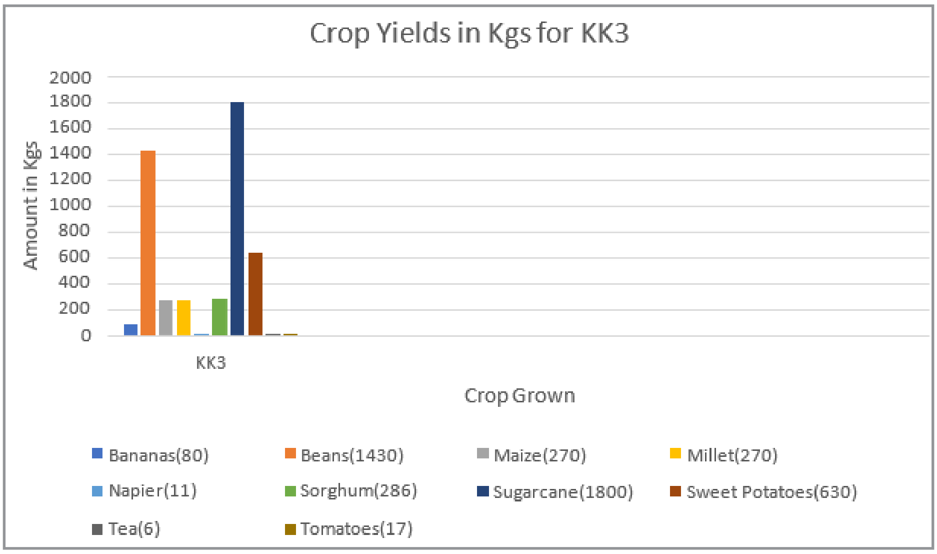

Figure 10: A Representation of Crop Yields in Kgs for KK3

In the figure above, the following are the crops gotten from land in KK3 of Nyando Region; 80kgs of bananas, 11kgs of Napier grass, 6Kgs of tea, 1430kgs of beans, 286 kgs of sorghum, 17kgs of tomatoes, 270kgs of maize, 1800 kgs of sugarcane, 270kgs of millet and 630 kgs of sweet potatoes.

Soil Fertility Management

This paper sought to investigate whether farmers in the Nyando Region of Kenya employ the use of fertilizers on their land. Out of 158 farmers in KK1, 70 of them admitted to the use of fertilizers while 76 acknowledged that they did not. In KK2, 74 farmers use fertilizers whereas 73 don't which is sharply contrasted in KK3 where 87 farmers use fertilizers and only 13 do not.

This data is represented in the figure below;

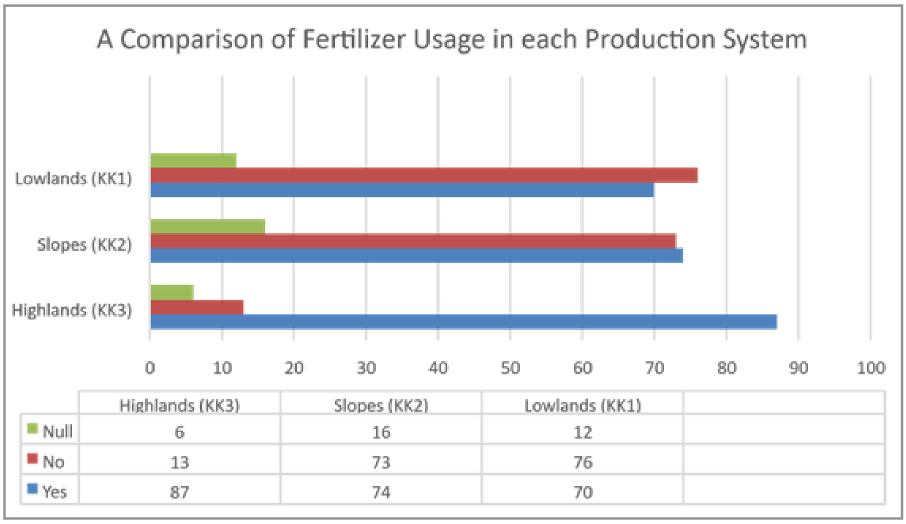

Figure 11: A Comparison of Fertilizer Usage in each Production System

Additionally, ensuring soil fertility is critical for sustaining agricultural productivity and livelihoods in smallholder farming systems operating within resource-constrained environments. The analysis reveals a diverse array of fertilizer practices, including the prevalent use of synthetic fertilizers such as diammonium phosphate (DAP) and urea.

While these fertilizers provide immediate nutrient boosts, their over-reliance can lead to soil acidification, nutrient imbalances, and environmental degradation [31].The figure below shows fertilizer preferences among 120 farmers;

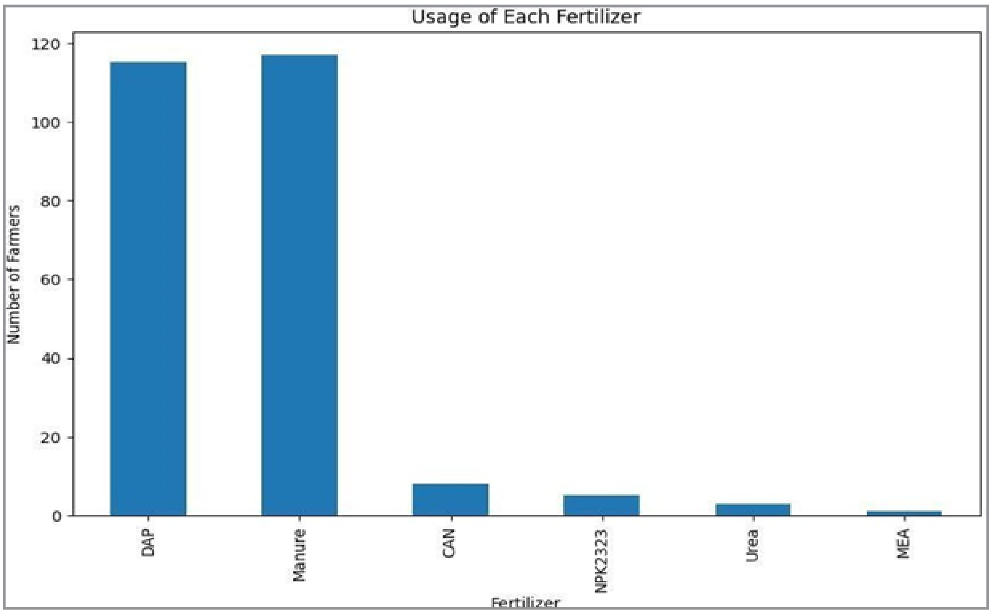

Figure 12: A Representation of Fertilizer Usage among Farmers in Nyando Region

The data shows that Di-Ammonium Phosphate (DAP) and Manure are highly sought after by these farmers as opposed to Calcium Ammonium Nitrate (CAN), a compound of Nitrogen, Potassium and Phosphorus. Urea and the compound identified as 'MEA'. Therefore, while the use of fertilizers is prevalent, the data also indicates the visible acceptance of organic soil amendments, including farmyard manure, compost, and bio-fertilizers, offering a sustainable alternative to synthetic inputs.

While fertilizers are readily available in the market, some small holder farmers may be unable to purchase them due to lack of money or the low prices that staple crops such as maize fetch in the market. Organic amendments like manure can improve soil structure, enhance water retention capacity, and foster beneficial microbial communities, promoting nutrient cycling and long-term soil fertility [26]. Transitioning to environmentally friendly alternatives, such as legumes (e.g., beans, cowpeas) and perennial crops (e.g., trees, perennial grasses), can further enhance soil health, reduce greenhouse gas emissions, and improve ecosystem resilience.

Homesteading, a practice deeply rooted in African agricultural traditions, is gaining recognition as a sustainable land management strategy in the context of climate change. The analysis reveals that 55.01% of farmers have homesteads integrated into their plots, highlighting the widespread adoption of this practice. However, it's essential to acknowledge that homesteads may vary in size and configuration, influenced by factors such as land tenure systems and plot size distribution.

Homesteading offers several advantages that contribute to climate resilience and sustainable agriculture. Firstly, it enables farmers to actively manage their environment, fostering biodiversity and ecosystem services within the homestead space. By integrating diverse plant species, such as fruit trees, vegetables, and medicinal herbs, homesteads enhance soil fertility, pest control, and water infiltration, thus reducing reliance on external inputs and chemical pesticides.

In the context of smallholder farming, where land resources are limited, homesteading optimizes land utilization by consolidating various functions within a single plot. By integrating livestock rearing, composting, and wastewater treatment facilities into homesteads, farmers can efficiently utilize space, minimize land fragmentation, and reduce the environmental footprint associated with external inputs and managed services such as sewage treatment.

Moreover, homesteading fosters adaptive management practices that enable farmers to respond to climate variability and change effectively. Through continuous observation and experimentation, homesteaders can identify climate-resilient crop varieties, water-efficient irrigation techniques, and agroforestry systems suited to their local conditions (Smith et al, 2014). This close proximity of homesteads facilitates real-time monitoring of crop performance, soil health indicators, and microclimate dynamics, enabling rapid adaptation to emerging challenges.

Ground Cover and Erosion Control

Ground cover, encompassing both woody and herbaceous vegetation, plays a crucial role in soil conservation, carbon sequestration, and climate regulation within agricultural landscapes. According to the analysis, there is a diverse distribution of woody cover across different categories. Approximately 63.33% of the surveyed area exhibits woody cover of less than 4%, indicating a significant proportion of land with sparse tree and shrub density. As woody cover density increases, the percentage of land decreases, with only 3.03% of the area having woody cover exceeding 65%. This distribution underscores the importance of promoting afforestation and agroforestry practices to increase woody cover density, which can effectively reduce soil erosion, enhance carbon sequestration, and provide multiple ecosystem services.

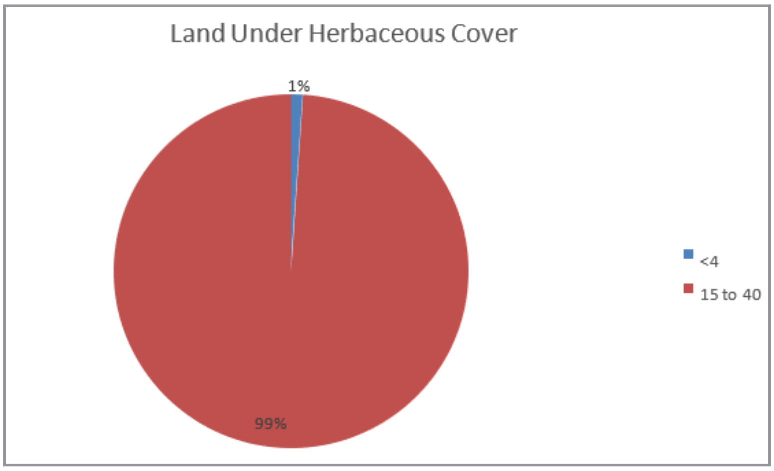

Figure 13: A Representation of Land Under Herbaceous Cover

Herbaceous cover analysis reveals varying degrees of vegetation density, with the majority (42.89%) of the surveyed area having less than 4% herbaceous cover (blue part). However, moderate to high herbaceous cover categories (15-40% and 4-15%){Green and red parts} collectively cover approximately 39.63% of the area. Herbaceous vegetation, including grasses and legumes, plays a crucial role in stabilizing soil, reducing surface runoff, and improving soil organic matter content. Promoting diverse herbaceous cover through conservation agriculture and cover cropping practices can enhance soil fertility, moisture retention, and biodiversity, thereby contributing to sustainable land management and climate resilience.

As for Woody cover, analysis reveals that 4% of the total study area of 63.3% has woody vegetation.

17.2 % of this land is covered under this type of vegetation for 4 to 15 % whereas 11.4 % of it has 15 to 40 %. Moreover, 5.6 % of the land has been under this vegetation for 40 to 65%, and another 2.40% for more than 65 %.

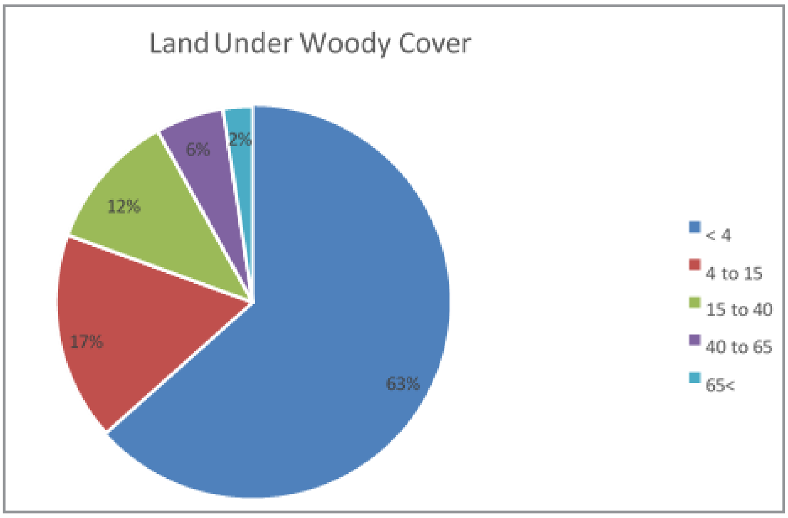

Figure 14: A Representation of Land Under Woody Cover Per Years

Additionally, in the Nyando region, erosion poses a significant challenge to agricultural productivity, with varying types of erosion observed across different production systems. In the lowlands (KK1), sheet erosion is prevalent, resulting in the gradual removal of topsoil over large areas, which can diminish soil fertility and crop yields. Conversely, the slopes (KK2) experience dominant gully erosion, characterized by the formation of deep channels that can severely disrupt land use and lead to the loss of arable land. In the highlands (KK3), erosion is moderate, indicating a less severe impact on the landscape and farming activities.

This data is represented in the figure below;

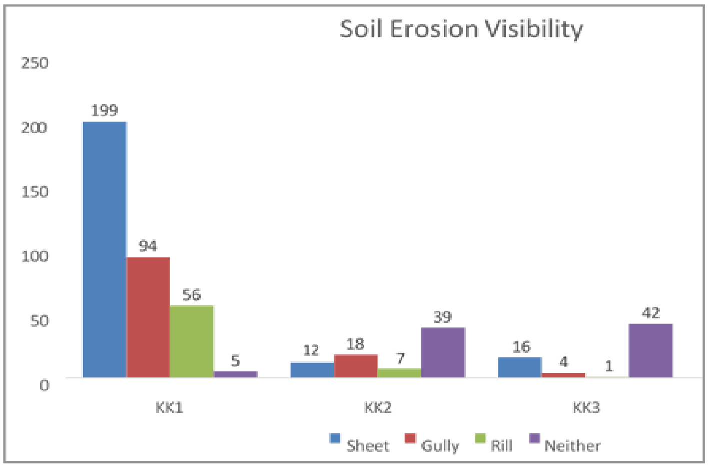

Figure 15: A Representation of Soil Erosion Visibility Per Production System in Nyando Region

Grazing As Means Of Carbon Cycling

Grazing animals contribute to the carbon cycle by facilitating the movement of carbon between the atmosphere, plants, soil, and livestock. Photosynthetic activity in grasses and shrubs absorbs atmospheric carbon dioxide (CO2), converting it into organic matter through the process of photosynthesis. Grazing animals then consume these plants, incorporating carbon into their tissues. Subsequent decomposition of plant residues and animal waste returns carbon to the soil, enriching soil organic matter and enhancing soil fertility. This process not only sequesters carbon in the soil but also promotes soil structure and microbial diversity, contributing to overall ecosystem health.

The data reveals a varied distribution of grazing frequencies among farms, indicating diverse grazing management practices within the agricultural landscape. The prevalence of no grazing (46.82%) suggests that a significant portion of farms may prioritize alternative land management strategies or have limited grazing capabilities. Conversely, the presence of farms engaging in grazing activities (23.05%) underscores the ongoing significance of livestock in agricultural landscapes.

Regular grazing (20.33%) indicates consistent utilization of pastures by livestock, potentially supporting ecosystem services such as nutrient cycling and soil health maintenance. Conversely, rare grazing occurrences (9.80%) may reflect seasonal or rotational grazing practices, where lands are periodically rested to allow for vegetation recovery and soil regeneration. Effective grazing management, as evidenced by the varying grazing frequencies, plays a crucial role in carbon management and ecosystem resilience. Rotational grazing practices, such as those observed in farms with rare grazing occurrences, allow for vegetation recovery and carbon sequestration, contributing to soil organic carbon accumulation and mitigating greenhouse gas emissions.

Weed Control Practices

The practice of burning land to clear weeds carries both benefits and demerits, which should be carefully considered in agricultural management strategies. The analysis indicates that only 0.73% of farmers practice burning to clear weeds, while the overwhelming majority (99.27%) abstain from this practice, likely due to awareness of its detrimental effects on soil health, air quality, and environmental sustainability.

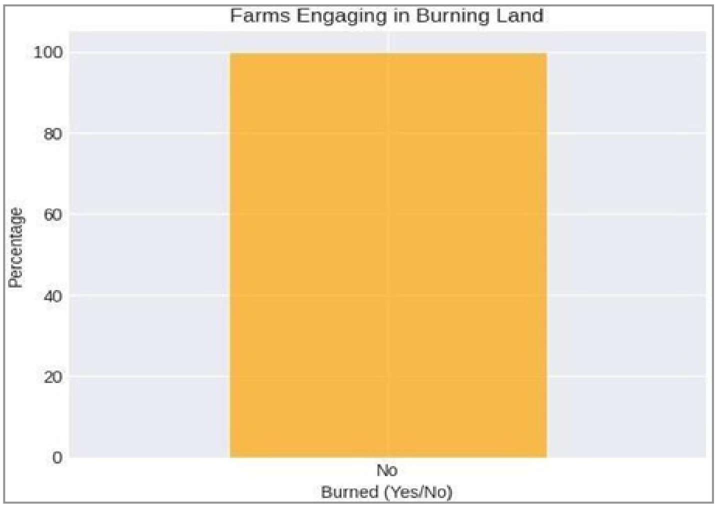

Figure 16: Weed control through burning

Burning can provide a quick and inexpensive method for removing unwanted vegetation, especially in areas with limited access to mechanical or chemical weed control options. However, this practice can lead to soil erosion, loss of soil organic matter, and the release of greenhouse gases and particulate matter, contributing to air pollution and respiratory health issues [21].

Instead, promoting alternative weed control methods such as mulching, cover cropping, crop rotation, and mechanical cultivation would align with sustainable agricultural practices that prioritize soil conservation, ecosystem health, and human well-being. Integrated weed management approaches, combining cultural, mechanical, and biological control methods, can effectively manage weed populations while minimizing negative environmental impacts (Bàrberi, 2002).

Moreover, providing education, training, and incentives for adopting these sustainable weed control methods could further support the transition away from burning as a weed control method. By fostering a deeper understanding of the long-term consequences of burning and promoting knowledge exchange on best practices, smallholder farmers can make informed decisions to safeguard their land's productivity and contribute to environmental stewardship.

Discussion

Overview

In 2012, the SAMPLES project compiled data from 196 households, which gave a better understanding of the agricultural practices from three different production systems: the lowlands (KK1), slopes (KK2), and highlands (KK3). Such variations in crop types, land management practices, across different altitudes and landscapes were also pointed out by the survey data.

The first significant result presented by the household survey is the diversity of crops that smallholder farmers cultivate, among which maize, beans, and cassava are the most commonly grown crops—with considerable differences in yields depending on locations and management practices. For example, the average yield for maize was found to be higher in the highlands than in the lowlands, and most probably, this can be explained by better soil fertility and the prevalence of favorable conditions. The magnitude of variation demonstrated in this study suggests that there is still a need for regional-based interventions and the development of agricultural technologies that consider the natural and environmental conditions of specific areas.

The survey also highlighted the prevalence of mixed cropping systems where farmers have different crops in the same plot. This practice, found among several households, is a way of mitigating risk and increasing household food security and resilience to climatic shocks. Homesteads within agricultural plots were also observed, indicative of an integration of the living and farming space, further emphasizing the multifunctional nature of smallholder farms.

The variety of fertilizer applications among the households differed widely, where some used substantial amounts of organic inputs, such as manure, and others applied large quantities of chemical fertilizers, such as DAP and urea. The resulting status of soil health from these practices was quite clear; good levels of soil organic carbon and soil structure characterized organic amendments in general. This would, therefore, suggest that the promotion of organic farming practices could be a viable option for improving soil health and sequestering carbon within smallholder systems.

Per Production System

Crop-Livestock Farming Integration

A major technique observed in the Nyando region is the integration of crop-livestock farming, a practice that creates a symbiotic relationship between crops and animals. This method ensures a continuous cycle of nutrients: livestock are fed crop residues, and in turn, the manure they produce is used to enhance soil fertility. This not only boosts productivity but also promotes food security and income diversification.

Additionally, livestock-crop integration has the potential to improve soil health and mitigate the negative effects of soil degradation. The recycling of organic matter through manure is a natural way to replenish soil nutrients, which is vital in an agricultural system where synthetic fertilizers may not always be accessible or affordable. This farming technique is central to maintaining soil productivity and, ultimately, increasing agricultural outputs.

Moreover, crop-livestock farming is key to establishing climate resilience. By maintaining both plant and animal production on the same farm, farmers can hedge against the risks of crop failure due to unpredictable weather conditions. This technique ensures that even if crop yields are lower, livestock can still provide a reliable source of income.

Soil Fertility Management

Maintaining and enhancing soil fertility is one of the core practices in smallholder farming systems. The combination of organic inputs such as manure and compost with inorganic fertilizers, as outlined in KK2, is essential for improving soil productivity and sustainability. Accordingly, the use of organic amendments is gaining traction as farmers recognize the long-term benefits of improving soil structure, increasing microbial activity, and enhancing the soil's ability to retain moisture and nutrients.

Organic inputs contribute significantly to enhancing soil fertility in the Nyando region, where intensive farming depletes soil nutrients over time. However, in KK2 the overuse of inorganic fertilizers, particularly synthetic nitrogen-based options like Di-Ammonium Phosphate (DAP) and urea, can lead to soil acidification and environmental degradation if not carefully managed.

Additionally, soil fertility management for the KK2 also involves incorporating legumes into crop rotations and intercropping systems. Legumes naturally fix nitrogen in the soil, enriching it for subsequent crops, thus reducing the need for synthetic fertilizers. This practice not only improves soil health but also contributes to biodiversity and natural pest control.

Homesteading as an Agricultural Practice

Homesteading is another significant technique employed by Nyando farmers, wherein various crops, livestock, and waste management systems are integrated within a single property.

Accordingly, this practice enhances resource efficiency and improves the resilience of smallholder farming systems against climate change.

Homesteading allows farmers to practice diverse agricultural activities on limited land, making it ideal for regions like Nyando, where land resources are scarce. By incorporating livestock rearing, composting, and wastewater management into a single homestead, farmers can reduce their reliance on external inputs, thus lowering the environmental footprint of their farming activities. This strategy also encourages adaptive management, enabling farmers to experiment with different crop varieties, water-efficient irrigation systems, and agroforestry techniques that best suit local conditions.

Moreover, homesteading enhances climate resilience by promoting biodiversity within homesteads, where farmers can protect their crops from pests and diseases while fostering ecosystem services such as pollination and soil nutrient cycling. This also references the importance of realtime monitoring of soil health indicators and crop performance, made possible by the close proximity of homesteads to the fields.

Land Use and Tenure Systems

Land use and tenure systems greatly influence the adoption of sustainable farming practices. Secure land tenure encourages farmers to invest in long-term soil conservation methods, such as agroforestry and reforestation. The analysis reveals that most smallholder farmers in Nyando own their land, which allows them to implement sustainable land management practices without the risk of losing access to their plots.

Additionally, there is also the need for improved land use classification methods to address the data gaps in land cover types. Accurate monitoring systems would enable farmers and policymakers to better understand landscape dynamics, ultimately leading to more informed land management decisions. For instance, rotational grazing, as observed in Nyando, ensures that pastures are not overgrazed, thus preventing soil erosion and promoting carbon sequestration.

Ground Cover and Erosion Control

Ground cover, both woody and herbaceous, plays a crucial role in preventing soil erosion and promoting soil carbon sequestration. This thesis looks at the importance of afforestation and agroforestry in increasing woody cover density, which can effectively reduce soil erosion and enhance the ecosystem's ability to store carbon.

Accordingly, promoting diverse herbaceous cover through conservation agriculture and cover cropping practices is another way to protect soil health. These practices help to retain soil moisture, reduce surface runoff, and improve soil organic matter, making the farming system more resilient to climatic changes. This aligns with the view that effective erosion control measures can mitigate the impacts of climate change and preserve soil fertility for future agricultural productivity.

Another main finding that has ensued from the landscape stratification is the existence of large areas with uncultivated vegetation, found mainly in off-grid areas. Such areas are often composed of natural grasslands and forests. These have an essential role not only in biodiversity conservation but also in carbon sequestration. The sustenance of such areas is essential in its own right, for the overall sustainability of the agricultural landscape by providing ecological buffers and enhancing resilience against climate change.

Additionally, In KK1, a lot of sheet erosion is noticed which can be attributed to the flat topography of the region as well as high rainfall that allows for the washing away of the topsoil. In KK2, a lot of sheet erosion still occurs but there is also an increase in gulley erosion. This is also because of the topography that allows a lot of the top soil to be carried away. Additionally, when the soil becomes saturated and the water begins to trickle down the slope, it creates small channels that eventually end up being gullies. In the highlands, erosion is moderately observed. This is because, while the terrain may increase the speed of water run off leading to both gully and sheet erosion, the highlands generally have better soils that are able to retain water, but also a lot of vegetative cover.

Further Research and Development

Continued research and development are essential to deepen our understanding of the interactions between agricultural practices and climate change. Areas that warrant further investigation include:

Long-term studies on soil health can provide insights into the sustainability of different farming practices and their impact on soil fertility and carbon sequestration. Monitoring changes in soil organic carbon, nutrient levels, and soil structure over time will help identify the most effective practices for enhancing soil health.

Understanding the impact of climate variability on crop yields and soil health is crucial for developing resilient farming systems. Research on the effects of changing rainfall patterns, temperature fluctuations, and extreme weather events can inform the development of adaptive strategies that enhance the resilience of smallholder farmers.

The integration of livestock into crop farming systems can provide multiple benefits, including enhanced soil fertility through manure application, diversified income sources, and improved food security. Research on the optimal integration of livestock and crops, as well as sustainable livestock management practices, can contribute to more resilient and productive farming systems.

Assessing the socio-economic impacts of climate-smart agricultural practices on smallholder farmers is essential for understanding their feasibility and scalability. Studies on the costs and benefits of different practices, as well as their impact on household income, food security, and livelihoods, can provide valuable insights for policymakers and development practitioners.

Ensuring that climate-smart agricultural practices are inclusive and equitable is critical for their success. Research on the gender and social dimensions of climate-smart agriculture can identify barriers to adoption and inform the development of interventions that promote the participation and empowerment of women, youth, and marginalized groups.

Scaling up successful interventions from pilot projects to broader regional or national levels requires a systematic approach. Research on the factors that facilitate or hinder the scaling up of climate-smart practices can inform the development of strategies for replicating successful models and achieving wider impact.

Summary and Conclusions

This will, therefore, be instructive to policymakers about the scaling up of sustainable land management practices, agricultural extension services, access to markets and finance, research and innovation, mainstreaming climate-smart agriculture into the national development plans and promoting social inclusion and gender equity. In conclusion, therefore, the study findings provide a solid basis to the enhancement of climate change mitigation efforts in smallholder farming systems. Smallholder farms will be a significant contributor in attaining mitigation efforts to address global climate change, improving agricultural productivity and sustainable development if they adopt targeted, site-specific interventions with an enabling policy environment. The key will be ongoing research, innovation, and the active engagement of communities and other stakeholders.

Summary of Findings

The discussion of agricultural management techniques used by smallholder farmers in Nyando reveals several key strategies:

- Smallholder farmers in Nyando strategically combine crop and livestock farming, where the waste from livestock, such as manure, is used as fertilizer for crops, while crop residues provide feed for animals. This closed-loop system improves soil fertility, reduces input costs, and increases overall farm productivity. This integration also offers farmers a buffer against climate risks, as diverse income streams from both crops and livestock stabilize farm income during periods of poor crop performance or animal production.
- Farmers balance the use of organic materials, such as animal manure, compost, and crop residues, with inorganic fertilizers to boost soil fertility. Organic inputs improve the soil's structure and water retention ability, while synthetic fertilizers provide immediate nutrients for plant growth. However, long-term reliance on synthetic fertilizers without adequate organic amendments can deplete soil quality, making it crucial for farmers to adopt integrated soil fertility management approaches.
- Additionally, crop rotations involving nitrogen-fixing legumes like beans and groundnuts contribute to maintaining soil health and fertility.
- The homesteading model in Nyando involves using every aspect of the farm to enhance productivity and self-sufficiency. Farmers plant crops, rear livestock, and may even include agroforestry and horticulture on their plots. By integrating multiple farming systems on one piece of land, they reduce waste and improve overall efficiency. For example, they can capture rainwater for irrigation or use plant residues for mulching. This approach not only enhances food security but also promotes environmental sustainability by minimizing the need for external inputs and encouraging diverse farming practices.
- Secure land tenure is vital for promoting sustainable farming practices. Farmers who own or have long-term rights to their land are more likely to invest in soil conservation methods likeagroforestry, where trees are planted among crops to improve biodiversity and soil health. In contrast, insecure land tenure discourages long-term investments, as farmers fear eviction or changes in land ownership. Strengthening land rights for smallholder farmers would promote longterm planning and adoption of sustainable agricultural techniques.
- Maintaining ground cover, whether through natural vegetation, cover crops, or agroforestry, helps to protect soil from erosion and degradation, especially in hilly or vulnerable areas. Farmers are increasingly using techniques like mulching, planting trees, and adopting no-till practices to prevent soil from being washed away during heavy rains. These practices not only preserve topsoil but also sequester carbon, contributing to climate change mitigation while enhancing soil health and farm resilience.
- The study also conducted a thorough assessment of soil health and fertility across different smallholder farms. It was found that soil health varied significantly across production systems, influenced by the type of land and agricultural management, crops grown, type of erosion experienced and type of fertilizers used.
- The study documented various agricultural practices, including conservation tillage, crop rotation, intercropping, and agroforestry. These practices were evaluated for their impact on soil health and crop productivity. Conservation tillage and crop rotation were found to enhance soil health by improving soil structure and fertility, while intercropping and agroforestry systems promoted biodiversity. Conservation tillage, for example, minimized soil disturbance, thereby preserving soil structure and reducing erosion. Intercropping increased biodiversity, providing habitat for beneficial organisms and improving pest management. Agroforestry, as mentioned earlier, not only sequestered carbon but also improved microclimatic conditions and provied additional sources of income and food.

Conclusion

The findings indicate that smallholder farmers in Nyando are making significant strides in integrating sustainable practices like crop-livestock systems and organic soil management. These approaches improve farm productivity while enhancing environmental sustainability. However, challenges remain, particularly with over-reliance on synthetic fertilizers and insecure land tenure, which limit the long-term effectiveness of sustainable practices. Overall, farmers are adapting to climate change by implementing diversified farming systems that increase resilience, but further support is necessary to scale these practices.

Recommendations

Based on the findings of this research, the following recommendations are made:

Agricultural extension services should promote the use of organic amendments such as compost and manure. Training programs should be developed to educate farmers on the benefits and application methods of these amendments to enhance soil health and fertility.

Farmers should be encouraged to adopt sustainable agricultural practices like conservation tillage, crop rotation, intercropping, and agroforestry. Demonstration projects and farmer field schools can be effective in showcasing the benefits of these practices.

Policymakers should support further adoption of climate-resilient farming practices, including rotational grazing, ground cover maintenance, and erosion control measures, to safeguard ecosystems and improve agricultural productivity in the face of changing weather patterns.

Strengthening land rights and providing secure land tenure would encourage farmers to adopt longterm sustainability measures, such as planting trees or investing in soil conservation structures. Policymakers could explore reforms or community land registration programs that empower smallholder farmers with more stable access to their land.

Provision of training and resources to ensure that farmers have the knowledge and skills needed to implement sustainable practices, targeted training sessions should be organized by agricultural extension officers. These workshops can demonstrate the benefits of organic farming, rotational cropping, and efficient resource management, which can increase yields without harming the environment.

Governments and policymakers should create supportive policies and incentives for farmers adopting sustainable practices. Subsidies for organic inputs, financial incentives for conservation practices, and technical support can significantly enhance adoption rates.

Continued research is essential to develop new and improved sustainable farming techniques. Collaborative research involving farmers, scientists, and policymakers can lead to innovations that further enhance soil health.

Raising awareness about the benefits of sustainable farming practices through community outreach programs, workshops, and media campaigns can increase the acceptance and implementation of these practices among smallholder farmers.

By implementing these recommendations, the Nyando region can achieve greater agricultural sustainability, improve food security, and contribute to global efforts in mitigating climate change.

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Declaration of the use of generative AI tools

I have used a few generative AI tools to help with different areas of the preparation and writing of this master's thesis. The use of these tools has been conducted in accordance with good scientific practice, ensuring transparency and accountability.

To ensure linguistic accuracy and clarity, I used QuillBot to correct grammatical and orthographic problems throughout the thesis. I made an initial draft of the abstract using ChatGPT, which I then built upon and improved. In order to ensure correct and fluid translation, I also utilised Google Translate to translate a preliminary draft of the German abstract, which was based on the English abstract I had already produced.

Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature, as well as those which were generated using artificial intelligence tools, are duly identified, and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, September 2024 Kiarie Alvin GITAU (manu propria)

Preface

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