RESILIENCE OF POLYCULTURE COFFEE CROPPING SYSTEMS IN BULAMBULI DISTRICT OF MOUNT ELGON REGION, EASTERN UGANDA

BY

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A RESEARCH DISSERTATION SUBMITTED TO THE DIRECTORATE OF GRADUATE STUDIES, RESEARCH AND INNOVATIONS IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE IN CLIMATE CHANGE AND DISASTER MANAGEMENT OF BUSITEMA UNIVERSITY

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ABSTRACT

This study examined the resilience of polyculture coffee cropping systems in Bulambuli District, Eastern Uganda. It compared polyculture and monoculture coffee systems using agronomic, ecological and socioeconomic indicators, including farmer practices, coffee yield, soil fertility, biodiversity, soil and water conservation, income diversification and farmer perceptions of resilience. A mixed-methods design was used. The study obtained 290 valid responses from farmers across four Sub Counties, supported by field observations, soil sampling, key-informant interviews and focus group discussions. Polyculture was practiced by approximately 63% of the respondents. Common practices included soil and water conservation, composting, mulching, crop rotation and shade-tree management, although organic and biological pest-control practices were less widely adopted. Comparative results showed that polyculture farms recorded a higher mean current coffee yield (1,535.13 kg/ha) than monoculture farms (1,452.12 kg/ha), but the difference was not statistically significant. Polyculture farms nevertheless showed stronger soil-health and biodiversity indicators in the available measurements, including higher organic matter, nutrient levels and biodiversity counts. Farmers also associated polyculture with income diversification, drought resilience and improved yield stability. At the same time, high labour requirements, continued dependence on chemical pest control, limited extension support and access to finance constrained adoption. Some findings were contrary to expected relationships; for example, the mulching comparison showed higher observed soil organic matter in farms reporting no mulching, and profit did not increase monotonically with the number of new practices. These findings were therefore interpreted cautiously rather than being forced to conform to prior literature. The study concludes that polyculture offers a promising, context-specific pathway for strengthening ecological stability, livelihood diversification and climate resilience among smallholder coffee farmers in the Mount Elgon region, while requiring targeted extension, soil-management and economic support.

DECLARATION AND COPYRIGHT

I the undersigned, declare that this research dissertation is my original work, except where due acknowledgement has been made. I declare that this work has never been submitted to this University or to any other institution for funding/for partial fulfillment for any award.

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SUPERVISORS' APPROVAL

This dissertation has been submitted as a partial fulfillment of requirements for the Master of Science degree in climate change and Disaster management of Busitema University with our approval as the academic supervisor (s)

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DEDICATION

This research dissertation is dedicated to my family.

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I would like to express my deepest gratitude to all those who have contributed to the completion of this research on the value of polyculture farming systems for coffee production in Bulambuli District.

I extend my sincere thanks to my academic supervisors, Associate Professor Wilson Mwanja and Dr. Sowedi Masaba, whose guidance, encouragement, and expertise were instrumental throughout this process. Your constructive feedback and unwavering support have greatly enriched this research.

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Lastly, I am immensely grateful to my family and friends for their unwavering support and understanding throughout this journey. Your encouragement has been my anchor through challenging times.

I hope the results of this work will be taken up or adopted by the coffee farmers and policymakers and will greatly contribute to the sustainable development and resilience of coffee farming systems in Bulambuli District.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
Ca	Calcium
CAO	Chief Administrative Officer
CSA	Climate-Smart Agriculture
DPO	District Production Officer
FEWS NET	Famine Early Warning Systems Network
FFS	Farmer Field Schools
FGDs	Focus Group Discussions
GPS	Global Positioning System
H2O	Water
IPDM	Integrated Pest and Disease Management
IPM	Integrated Pest Management
K	Potassium
Kg	Kilogram
KIIs	Key Informant Interviews
Mg	Magnesium
Mt	Mountain
NDVI	Normalized Difference Vegetation Index
NGO	Non- Government Organisation
pH	potential of Hydrogen
SDGs	Sustainable Development Goals
TEK	Traditional Ecological Knowledge
UCDA	Uganda Coffee Development Authority
UNMA	Uganda National Meteorological Authority
VSLAs	Village Savings and Loan Associations

CHAPTER ONE
INTRODUCTION

1.1. Introduction

The resilience of polyculture coffee cropping systems characterized by the cultivation of coffee plants interspersed with different crop combinations, has gained attention recently as an adaptive strategy against climate change, pests, and socioeconomic challenges. These systems provide a model system for crop farming that supports both ecological stability and economic resilience of the crop production system (Davis & Kiwuka, 2023). Coffee cultivation is an important source of income in Bulambuli District, and plays a crucial role in maintaining local economies, making and therefore the farming systems environmental health and resilience takes on particular significance. The study assesses the capacity of polyculture coffee farming systems by assessing how coffee farming systems tolerate, bounce back from, and adjust to shocks or stresses related to the environment, the economy, and society. These stressors include the consequences of climate change, such as drought, severe rainfall, pests and illnesses, changes in market prices, and the socioeconomic difficulties farmers confront.

Furthermore, water retention and conservation practices were examined to determine the effectiveness of the two farming systems in maintaining soil moisture and preventing erosion. Techniques such as mulching, terracing, and agroforestry were evaluated for their role in improving water infiltration, reducing runoffs, and promoting sustainable land use. These practices are particularly crucial in the hilly terrains, where soil erosion can significantly impact coffee yields (Davis & Kiwuka, 2023).

Pest and disease resistance were also assessed by comparing the incidence and severity of common coffee diseases and pest infestations in polyculture and monoculture systems. provided valuable insights into how polyculture coffee farming enhances ecological sustainability and resilience in the face of environmental challenges.

This study sought to illustrate how smallholder farmers engage in co-constructing sustainability within their agricultural systems, forming collaborative networks that support adaptive practices and knowledge sharing, in Uganda. The study also sought to explore the dynamics, of the different farming practices within the polyculture cropping systems, in collaboration within polyculture models.

The study used a comprehensive set of assessment criteria to evaluate whether sustainability and co-sustainability were achieved by farmers for practiced polyculture systems of coffee farming and production. First, environmental indicators were identified and examined. These environmental indicators were crop and plant biodiversity, soil health, water conservation practices, and pest resistance to determine ecological balance and long-term productivity. The study also assessed set socioeconomics indicators that is, income stability, investment in agricultural inputs, cost-benefit ratios, and farmers‘ ability to adapt to market changes. In addition, social indicators were analyzed by measuring knowledge-sharing, participation in cooperatives, and household food security, which contribute to community resilience and cooperative sustainability. Finally, cross-system interactions were explored to identify synergies between ecological, economic, and social factors, such as the role of diversified cropping in enhancing both environmental resilience and household food security. Through this multi-dimensional approach, the study determined the extent to which sustainability and co-sustainability are being realized.

1.2 Background to the study

Bulambuli District, which is located on the slopes of Mount Elgon, is ideal for a range of agricultural production methods, including coffee production, due to its rich volcanic soils and bimodal rainfall pattern (Svedhem, 2024). However, the author notes that despite these benefits, Bulambuli coffee growers face numerous challenges, including soil degradation, climate change impacts, and economic instability. Increasingly, coffee farmers are practicing polyculture systems. The polyculture farming system has been found to improve resilience by enhancing soil fertility, increasing biodiversity, and providing farmers with additional income sources (Onyas et al., 2018); (Davis & Kiwuka, 2023).

Globally, coffee farming faces mounting challenges from climate change, disease, and market volatility, pushing researchers and practitioners to explore resilient agricultural models (Sibelet & Montzieux, 2012). Polyculture coffee systems, which integrate coffee with other crops, offer a promising alternative to traditional monoculture coffee farming (Sibelet & Montzieux, 2012). In Africa, the resilience of polyculture coffee systems is essential due to the continent's unique climatic and socioeconomic pressures, and many coffee-producing areas on the continent experience fluctuating weather patterns, which strain monoculture coffee. Polyculture coffee farming, on the other hand, enhances adaptability by promoting ecological diversity farms (Valérie et al., 2024).

In eastern Africa, countries of Uganda, Kenya, and Ethiopia rely heavily on coffee as an economic driver. Resilience is especially vital in this region, where environmental volatility can threaten coffee yields (Lemma & Megersa, 2021).

In Uganda, coffee is a leading agricultural commodity, with both Robusta and Arabica varieties cultivated across the country (Valérie et al., 2024). According to a study by (Onyas et al., 2018), Ugandan smallholder farmers actively participate in co-constructing sustainability, with many adopting polyculture systems. At the local level in the Bulambuli District, polyculture coffee cropping systems play a crucial role in sustaining smallholder livelihoods (Migadde, 2020), noting that coffee farms are often intercropped with bananas, beans, and native species, creating an agroecosystem that supports soil fertility and biodiversity.

These climatic challenges are exacerbated by the widespread use of monoculture practices, leading to soil degradation, reduced fertility, and heightened vulnerability to pests and diseases such as the coffee berry borer (Kagezi et al., 2018). The decline in coffee productivity jeopardizes both the sustainability of farming systems and the livelihoods of the communities reliant on them (Kagezi et al., 2018).

Polyculture coffee cropping systems have presented a promising alternative for enhancing the resilience of coffee farming in the region (Migadde, 2020). Through integration of coffee plants with crops such as bananas, beans, and maize, the systems improve soil fertility, promote biodiversity, and provide natural pest control, while diversifying income streams and reducing dependency on coffee as a sole cash crop (Mubiru et al., 2009); (Migadde, 2020).

1.3 Statement of the problem

Coffee farming has remained key to the livelihoods of households in Bulambuli District, supporting many smallholder farmers who rely on it for income and food. However, due to climatic changes, degraded soils, and unstable market prices, farming stability and outputs have been severely hurt. Practices of growing coffee in monoculture systems have increased, leading to soil degradation, biodiversity loss, and vulnerability to pests and diseases. This shows we need other farming models that enhance both ecological and economic resilience.

To address these challenges, some farmers in the district now grow coffee alongside other crops like bananas, beans, maize, and vegetables (polyculture). This would help in better land use at the same time, boosting soil health, aligning with the idea that mixed farming aids sustainable agricultural production and better livelihood stability.

Polyculture coffee farming systems have been shown to improve ecological sustainability, improve soil fertility, and enhance socioeconomic outcomes compared to monoculture coffee farming systems in Bulambuli District.

Though polyculture coffee systems show promise, there‘s limited evidence on how much they boost resilience and sustainability for smallholder farmers in Bulambuli District. Understanding how polyculture system components interact to influence environmental and socioeconomic outcomes among smallholder coffee farmers remains inadequate and little explored.

1.4. Purpose of the study

The purpose of this study was to investigate the effectiveness of polyculture coffee cropping systems in enhancing the ecological sustainability and resilience of coffee farming in Bulambuli District, Mountain Elgon Region, Eastern Uganda in the face of the changing climate.

This study addressed these critical challenges by assessing the resilience of polyculture coffee cropping systems in Bulambuli District. Through this evaluation, the research aims to provide evidence-based insights to inform policy frameworks, enhance smallholder farmers‘ adaptive strategies, and promote sustainable agricultural practices tailored to the region‘s unique ecological and socioeconomic conditions.

1.5. Objective

To assess the ecological sustainability, environmental health and socioeconomics indices of different coffee cropping systems in fostering and ensuring resilience and sustainability in Bulambuli District.

1.5.1. Specific Objectives

The specific objectives of the study are

a) Investigate the practices of farmers in coffee cropping systems in Bulambuli District.

b) Assess the agricultural outputs of monoculture compared to polyculture coffee cropping systems in Bulambuli District.
c) Assess the contribution of monoculture compared to polyculture coffee farming systems to the sustainability, resilience and productivity of the respective coffee cropping systems in Bulambuli District.

1.6. Research questions

a) What farming practices are used in coffee cropping systems in Bulambuli District?
b) How do agricultural outputs differ between polyculture and monoculture coffee cropping systems in Bulambuli District?
c) To what extent does polyculture and monoculture coffee farming systems contribute to sustainability, resilience and productivity in Bulambuli District?

1.7. Justification of the study

Through analyzing the practices of coffee farmers in Bulambuli District, the research seeks to examine how the current coffee farming systems contribute to the ecological sustainability and resilience of the coffee farming systems to climate change. Through this evaluation, the research aims to provide evidence of the most effective of the two coffee cropping systems in enhancing smallholder farmers‘ adaptive strategies. Recommendations shall be made for consideration of different coffee farming value chain actors on ways for promoting sustainable coffee farming practices tailored to the Bulambuli region‘s unique ecological and socioeconomic conditions.

1.8. Scope of the Study

This study investigates the contribution of polyculture coffee cropping systems to coffee production in Bulambuli District, through examination of farmers‘ practices, agricultural outputs, and the systems‘ potential to enhance resilience. It investigates the intricate dynamics of crop combinations, farming techniques, soil management, and pest control strategies, evaluating their influence on productivity.

Set in Bulambuli District, a mountainous terrain, the study took one year, from January 2025 to December 2025, encompassing two full coffee production cycles, ensuring a robust and longitudinal understanding of polyculture practices and their implications for resilience.

Specifically, the study focused on assessing the value of intercropping techniques, such as growing coffee alongside bananas, beans, and maize, to assess their impact on soil health, biodiversity, and economic viability.

1.9. Theoretical and Conceptual Framework

The theoretical framework for this study on the resilience of coffee cropping systems in Bulambuli District, Mountain Elgon Region, Eastern Uganda, draws on Resilience Theory. This theory provides the foundation for understanding how polyculture cropping systems can enhance resilience in coffee farming, addressing the intertwined challenges of climate change, soil degradation, and pest and disease management.

Resilience Theory

Resilience theory by (Gunderson et al., 2012), (Gunderson, 2017) and (Walker & Salt, 2012a) provides a comprehensive framework for understanding and enhancing the stability and adaptability of agricultural systems in the face of various disturbances. By integrating ecological principles with social and economic considerations, resilience theory offers valuable insights for developing sustainable and resilient farming practices that can withstand and thrive under changing conditions. The theory, originating from ecology, focuses on the capacity of systems to absorb disturbances, adapt, and maintain function in the face of external stress and shocks. In the context of agricultural systems, resilience is about the ability of farming practices to withstand environmental stresses, for example, climate change, pests, diseases while maintaining productivity and livelihoods.

1.10 Conceptual Framework for the Study

This study‘s conceptual framework for understanding coffee cropping systems‘ resilience combines variables and shows in a nutshell how they connect to meet the study‘s purpose and objectives. The framework is arranged in three main parts: farmers‘ practices in coffee cultivation, agricultural outputs from both polyculture and monoculture systems, and ways systems cope with challenges caused by climatic change, all working together in Bulambuli District's social and environmental context (Figure 1).

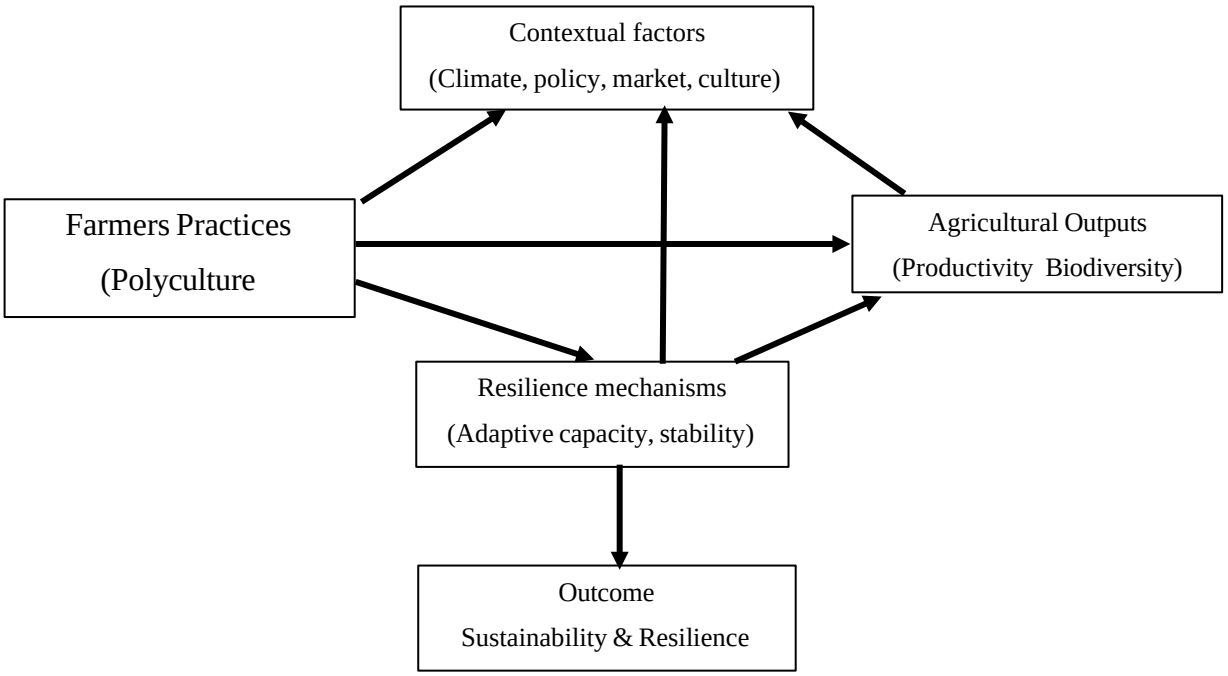


Figure 1: Conceptual Framework

The study‘s conceptual framework on the resilience of polyculture coffee cropping systems in Bulambuli District, integrates the key variables and their interactions to illustrate how various agronomic, ecological, and socioeconomic factors collectively influence the resilience to climate change and sustainability of coffee farming systems. The idea is based on Resilience Theory (Gunderson et al., 2012; Walker & Salt, 2012), which talks about how systems dealing with people and nature handles tough times, adjust to pressures, and change while keeping key functions

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The resilience of agricultural systems, particularly in regions susceptible to climatic and economic variability, has garnered significant academic attention (Meuwissen et al., 2019; Walker & Salt, 2012b). In the context, coffee farming system in the Mountain Elgon Region of Eastern Uganda has been studied for aspects such as polyculture systems potential to enhance resilience to climate change through ecological, economic, and social benefits (Kral & Probst, 2016a). This literature review aims to synthesize existing research on the practices, outputs, and impacts of polyculture coffee cropping systems, with a focus on Bulambuli District.

2.2 Climate change

Climate change is one of the major challenges facing agriculture, particularly in developing countries where livelihoods depend heavily on climate-sensitive agricultural systems. Climate variability and increasing climatic extremes can affect agricultural production through changes in rainfall patterns, temperature, drought and other weather-related stresses (Hope, 2009; Kyoheirwe et al., 2016). In Uganda, environmental degradation and climatic variability have also increased the vulnerability of agricultural and natural resource systems (National Environment Management Authority [NEMA], 2008). These changes pose particular challenges to farming systems that depend on rainfall and natural water resources.

Agriculture is highly sensitive to climate variability because crop growth and productivity depend on temperature, rainfall and soil-water availability. Climate change can therefore influence agricultural productivity and farmers' decisions concerning crop choice, planting periods and farm management (Houghton et al., 2001; Knox et al., 2012). Climate variability also creates uncertainty for farming households, making the capacity to adjust agricultural practices increasingly important (Smit et al., 2000; Wall & Smit, 2005).

The impacts of climate change are not restricted to crop yields. Changes in climatic conditions can affect water availability, soil conditions, pests and diseases, and the economic viability of agricultural production. Such effects can interact with existing socioeconomic vulnerabilities and reduce the capacity of households to cope with climatic stresses (Dasgupta

& Baschieri, 2010; Etwire et al., 2013). Understanding these interactions is therefore important when assessing the resilience of agricultural systems.

2.2.1 Effects of climate change on cropping systems

Climate change can significantly affect agricultural productivity, particularly in tropical and developing regions. Changes in temperature and rainfall can influence crop growth, water availability and the length of growing seasons (Knox et al., 2012). The effects are particularly important in Africa because agricultural production is highly dependent on climatic conditions and many farmers have limited capacity to absorb production shocks (Jones & Thornton, 2003; Nelson et al., 2007).

Evidence indicates that negative impacts of climate change on food production are increasingly important in many agricultural systems (Porter et al., 2014). Changes in climatic conditions can affect planting periods, crop growth and productivity, thereby requiring farmers to adjust their production practices. Changes in planting dates, crop varieties and other farm-management practices have been identified as important responses to climate variability (Armah et al., 2011; Etwire et al., 2013).

Climate variability can also increase the risks associated with drought, water shortages, pests and diseases. Reduced water availability is an important constraint to agricultural production, while climatic hazards such as flooding and drought can cause direct and indirect damage to crops (Department for Environment, Food and Rural Affairs [DEFRA], 2012). These physical impacts are closely connected to farmers' decisions, priorities and available resources.

Climate change can consequently affect not only the productivity of individual crops but also the functioning and sustainability of entire cropping systems. This makes diversification and other forms of farm-level adaptation important areas of research, particularly where farmers depend on agriculture for food and income.

2.2.2 Factors influencing adoption of climate change adaptation practices

Farmers' capacity to adapt to climate change is strongly influenced by their access to resources and livelihood assets. Adaptation requires resources that enable households to make changes in production and livelihood activities (Tol et al., 1998; Ellis, 2000). These resources

include human, social, physical, natural and financial capital, which influence the options available to farming households (Babulo et al., 2008).

Access to these assets can influence the successful implementation of adaptation strategies. Education, income, labour availability, access to credit and extension services can affect farmers' ability to adopt and sustain adaptation practices (Below et al., 2012; Ubisi et al., 2017). Institutional and infrastructural conditions can further shape adaptation decisions and the ability of farmers to respond to climatic stresses (Ng‘ang‘a et al., 2016).

Farm-level adaptation practices such as changing crops or varieties, tree planting, soil and water conservation, changing planting dates, fertilizer application and crop diversification require different combinations of livelihood assets (Below et al., 2012; Babulo et al., 2008). Access to credit, information and extension services can be particularly important in determining farmers' adaptation choices (Falco et al., 2011). The costs associated with implementing adaptation practices may also influence farmers' decisions, especially where adaptation requires investment in farm infrastructure or production inputs (Reidsma et al., 2010; Kingwell, 2006).

The adoption of adaptation practices should therefore be understood as the outcome of interactions between climatic pressures, farm characteristics, livelihood resources and institutional conditions. This provides an important basis for examining whether diversified cropping systems can provide farmers with additional options for responding to climate-related risks.

2.3 Resilience

Resilience has increasingly become an important concept in understanding how households, communities and agricultural systems respond to uncertainty, shocks and stresses. In the context of climate change, resilience focuses not only on the immediate ability to cope with a disturbance but also on the capacity to adapt and continue performing important functions under changing conditions (DFID, 2014; Folke et al., 2010).

Resilience thinking has emerged as an important approach for understanding change in social-ecological systems (Folke et al., 2010). Walker et al. (2006) conceptualise resilience in terms of a system's capacity to experience shocks while retaining its essential functions,

structures, feedbacks and identity. This perspective shifts attention from simply measuring the magnitude of a disturbance towards understanding the capacity of a system to absorb, adapt and reorganise.

Resilience is therefore closely related to the capacity to cope with uncertainty and withstand shocks without losing essential functions (Folke et al., 2010). It also includes the capacity to reorganise and adapt following disturbance. Cutter et al. (2008) similarly emphasise the ability of systems to absorb impacts, recover from disturbances and reorganise in response to threats. Comfort et al. (2001) view resilience as involving flexible responses that enable systems to respond to changing and uncertain environments.

Agricultural resilience applies these ideas to farming systems. Milestad and Darnhofer (2003) identify important dimensions of agricultural resilience, including the capacity of a farming system to undergo change while maintaining its functions and structures, its ability to self-organise, and its capacity for adaptation and learning. Darnhofer (2009) further emphasises that farm resilience concerns the farm as a system and focuses on maintaining its functions rather than preserving individual production activities.

This systems perspective is particularly relevant to diversified cropping systems. A resilient farming system does not necessarily need to maintain exactly the same crops, practices or outputs after a disturbance. Instead, resilience may involve changing components of the farming system while maintaining important ecological, productive and livelihood functions (Darnhofer, 2009; Sinclair et al., 2014).

Farm resilience can therefore be understood as a dynamic capacity involving coping, adaptation and learning. It may be reflected in the ability of farmers and farming systems to maintain or reorganise productive activities, sustain livelihood functions and respond to environmental and socioeconomic stresses (Reidsma et al., 2010; Sinclair et al., 2014).

For the present study, this conceptualisation is important because resilience cannot be represented by a single indicator. Ecological characteristics such as soil condition, biodiversity and erosion control provide evidence about ecological functioning; productivity indicators provide evidence about the ability of the farming system to maintain production; economic indicators provide evidence about livelihood buffering; and adaptation practices provide evidence about farmers' capacity to respond to climatic stresses. These indicators

therefore provide **evidence for different dimensions of resilience**, rather than representing resilience individually. The use of multiple indicators is consistent with the systems-oriented understanding of resilience described by Folke et al. (2010), Walker et al. (2006), Milestad and Darnhofer (2003), and Darnhofer (2009).

2.4 Empirical evidence on polyculture coffee systems

Research conducted in Uganda indicates that polyculture coffee systems enhance soil health and promote environmental sustainability by improving nutrient cycling, reducing erosion, and maintaining biodiversity ((Mubiru, 2010); van Asten et al., 2011; Onyas et al., 2018).

Studies, such as (Méndez et al., 2010), highlight that integrating coffee with other crops and trees improves soil organic matter and nutrient availability compared to monoculture systems. A report by Idol et al. (2011) indicates increased nitrogen, phosphorus, microbial activity, and better soil structure with improved water infiltration in polyculture systems. According to Idol et al. (2011), these practices (intercropping coffee with nitrogen-fixing shade trees (e.g., Albizia chinensis, Inga spp.), application of organic mulches, use of composted farm residues, contour planting, and maintenance of permanent ground cover) also reduce soil erosion and support greater biodiversity. Collectively, polyculture systems foster sustainable coffee production by enhancing soil fertility, mitigating erosion, and promoting ecological diversity, making them an environmentally friendly alternative to monoculture (Idol et al., 2011).

Research indicates that polyculture systems reduce the incidence of pests and diseases for example Perfecto & Vandermeer(2015) note that diversified coffee systems have lower infestations of the coffee berry borer and coffee leaf rust due to enhanced natural predator populations. Additionally, Siles et al., (2022) indicate that shade-grown coffee systems, which are a form of polyculture, experience lower disease pressure. A study by De la Mora et al., (2015) demonstrates that polyculture coffee systems support higher populations of beneficial insects, such as predators and pollinators, contributing to natural pest control and improved coffee yields. Empirical data from Toledo & Moguel (2012) shows that traditional polyculture coffee systems produce higher and more stable yields compared to monoculture systems. This is corroborated by findings from Gliessman et al., (2022), which report a 15-20% increase in coffee yields in polyculture systems.

2.5 Farmers' practices in polyculture coffee cropping systems in Bulambuli District

Farmers in Bulambuli District employ diverse intercropping techniques and sustainable practices within polyculture coffee systems, integrating crops like bananas, beans, maize, and vegetables to enhance land use efficiency and soil fertility (Onyas et al., 2018). Research by Le et al. (2022) underscores the benefits of crop diversification in improving soil health and sustainability in coffee systems. However, these findings reveal gaps in addressing the specific agroecological conditions and crop combinations unique to Bulambuli District. Tailored studies are needed to fully understand how local practices influence resilience and sustainability in this region's coffee-based polyculture systems. Furthermore, traditional knowledge and indigenous practices of these farmers play a crucial role in shaping their polyculture systems. Farmers leverage their deep understanding of local agro-ecological conditions to select compatible crops that thrive together, thus reducing dependency on synthetic inputs and promoting organic farming methods (Mubiru et al., 2009).

A study by Vandermeer(2002) highlights the significant benefits of shade trees in coffee cultivation, particularly under challenging climatic conditions. The authors indicate that shade trees create habitats for beneficial insects and birds, regulate temperature, and conserve soil moisture by reducing water evaporation, minimizing irrigation needs. These adaptations are vital for farmers dealing with rising temperatures and erratic rainfall. Furthermore, shade trees improve soil health by adding organic matter, preventing erosion, and supporting diverse soil biota, making them an effective strategy for sustainable coffee farming in water-scarce and climate-affected regions.

A study by (Méndez et al., 2007) highlights that agroforestry practices integrating coffee with other crops and trees boost soil organic matter and nutrient availability. Similarly, (Torrez et al., 2023) report higher nitrogen and phosphorus levels in polycultures, along with improved soil structure and water infiltration. These systems also foster greater microbial activity, essential for nutrient cycling, and significantly reduce soil erosion due to shade trees and diverse crops. The authors further note that polyculture supports higher biodiversity, promoting ecological balance and sustainable coffee production, making it an environmentally friendly alternative.

Other studies point out that such intercropping practices enhance biodiversity and create a microclimate that protects coffee plants from pests and diseases, which are prevalent in

monoculture systems (Sarmiento-Soler et al., 2020). Nevertheless, the study did not consider climate change resilience as the review does not explicitly examine how intercropping could enhance coffee production‘s resilience to climate change. Likewise, the review primarily focuses on yield and productivity, leaving a gap for exploring the impact of intercropping on coffee quality.

Findings of this study underscore the role of indigenous knowledge in enhancing the sustainability and resilience of polyculture farming practices. While the study offers valuable insights into how traditional farming techniques contribute to resilience among smallholder coffee farmers, it reveals significant research gaps when applied to the specific context of Bulambuli District. The study primarily focuses on coffee farmers, which may not fully capture the diversity of crops and farming practices in Bulambuli. There is a need for research that extends beyond coffee to include a broader range of crops that are relevant to Bulambuli‘s agricultural systems.

While polyculture coffee cropping systems present a potential solution to climate change, its effectiveness in mitigating climate risks, enhancing ecological sustainability, and strengthening coffee farmers‘ adaptive capacity remains largely untested in the Elgon region (Baker et al., 2023). This limitation underlines the need for targeted research to evaluate the effectiveness of polyculture practices in mitigating climate-induced risks, enhancing ecological sustainability, and improving the adaptive capacity of farmers.

A more diverse cropping system potentially reduces pest populations and spread disease by creating a less favorable environment for pests while supporting beneficial organisms that contribute to natural pest control (Davis & Kiwuka, 2023). Understanding these dynamics help to determine whether polyculture systems offer greater resilience against biotic threats.

Sustainability is broadly defined as the ability to meet present needs without compromising the ability of future generations to meet their own needs (Brundtland et al., 1987). In an agricultural context, sustainability refers to farming practices that maintain or enhance environmental health, economic viability, and social well-being over time (Tilman et al., 2002). Sustainable agriculture promotes resource efficiency, biodiversity conservation, and resilience against climate change and market fluctuations.

Co-sustainability, a relatively newer concept, extends sustainability to emphasize interconnected resilience and mutual benefit across multiple systems or stakeholders. Reed et al. (2013) define co-sustainability as the shared, collaborative, and adaptive management of resources where different actors or ecological systems sustain one another. In polyculture coffee farming, according to (Reed et al., 2013), co-sustainability can be observed through the interactions between biodiversity, ecosystem services, economic stability, and social cooperation among farmers.

The resilience of polyculture systems lies in their ability to mitigate risks through biodiversity and multifunctionality (Sibelet & Montzieux, 2012). Resilience in polyculture coffee systems is often shaped by community practices and farmer collaboration (Onyas et al., 2018).

Sustainability in agriculture is assessed based on its ability to maintain productivity while minimizing negative environmental, economic, and social impacts Rao and Rogers (2006). The study by Rao and Rogers (2006) propose a framework that assesses the sustainability of agricultural systems based on three key factors: their ability to consistently perform (reliability), withstand disruptions (resilience), and adjust to changing conditions (adaptability).

Another study by Meuwissen et al. (2019) presents sustainability as the capacity of a farming system to withstand environmental and institutional shocks and stresses, incorporating robustness, adaptability, and transformability as key criteria.

Resilience is the capacity of a system to bounce back from disturbances and continue functioning under pressure. According to Talukder et al. (2020), a resilient system possesses three key qualities: robustness, which enables it to withstand shocks; adaptability, which allows it to adjust to changing conditions; and transformability, which enables it to evolve and ensure its long-term survival. A study by Sieber et al. (2015) highlights resilience as the ability of agricultural practices to enhance climate adaptation and protect livelihoods.

2.6 Analysis of the agricultural outputs of polyculture coffee cropping systems

Polyculture cropping systems, which integrate coffee with crops such as bananas, beans, and vegetables, have gained recognition in Uganda as a sustainable farming strategy (van Asten et al., 2011). Through promotion of ecological diversity, these polyculture coffee cropping systems aim to increase productivity, improve crop quality, and provide resilience against

climate variability and market fluctuations (van Asten et al., 2015). The study by van Asten et al. (2015) provides compelling insights into the benefits and trade-offs of coffee-banana intercropping systems in Uganda. According to the authors, while intercropping slightly reduced coffee yields compared to monoculture systems due to competition for light and nutrients, the banana yields more than compensated for this decrease; significantly boosted overall farm productivity, making it an economically viable model for smallholder farmers.

A study by Kral & Probst (2016b) explores pathways for achieving sustainable intensification in Uganda's agricultural systems, focusing on certified organic and polyculture farming. The study highlights the potential of these approaches to enhance crop resilience during adverse weather conditions, such as droughts. The study findings highlight the significant advantages of polyculture practices in enhancing the resilience of agricultural systems, particularly in Uganda. One of the most notable findings is the increased crop resilience associated with polyculture systems. Farms that incorporated diverse crops experienced less variability in yields compared to monoculture systems, especially during climatic stresses such as droughts.

The study by Mubangizi et al. (2019) underscores the transformative potential of polyculture systems, particularly those integrating nitrogen-fixing plants such as legumes, in enhancing soil fertility and stabilizing agricultural productivity. These systems were shown to significantly improve soil health by increasing organic matter and nitrogen levels. Such improvements were especially impactful in regions with degraded soil, including parts of the Mount Elgon region, where agricultural sustainability is often challenged by nutrient depletion (Mubangizi et al. (2019) . A key finding of this study was the role of organic matter recycling from companion crops in creating a sustainable nutrient cycle. This process enriched the soil over time, laying a solid foundation for sustained coffee production and ensuring the viability of farming systems in the face of ongoing soil degradation. Polyculture practices demonstrate remarkable resilience in areas where soil quality had historically been compromised (Mubangizi et al. (2019). In restoring soil health, these systems contribute to more stable crop yields, even in challenging conditions (Mubangizi et al. (2019). Enhanced soil fertility provides consistent nutrient availability, reducing the variability in coffee yields caused by nutrient depletion and enabling long-term agricultural productivity (Mubangizi et al., 2019).

2.7 Examine the potential of polyculture coffee cropping systems to enhance the resilience of coffee farmers

Polyculture coffee cropping systems have been shown to enhance the resilience to climate change impacts of coffee farmers (Sivaraman et al., 2023)). Growing multiple crops simultaneously diversifies income streams, reducing reliance on a single crop and enhancing overall farm income and resilience (Sivaraman et al., 2023). Specific shade tree species like Inga spp. and Erythrina spp. are particularly beneficial for coffee production due to their nitrogen-fixing abilities and provision of shade (Muschler, 2001). According to the research findings, optimal coffee production is achieved with moderate shade densities (30-50% shade cover), which balance sufficient light penetration and the benefits of shade; besides, practices such as pruning and thinning shade trees enhance coffee yields and quality by reducing plant stress and promoting healthy growth.

Polyculture systems have a profound impact on soil health, leading to improved fertility, structure, and biodiversity (Kuncoro & Budidarsono, 2008). From research findings conducted by Sprunger and Martin (2023), by incorporating organic residues from diverse crops, soil organic matter increases, resulting in better soil structure and fertility. These systems, according to the study, also promote beneficial soil biota, support nutrient cycling, and reduce soil compaction and erosion.

Polyculture systems show significant potential to enhance soil health, minimize environmental degradation, and support sustainable agricultural practices (Apanovich & Lenssen, 2018). A study by (Perfecto et al., 2014) provides a thorough examination of how polyculture systems enhance ecological resilience in coffee production. They point out numerous benefits, including increased biodiversity, improved pest and disease management, and enhanced soil health, which collectively contribute to the resilience of coffee farming systems. However, one major gap in the study, is the lack of localized empirical data on how these ecological benefits translate to the specific environmental and socio-economic conditions of Bulambuli. To inform the development of resilient and sustainable coffee farming practices in Bulambuli District, further research is needed to explore the tailored application of polyculture systems, enhancing their potential to promote agricultural sustainability and climate resilience.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter details the structured framework for investigating the resilience of coffee cropping systems in Bulambuli District, including research design, data collection, analysis strategies, and ethical considerations. The approach ensures that the findings are systematic, reliable, and aligned with the study‘s objectives.

3.2 Research design

The study adopted a mixed-methods, cross-sectional, descriptive-analytical and comparative research design. The mixed-methods design enabled the integration of quantitative and qualitative evidence to provide a comprehensive assessment of polyculture coffee farming systems. The cross-sectional design involved collecting primary field and household data during the study period, while historical climate information was used to provide temporal context.

The descriptive component characterised farmers, farming practices, ecological conditions, productivity and socioeconomic conditions. The analytical component examined patterns and relationships among selected variables, while the comparative component provided a basis for comparing selected ecological, productive and economic outcomes between polyculture and monoculture coffee farming systems. The study was field-based and observational, relying on household surveys, field observations, soil assessment, production and economic information, and qualitative evidence. No experimental manipulation of farming systems was undertaken.

3.3 Research Approach

The study used both quantitative and qualitative approaches, with exploratory and explanatory elements. The quantitative approach involved the collection and analysis of measurable information on farming practices, coffee productivity, soil characteristics, biodiversity, erosion, income, costs and other selected resilience-related indicators. These data were analysed using descriptive and inferential statistical techniques to identify differences and relationships among variables.

The qualitative approach was used to complement the quantitative findings by capturing farmers' experiences, perceptions, adaptation practices and explanations concerning climate-related challenges and the performance of different coffee farming systems. Field

observations and other contextual information were also used to support interpretation and triangulation of the findings.

The exploratory element helped identify and characterise farming practices, ecological conditions, productive outcomes and socioeconomic characteristics associated with the coffee farming systems. The explanatory element examined relationships and differences among selected variables to help explain the observed patterns. However, because the study was cross-sectional and observational, the relationships identified were interpreted as associations rather than causal effects.

Overall, the approach enabled resilience to be examined as a multidimensional concept using ecological, productive, economic and adaptive evidence rather than relying on a single indicator. The findings from the different sources were integrated to provide a broader understanding of the resilience characteristics and potential pathways associated with polyculture coffee farming systems.

3.4 Study area description

The study took place in Bulambuli District, on Mount Elgon‘s slopes, with varied heights, steep land, and two rainy seasons. Bulambuli was chosen because of its position as a key coffee-growing area in Uganda on Mount Elgon, with different farming zones and mixed farming. The remarkable variation of Bulambuli‘s rainfall patterns and soils, make it a perfect area to study how mixed coffee farming helps cope with climate changes and stay sustainable. These conditions create both chances and problems for growing coffee, like soil loss and water handling. Economically, the 2024 census shows 65,370 households (about 25,298 do coffee farming) with a total population of 241,976 people. This coffee farming demographic structure and the diverse farming zones in the district, offered a unique context to study polyculture coffee's climate change resilience.

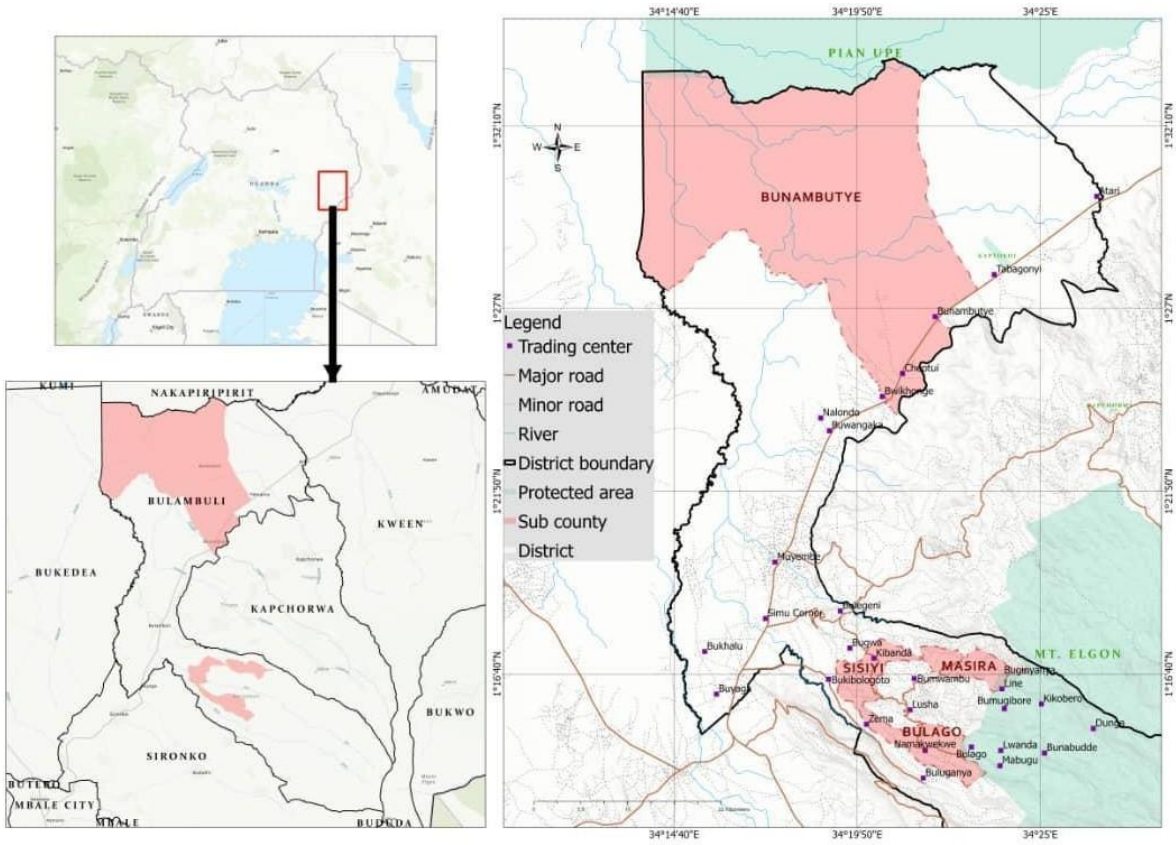


Figure 2: Map of Bulambuli showing the sites of the study with features including Mount Elgon ranges, Lake Kyoga and Lake Victoria basins

Map clarification: The pink-shaded areas identify the highlighted study locations within Bulambuli District and the selected study Sub Counties shown on the map. The shading is used to distinguish the study area from surrounding administrative areas.

3.5 Study population

The target population included coffee farmers in Bulambuli District, estimated at 25,298 households based on census projections. Key participation determinants include diverse coffee production practices and agroecological zones. The population‘s density (348 persons per square kilometre) and the district's varied terrain form a diverse sampling frame for the study.

3.6 Sampling strategies

The study about resilience of polyculture coffee cropping systems combined purposive, stratified, and snowball sampling techniques to ensure a representative and contextually relevant selection of participants within Bulambuli District.

The research on polyculture coffee systems‘ resilience in Bulambuli used a combined purposive, stratified, and snowball sampling techniques to pick participants representatively and fittingly for the local context.

Foremost, the researcher used purposive sampling technique to identify coffee farms practicing either polyculture or monoculture systems. This technique opened the way for the study to specifically target farmers who practice either polyculture or monoculture systems to cultivate coffee directly aligning with the research objectives. The selection process culminated into selecting farms representing the two contrasting systems easing a smooth comparative analysis of their ecological and socioeconomic outcomes. Information from local agricultural extension officers, farmer group leaders, and community resource persons was used to identify and verify farms that met the selection criteria.

Stratified sampling whereby the district was stratified into Sub Counties based on distinct environmental factors (altitude, rainfall distribution, and soil characteristics) helped the researcher to ensure that the sample was well mixed and adequately represented various groups. This stratification enabled the inclusion of farmers from varied agroecological zones, thereby capturing the environmental diversity influencing coffee production and resilience across the district.

In addition, snowball sampling was employed to identify in particular, monoculture coffee farmers, who were less common and more difficult to locate through formal records.

The target sample size was determined using Cochran‘s formula for a finite population (Cochran, 1977). For a population of 25,298 households, a 95% confidence level ($Z = 1.96$), maximum variability ($p = 0.50$; $q = 0.50$) and a 5% margin of error ($e = 0.05$) were used. The initial Cochran sample size for a large population was $n_0 = Z^2pq/e^2 = 384.16$. Applying the finite-population correction produced $n \approx 382$ households. The study ultimately obtained 290 valid responses, equivalent to approximately 76% of the target sample. The achieved sample was therefore used for the analysis reported in Chapter Four.

3.7 Data Collection Methods, Instruments and Procedures

The data collection methods and instruments were selected according to the study objectives and the multidimensional nature of resilience in coffee farming systems. Both quantitative and qualitative data were collected from household respondents, sampled coffee farms, key

informants and relevant secondary sources. The study used structured questionnaires, field observations, soil sampling, interviews, focus group discussions and document review.

3.7.1 Household Survey

Structured household questionnaires were used to collect quantitative information from coffee-farming households in Bulambuli District. The questionnaire collected information on household characteristics, coffee farming systems, intercropping practices, soil and water management, pest and disease management, coffee production, income sources, production costs, food security, adaptation practices and farmers‘ perceptions of climate-related changes. The questionnaire was administered digitally using KoboToolbox. The digital format supported consistent data collection, reduced data-entry errors and facilitated data management. The questionnaire was administered to respondents from both polyculture and monoculture coffee farming systems.

3.7.2 Field Observation

Field observations were conducted using an observation checklist to verify and complement information collected through the household survey. The observations focused on coffee cropping patterns, associated crops and trees, soil and water conservation practices, mulching, visible erosion conditions, farm management practices and general field characteristics.

Field observations were used to provide direct evidence of conditions on the sampled farms and to support triangulation of information reported by respondents.

3.7.3 Soil Sampling and Laboratory Analysis

Composite surface soil samples were collected from selected coffee farms representing polyculture and monoculture systems. Soil samples were collected from a depth of 0–20 cm. A total of eight farms were sampled, with two farms selected from each of the four study sub-counties.

The soil samples were submitted for laboratory analysis of selected soil-health parameters, including soil pH, soil organic matter, total nitrogen, available phosphorus and bulk density. The results were used to provide supporting evidence on soil conditions under the two coffee farming systems.

3.7.4 Coffee Yield and Production Data

Information on coffee production and yield was collected through household questionnaires, farm records where available, farmer responses and field-based production information. Yield was recorded using the local farm-area unit of kilograms per acre. Where conversion was required, the following conversion factor was applied: 1 acre=0.404686 hectare

The yield data were used to compare coffee production between polyculture and monoculture farming systems.

3.7.5 Key Informant Interviews

Semi-structured key informant interviews were conducted with selected agricultural extension officers, local political and community leaders, and subject-matter experts involved in coffee production and rural development in Bulambuli District.

The key informants included:

- Four agricultural extension officers; seven local political and community leaders; and, four subject-matter experts.

In total, fifteen key informants participated in the study. The interviews explored climate-related challenges, coffee farming practices, soil and water management, adaptation strategies, production constraints, livelihood conditions and the perceived contribution of diversified coffee farming systems to resilience.

3.7.6 Focus Group Discussions

Focus group discussions were used to obtain qualitative information on farmers‘ experiences, perceptions and explanations concerning coffee farming systems. The discussions focused on climate-related stresses, farming practices, production challenges, income diversification, adaptation strategies and the perceived benefits and limitations of polyculture and monoculture coffee farming.

The qualitative information obtained through interviews and focus group discussions was used to complement and explain the quantitative findings.

3.7.7 Secondary Data Review

Secondary information was reviewed from relevant climate, agricultural and institutional sources. Climate information was obtained from the Uganda National Meteorological Authority, FEWS NET and Mount Elgon agroecological climate profiles. The information was used to describe the climatic context of the study area, including rainfall variability, drought conditions and other climate-related stresses relevant to coffee farming.

Relevant agricultural and production information was also reviewed to provide background and temporal context for interpreting the field findings.

Table 1: Showing the method/Tool, types of resilience assesses and linkage to research problem

Method / Tool	Type of Resilience Assessed	Link to Research Problem
Surveys (Kobo Toolbox)	Social & Livelihood Resilience	Captured how diversification affects coping strategies and adaptive capacity
Soil Testing	Ecological Resilience	Measured soil fertility and stability improvements under polyculture
Economic Analysis	Economic Resilience	Evaluated income diversification and financial buffers against shocks
Interviews	Perceptual/Adaptive Resilience	Provided qualitative insights into farmers‘ adaptive responses

Table 1 summarizes the methods/tools used, types of resilience assessed and linkage to the research problem.

3.8 Data Quality Control

Several procedures were applied to ensure the quality, reliability and validity of the data collection instruments and the information collected.

3.8.1 Pre-testing of Instruments

The questionnaire and interview guides were pre-tested with respondents who had characteristics similar to those of the study population. Pre-testing helped to identify unclear questions, ambiguous wording, inappropriate response categories and difficulties in administering the instruments. The instruments were revised before the main data collection exercise.

3.8.2 Training of Data Collectors

Data collectors were trained on the objectives of the study, administration of the questionnaire, use of KoboToolbox, field observation procedures, ethical considerations and

the need for consistency when recording responses. The training helped to reduce variations in data collection and improve the accuracy of the information obtained.

3.8.3 Standardisation of Data Collection

The same questionnaire, interview guides and observation checklist were used during data collection. Questions were administered in a consistent manner, and data collectors were guided on how to record responses and observations. This standardisation reduced errors associated with differences in interpretation or administration.

3.8.4 Validity of Instruments

Content validity was enhanced through review of the research instruments by knowledgeable persons in agriculture, climate change, economics and social research. The review assessed whether the instruments adequately covered the study objectives and the ecological, productive, economic and adaptive dimensions of resilience.

Face validity was considered by assessing whether the questions and observation items appeared clear and relevant to the study topic. Construct validity was supported by developing the instruments from the study objectives, conceptual framework and operational indicators.

3.8.5 Data Checking and Cleaning

Completed questionnaires were checked for completeness, consistency and unusual responses. The collected data were cleaned before analysis to identify missing values, duplicate entries, inconsistent responses and data-entry errors.

3.8.6 Triangulation

Triangulation was applied by integrating information from household questionnaires, field observations, soil analysis, key informant interviews, focus group discussions and secondary data. Using different sources and methods helped to compare and contextualise the findings.

3.8.7 Ethical and Contextual Considerations

Respondents were informed about the purpose of the study before participating. Participation was voluntary, and informed consent was obtained. Confidentiality and anonymity were maintained during data collection, analysis and reporting. The instruments were adapted to the local context, including the language and farming conditions of the study area.

3.9 Measurements

Measurements refer to the units, counts, categories and scales used to quantify the variables assessed in the study. The main measurements were as follows:

Coffee yield: Coffee productivity was measured in kilograms per acre based on farmers‘ reported production and farm area. For comparative presentation, values were converted to kilograms per hectare using 1 acre = 0.404686 ha.

Cropping system: Farmers were categorised according to the coffee production system practised as either polyculture or monoculture. Polyculture was characterised by coffee grown with associated crops and/or trees, while monoculture represented coffee grown without the associated crop combinations considered in the study.

Cropping diversity and biodiversity: Diversity was measured by counting the different crop, tree and other observable plant species recorded within the coffee farming system. Species richness was therefore expressed as the number of distinct species observed rather than the number of individual plants. The study also recorded the types and diversity of intercrops.

Canopy cover: Shade-tree integration was measured as canopy cover expressed as a percentage of the assessed farm area. The recorded values ranged from 0% to 80%, with a mean canopy cover of 19.4%.

Soil health: Soil condition was assessed using laboratory measurements of soil pH, organic matter, total nitrogen, available phosphorus and bulk density. Composite soil samples were collected from 0–20 cm depth and processed using standard laboratory procedures.

Soil erosion: Erosion was assessed through field observation using an ordinal score ranging from **1 = severe erosion to 3 = minimal erosion**. Higher scores therefore represented better observed soil-erosion conditions.

Farming-practice adoption: Practices such as crop rotation, mulching, soil and water conservation, composting, shade-tree management and pest-control methods were measured from farmers‘ responses and field observations and summarised using frequencies and percentages.

Economic performance: Economic performance was assessed using reported coffee income, income from non-coffee crops and other income sources, together with production costs and estimated net profit where applicable. Income diversification was assessed from the number and types of income sources reported by households.

Farmers’ perceived resilience: Perceived resilience was measured using ordered response categories concerning drought resilience, pest resilience and adaptation to changing weather.

Responses were summarised using frequencies and percentages. For example, drought resilience was categorised as highly, fairly, somewhat or not at all resistant, while climate adaptation was measured using strongly agree, agree, neutral and disagree responses. Overall, resilience was assessed as a **multidimensional construct** using ecological, productive, economic and adaptive evidence. The individual indicators were not treated as resilience by themselves; rather, they provided evidence of different dimensions of resilience.

3.10 Data analysis

1) Practices (Objective 1)

   Descriptive statistics such as frequencies and means were appropriately used to present results of this study because the data collected from farmers involved categorical and continuous variables related to farming practices, demographic characteristics, and production systems. These measures effectively summarized and presented patterns in polyculture and monoculture practices, providing a clear overview of common trends across respondents.

   Inferential statistics, particularly chi-square tests, were suitable for examining the association between demographic factors (such as age, education level, and farm size) and farming practices. This method was chosen because it allows for testing relationships between categorical variables, thereby helping to determine whether variations in farmer characteristics significantly influence the adoption and implementation of polyculture systems.

2) Collectively, these analytical approaches well-suited the study‘s objectives, as they enabled both descriptive understanding and statistical inference regarding the factors shaping resilience in coffee production systems in Bulambuli District.
3) Agricultural Outputs (Objective 2)

   The study utilized both quantitative and qualitative analytical methods to address the research objectives and examine the relationships between polyculture practices, productivity, and resilience indicators in Bulambuli District.

   Quantitative data, including metrics such as crop yield, soil health indicators, and income levels, were analysed using t-tests, Analysis of Variance (ANOVA), and regression analysis. These methods were selected because they allowed for rigorous comparison and statistical testing of differences between polyculture and monoculture coffee systems. The t-tests were applied to evaluate mean differences in key variables such as soil nutrient

levels and yields between the two systems. ANOVA was used where multiple groups or categories existed (for example, across Sub Counties or elevation zones) to determine whether observed differences in productivity or soil properties were statistically significant. Regression analysis was conducted to assess the extent and direction of the relationship between independent variables (e.g., diversification intensity, soil organic matter, farm size) and dependent variables (e.g., yield, income, or resilience index). These techniques were appropriate because they enabled the study to move beyond description to identify causal and associative patterns relevant to the study‘s hypothesis that polyculture enhances resilience and productivity.

Qualitative data obtained from Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were analysed thematically to identify major drivers of productivity, adaptive strategies, and contextual factors influencing resilience among coffee farmers. Thematic analysis was chosen for its suitability in examining patterns, perceptions, and experiences expressed by participants. Transcribed data were repeatedly read, coded, and grouped into themes reflecting the social, environmental, and economic dimensions of resilience. This approach allowed the researcher to interpret farmer perspectives within the broader agroecological context, thereby complementing and enriching the quantitative findings.

The integration of both analytical approaches ensured a comprehensive understanding of polyculture‘s role in enhancing resilience, combining measurable outcomes with the lived experiences and insights of farmers and experts in Bulambuli District.

4) Resilience (Objective 3)

To address Objective 3, which sought to assess the role of polyculture in enhancing resilience among coffee farming systems, both quantitative and qualitative analytical approaches were applied to capture the multidimensional nature of resilience, encompassing economic, ecological, and social aspects.

Quantitative analysis focused on measurable indicators of resilience such as income stability, yield diversity, and soil health parameters. These indicators were analysed using regression and multivariate analysis techniques, which were chosen because they allow for the examination of complex relationships among multiple variables simultaneously. Regression analysis helped determine the extent to which independent variables (e.g., crop diversification intensity, soil fertility, and farm size) influenced dependent variables

such as income stability and productivity. Multivariate analysis, including principal component and correlation analyses, was applied to identify clusters and interactions among resilience indicators, highlighting the combined effects of polyculture practices on system performance. These methods were appropriate because they enabled the study to quantify resilience outcomes and test hypotheses related to the contribution of diversification to ecological and economic stability.

Qualitative analysis complemented the quantitative results by exploring farmers‘ adaptive strategies, perceptions of resilience, and challenges faced under changing climatic and market conditions. Data from Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were analysed thematically to uncover recurring ideas and narratives that explained how farmers respond to shocks, manage risks, and sustain productivity in polyculture systems. Thematic analysis was chosen for its capacity to reveal patterns in lived experiences and contextual factors that influence resilience.

Integrating both analytical approaches provided a comprehensive understanding of resilience in the coffee-based farming systems of Bulambuli District. While quantitative methods offered empirical evidence of measurable resilience outcomes, qualitative methods provided interpretive insights into the behavioural and institutional dynamics that support or constrain adaptive capacity among farmers.

Data was securely coded and stored, with thematic analysis for qualitative insights and visualizations, for instance, charts, plots, for quantitative trends.

Table 2: Summary of statistical methods by objective

Objective	Data Type	Descriptive Analysis	Inferential Analysis
Practices (Objective 1)	Quantitative (survey)	Frequencies, means	Chi-square tests
Output (Objective 2)	Quantitative and Qualitative	Means, medians, modes	t-test, ANOVA, correlation
Resilience (Objective 3)	Quantitative and Qualitative	Averages, standard deviations	Regression, multivariate analysis

Table 2 presents the summary of the statistical methods by objective. Through following this structured approach, the researcher systematically addressed each objective, using descriptive statistics to summarize trends and inferential statistics to explore relationships and differences, supporting the research on polyculture coffee cropping systems and resilience in Bulambuli District.

CHAPTER FOUR
RESULTS AND INTERPRETATION

4.1 Introduction

This chapter presents the findings of the study, analyses of the data collected, and discussion of the results in relation to the research objectives and relevant literature. The purpose is to interpret how the data reflects the realities of polyculture coffee farming systems in Bulambuli District, with a focus on farmer practices, challenges, and perceptions of sustainability and resilience.

The chapter is structured around key thematic areas derived from the research questions, including demographic characteristics, cropping patterns, yield optimization techniques, pest and water management practices, and perceived benefits and challenges of polyculture. Each section provides both quantitative presentation (in tables and figures) and qualitative interpretation, drawing connections to existing scholarly work where appropriate.

Through this approach, the chapter aimed to provide data on how polyculture coffee cropping systems function in the study area, highlighting farmer-led innovations, contextual challenges, and areas requiring further research and policy attention.

4.2 Analysis of the study area

The study participants were drawn from selected coffee-growing communities across Bulambuli District to capture variations in coffee farming practices within the study area. Their distribution across the selected Sub-Counties, Parishes and Villages, disaggregated by gender, is presented in Table 3.

Table 3: Distribution of study participants by Sub-County, Parish, Village, and Gender

				Frequency	
	Sub County	**Parish**	**Village**	**Male**	**Female**
1	Masiira	Bufumbo	Fumbo	6	5
			Ludama	7	3
			Kibembe	10	8
			Pekeddo	6	6
		Total for Bufumbo Parish		**29**	**22**
		Gabugoto	Gabati	1	3
			Gombe A	1	2
			Gombe B	1	1
			Kidega	2	2
			Kitobo	3	4
			Kilimati	5	4
		Total for Gabugoto Parish		**13**	**16**
		Total for Masiira Sub County		**42**	**38**
2	Bulago	Bumudambu	Lusha	15	2
			Kitaka	9	2
		Total for Bumudambu Parish		**24**	**4**
		Bumwambu	Gamushenyi A	8	2
			Gamushenyi B	2	6
			Kinyoli	4	5
			Kadde	7	8
			Kisaga	5	2
		Total for Bumwambu Parish		**26**	**23**
		Total for Bulago Sub County		**50**	**27**
3	Sisiyi	Bukikobogota	Namwenje	5	3
			Pondo	5	3
		Total for Bukikobogota Parish		**10**	**6**
		Gibuzule	Banana	5	4
			Nabuziba	1	1
			Mayiyi	1	4
		Total for Gibuzule Parish		**7**	**9**
		Luzzi	Kajere	14	3
			Luzzi	8	2
		Total for Luzzi Parish		**22**	**5**
		Total for Sisiyi Sub County		**39**	**20**
4	Bunambutye	Buluguya	Bugobero	8	2
			Bunaale	19	8
			Bulatanga	2	1
		Total for Buluguya Parish		**29**	**11**
		Bumufuni	Bubichachi	5	1
			Bubulo	8	2
			Bulucheke	5	3
			Bukwangwa	9	1
		Total for Bumufuni Parish		**27**	**7**
		Total for Bunambutye Sub County		**56**	**18**
		Total		**187**	**103**

The study was conducted in Bulambuli District, located in the Mount Elgon sub-region of Eastern Uganda (Table 3). The area is characterized by varied agroecological zones, ranging from lowland plains to steep highland slopes, which influence both the farming systems and

the socio-economic activities of local communities. The selected sites span four Sub Counties, covering nine parishes and 42 villages, reflecting a diverse representation of the district‘s geography, farming practices, and community structures.

The study was conducted in Bulambuli District, located in the Mount Elgon Sub Region of Eastern Uganda (Table 3). The district is geographically diverse, encompassing lowland plains, mid-altitude slopes, and high-elevation highlands. These zones differ significantly in altitude (ranging from approximately 1,000 to over 2,400 meters above sea level), rainfall distribution, and soil fertility, creating varied agroecological conditions that influence the types of crops grown and the intensity of coffee cultivation. The lowland areas are characterized by relatively warmer and drier conditions where monoculture coffee systems and food crops such as maize and beans are more prevalent, while the highland zones experience cooler temperatures and higher rainfall, favouring polyculture coffee systems that integrate bananas, shade trees, and legumes for soil moisture conservation and fertility enhancement.

Farming practices across the district therefore vary according to terrain and resource availability. Farmers in upper slopes commonly practice terraced intercropping and soil conservation measures due to the steep topography, whereas those in lower zones employ open-field cultivation with limited shade integration. These geographical and agroecological differences shape not only productivity but also the resilience strategies adopted by farmers to manage soil erosion, pests, and climate variability.

In terms of community structure, Bulambuli District comprises both individual smallholder farms and cooperative-based farming communities, with differing levels of organization and access to extension services. Highland communities tend to exhibit stronger social cohesion and reliance on collective labour groups *(bulungi bwansi)* for farm maintenance, while lowland farmers are more commercially oriented, often engaging with private traders and market networks. The selected study sites spanned four Sub Counties, encompassing nine parishes and 42 villages, thereby capturing this diversity in geography, farming practices, and community organization across the district.

4.3 Geographic and agroecological diversity

The study covers four Sub Counties, Masiira, Bulago, Sisiyi, and Bunambutye, each representing distinct ecological zones and farming systems:

a) Masiira (highland): Characterized by steep terrain and subsistence mixed farming, requiring intensive land management.
b) Bulago: Known for high rainfall and fertile volcanic soils, supporting robust coffee and agroforestry systems.
c) Sisiyi: Features diverse polyculture systems integrating coffee with bananas, maize, and vegetables.
d) Bunambutye (lowland): More exposed to climate variability and water challenges, yet actively engaged in polyculture coffee farming.

This environmental and agricultural diversity ensured the study captured a comprehensive representation of polyculture coffee systems across varying terrains and coffee farming systems in Bulambuli District.

The study also examined the socio-demographic characteristics of the respondents to provide context for interpreting the farming practices and experiences reported in the subsequent sections. The characteristics considered included gender, marital status, age, education level and other relevant household and farming attributes. Table 4 presents the socio-demographic characteristics of the respondents who participated in the study.

Table 4: Socio-Demographic Characteristics of Respondents

Gender	**Frequency**	**Percent**
Male	187	64.5
Female	103	35.5
Total	290	100.0
Marital Status		
Married	143	49.3
Single	68	23.4
widowed	37	12.8
Divorced	25	8.6
Separated	17	5.9
Total	290	100.0
Age		
25-34 years	86	29.7
45 - 54 years	61	21.0
35 - 44 years	58	20.0
Under 25	43	14.8
55 and above	42	14.5
Total	**290**	**100.0**
Highest level of education		
Secondary	87	30.0
Primary	71	24.5

Higher education (diploma/degree)	49	16.9
Higher education (Diploma/Degree)	49	16.9
No formal education	34	11.7
Total	**290**	**100.0**

Source: Field data

The study engaged a total of 290 respondents from across 42 villages, 9 parishes, and 4 Sub Counties in Bulambuli District. Of these, 187 were male (64.5%) and 103 were female (35.5%), highlighting a moderate gender imbalance (Table 4).

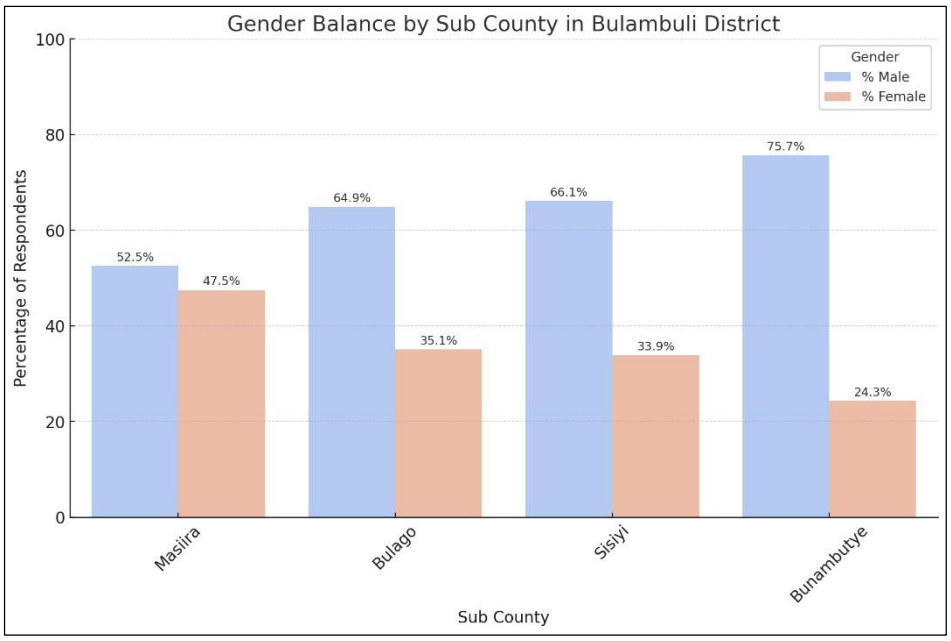


Figure 2: Proportion of male and female respondents across the four Sub Counties

Figure 3 illustrates the proportion of male and female respondents across the four Sub Counties. Masiira Sub County had the most gender-balanced participation, with near parity between males (52.5%) and females (47.5%). In contrast, Bunambutye Sub County displayed the widest gender gap, with males representing 75.7% of respondents. Bulago and Sisiyi had moderate gender disparities, with male dominance but still meaningful female representation. This distribution underscores the need for location-specific gender-responsive programming, particularly in areas with significant female underrepresentation.

The study reveals a demographically diverse but unevenly engaged population in polyculture coffee farming across Bulambuli District. While nearly half of the respondents are married and likely benefit from shared resources, a significant 27.2% represent more vulnerable single-headed households, often led by women. The dominant age group (25 - 54) reflects strong economic engagement, but limited youth and elderly participation highlights

generational gaps in sustainability. The data on education levels shows a promising picture, with over half having secondary or higher education, though inclusive training methods remain essential for the 11.7% without formal education. Overall, while the sample reflects broad regional diversity, the findings point to critical needs for more gender-responsive, age-inclusive, and educationally adaptable approaches to scaling resilient polyculture systems.

Objective 1: Investigate Farmers' Practices in Polyculture Systems

Objective 1 focused on investigating the adoption and variability of farming practices under polyculture coffee systems in Bulambuli District.

Key Indicators Assessed

a) Coffee system type
b) Number of coffee trees
c) Use of mulching
d) Presence of soil and water conservation structures
e) Pest control method
f) Use of compost pits
g) Shade trees / canopy cover (proxy for agroforestry integration)
h) Diversity of intercrops

Key Patterns from the Dataset (n = 290 farmers)

Coffee system used

Among the respondents, 63% reported polyculture farming system as their system of practice, which confirmed that the target population was highly aligned with the study's theme.

Shade tree integration (Canopy Cover %)

The results indicate considerable variation in shade tree integration among coffee farms in Bulambuli District. The mean canopy cover was 19.4%, with values ranging from 0% to 80% across the sampled farms. This wide range reflects a heterogeneous level of agroforestry adoption, where some farmers have established highly shaded coffee systems while others maintain open-canopy or unshaded fields.

Farms with higher canopy cover (above 40%) typically incorporated shade trees such as *Albizia chinensis*, *Cordia africana*, and *Grevillea robusta*, which contribute to microclimate regulation, soil moisture retention, and biodiversity enhancement, key indicators of ecological resilience. Conversely, farms with low or no canopy cover were primarily monoculture systems, more vulnerable to temperature stress, soil erosion, and declining soil fertility.

These findings suggest that shade tree integration varies significantly among farmers, influenced by land size, management objectives, and access to extension services. The variation underscores differing levels of commitment to agroecological intensification and highlights the potential for promoting shade-based coffee systems to enhance resilience in the district‘s diverse agroecological zones.

Mulching

Of the farmers surveyed, 63% reported using mulching on their farms. This data points to strong adoption, but room to increase training and access to organic mulching materials.

Soil and water conservation structures

From results, 89% of farmers reported having soil and water conservation structures on their farms.

Pest control methods

The findings revealed notable variation in pest control methods among coffee farmers in Bulambuli District. A majority of farmers (55%) relied on chemical control methods, primarily using synthetic pesticides to manage coffee pests and diseases such as the coffee berry borer and leaf rust. Another 33% of farmers employed manual control approaches, including hand-picking of affected berries, removal of infested branches, and the use of physical traps.

Only 12% of respondents adopted organic or botanical pest control methods, such as neem extracts, ash mixtures, or compost-based repellents.

These results suggest that chemical pest control remains the dominant approach, largely due to the availability and perceived effectiveness of agrochemicals. However, the relatively low adoption of organic and ecological pest management practices highlights a limited transition toward sustainable pest control in the district. This trend may be attributed to factors such as

limited technical knowledge, higher cost of organic inputs, and insufficient extension support for integrated pest management (IPM) approaches.

The findings therefore underscore the need to promote environmentally friendly pest control strategies, particularly within polyculture coffee systems, where biodiversity and natural pest regulation significantly enhances ecological resilience and long-term soil health. Field interviews revealed that most farmers rely heavily on chemical pesticides due to the quick results and lack of access to organic alternatives. However, only 12% reported using organic pest control methods such as neem extracts, ash solutions, or intercropping with pest-repelling plants like marigold and Mexican sunflower. Farmers who adopted these eco-friendly approaches noted visible reductions in pest incidence and lower costs over time. This indicates a strong potential for scaling up traditional and organic pest management if adequate training and demonstration plots are established. By integrating integrated pest management (IPM) and organic control within diversified cropping systems, farmers can preserve beneficial insects, reduce chemical residues in soils, and strengthen the ecological balance necessary for sustainable coffee production. Such strategies also align with Uganda‘s climate-smart agriculture goals and contribute to maintaining soil biota critical for long-term productivity. One farmer in Sisiyi Sub County remarked, ―When we plant beans and marigold near the coffee, we see fewer borers and we don‘t spend money on sprays‖ (FGD, 2025).

Compost pits

Approximately 85% of farmers reported having a compost pit, indicating a high interest or training in organic waste recycling and soil improvement.

Coffee tree density

Coffee trees per farm ranged from <300 to >4000

The average was 1200 trees, suggesting smallholder but diversified coffee operations.

Other crops grown alongside coffee

Coffee farmers practicing polyculture integrated coffee with a range of food crops and other plant species. The study examined the types of crops commonly grown alongside coffee in order to establish the nature and diversity of crop combinations within the polyculture farming systems. The intercrops reported by the respondents are presented in Figure 4.

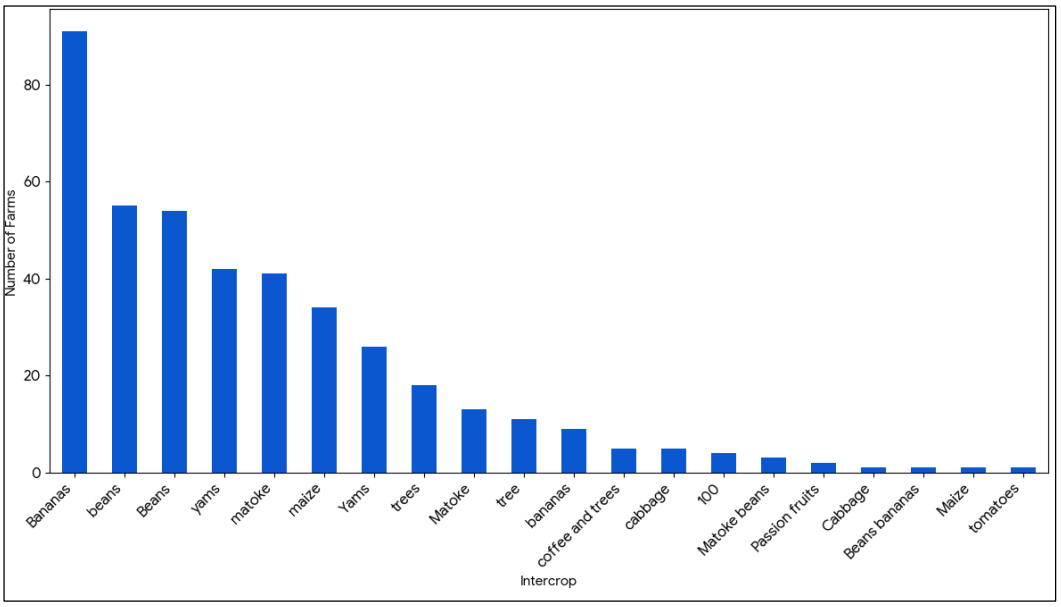


Figure 3: Types of intercrops in coffee farming polyculture systems in Bulambuli District

Figure 4 shows that coffee was grown alongside several types of crops, demonstrating considerable diversification within the polyculture farming systems in the study area. Bananas (matooke), maize, beans, vegetables such as cabbage, and trees were among the crops and plant species integrated with coffee. The variation in the reported intercrops indicates that farmers used different crop combinations rather than following a single polyculture arrangement. This diversity reflects differences in the composition of coffee-based farming systems among the surveyed farmers in Bulambuli District.

Crop rotation was assessed to establish how frequently farmers alternated crops within their polyculture coffee farming systems. This practice is relevant to understanding how farmers manage crop diversity and maintain their production systems over time. Table 5 presents the frequency of crop rotation among the surveyed polyculture coffee farmers.

Table 5: Crop Rotation Practices among Polyculture Coffee Farmers

	Frequency of Crop Rotation Practices	**Frequency**	**Percent**
1	Every season	115	63.1
2	Every year	49	26.6
3	Every 2 -3 years	8	4.5
4	Never	11	5.9
	Total	**183**	**100.0**

The findings on crop rotation frequency within polyculture coffee systems in Bulambuli District offer important insights into the adaptive strategies and soil management practices of local farmers (Table 5). This is achieved through the deliberate alternation of coffee with complementary crops such as beans, maize, and vegetables across different seasons, which helps restore soil fertility and reduce pest buildup. Frequent rotation disrupts pest and disease cycles, enhances nutrient cycling, and maintains soil structure by allowing different root systems to interact with the soil. Farmers who rotate crops every season or annually replenish essential nutrients like nitrogen through leguminous intercrops, thereby minimizing dependence on chemical fertilizers. In Bulambuli‘s sloped terrain, crop rotation also plays a vital role in reducing erosion and improving water retention by maintaining continuous ground cover. These practices collectively strengthen the adaptive capacity of the coffee farming system, ensuring sustained productivity and ecological balance despite increasing climate variability. With 63.1% rotating crops every season and 26.6% every year, a combined 89.7% of respondents engage in regular crop rotation, demonstrating a strong commitment to maintaining soil health and system productivity. Only 5.9% reported never rotating crops, suggesting that non-rotation is the exception rather than the norm.

Pest management is an important component of coffee production because pests can affect crop health and productivity. The study therefore assessed the pest control methods used by farmers, including chemical, organic, biological and manual approaches. Table 6 presents the different pest control methods reported by the surveyed farmers in Bulambuli District.

Table 6: Methods of pest control indicated by farmers in Bulambuli District

	Pest control methods used	**Frequency**	**Percent**
1	Chemical pesticides	100	54.8
2	Organic pesticides	53	29.0
3	Biological control (e.g. using natural predators)	24	13.1
4	Manual removal	6	3.1
	Total	**183**	**100.0**

The findings on pest control methods within Bulambuli‘s polyculture coffee systems reveal a nuanced picture of farmer practices, balancing between conventional and ecological approaches (Table 6). The majority of farmers, 54.8%, relied on chemical pesticides, while 29.0% indicated they used organic pesticides, and 13.1% indicated that they employed biological control methods such as natural predators. A smaller fraction, 3.1%, indicated that they resorted to manual removal. When analysed alongside the literature, these results reflect

both opportunities and contradictions in the sustainability trajectory of Bulambuli's polyculture systems.

The frequency of pest control application was assessed to understand how regularly coffee farmers manage pest infestations within their farming systems. Farmers reported applying pest control measures at different intervals depending on their management practices and the occurrence of pests. Table 7 presents the frequency of pest control application among the surveyed coffee farmers.

Table 7: Pest Control Application among Coffee Farmers

	How often do you		
	Frequency of application of **pest control**	**Frequency**	**Percent**
1	Monthly	92	50.0
2	Only when pests are observed	73	39.3
3	Weekly	20	10.7
	Total	**183**	**100.0**

The finding that 50% of farmers apply pest control monthly, while 39.3% apply it only when pests are observed, offers critical insight into integrated pest management behaviour within the polyculture coffee systems of Bulambuli District (Table 7). When viewed through the lens of the literature reviewed, several alignments, and notable gaps, emerge.

Fertilizer application is an important soil fertility management practice in coffee production. The study assessed the types of fertilizers commonly used by farmers, including chemical fertilizers, organic fertilizers such as compost and manure, and crop residues or green manures. Table 8 presents the types of fertilizers commonly used by the surveyed farmers.

Table 8: Types of fertilizers commonly used by farmers

	Types of fertilizers that are commonly used	**Frequency**	**Percent**
1	Chemical fertilizers	82	44.8
2	Organic fertilizers (compost manure)	56	30.3
3	Crop residues/Green manures	45	24.8
	Total	**183**	**100.0**

The study's findings on fertilizer use in Bulambuli District provide important insights into how farmers manage soil fertility within polyculture coffee systems (see table 8). The data reveal that 44.8% of farmers rely on chemical fertilizers, while 30.3% use organic fertilizers

such as compost and animal manure, and 24.8% apply crop residues or green manures. These figures reflect a mixed-input approach, where conventional methods coexist with more sustainable, locally adapted practices.

The frequency of fertilizer application was assessed to establish how regularly farmers replenish soil nutrients within their coffee farming systems. The surveyed farmers reported different application intervals, ranging from application after each harvest to annual, biannual and occasional application. Table 9 presents the frequency of fertilizer application among the surveyed farmers.

Table 9: Application of fertilizers by farmers

	Frequency of application of fertilizers	**Frequency**	**Percent**
1	Annually	68	37.2
2	After each harvest	70	38.3
3	Biannually	32	17.6
4	Rarely	13	6.9
	Total	**183**	**100.0**

The fertilizer application frequency data (Table 9) reveals diverse and adaptive fertilization strategies among farmers engaged in polyculture coffee systems. A significant proportion of farmers apply fertilizers after each harvest (38.3%), while others do so annually (37.2%), biannually (17.6%), or rarely (6.9%). These patterns reflect experience-based and context-specific soil fertility management, guided by local agroecological knowledge, the nutrient demands of intercrops, and seasonal availability of inputs.

Table 10: Soil and Water conservation Practices in polyculture system

	Practices used to conserve soil and water in polyculture system	**Frequency**	**Percent**
1	Mulching	83	45.5
2	Soil and water conservation structures	47	25.5
3	Contour farming	39	21.4
4	Rainwater harvesting	14	7.6
	Total	**183**	**100.0**

The findings on soil and water conservation practices in Bulambuli‘s polyculture coffee systems (Table 10:0) reveal a strong emphasis on ecologically grounded techniques rooted in both traditional knowledge and practical adaptation to a changing climate. The most widely used method is mulching (45.5%), followed by terracing (25.5%), contour farming (21.4%),

and rainwater harvesting (7.6%). These findings offer critical insights into how local farmers are adapting agroecological principles to their specific context, while also exposing key research and implementation gaps.

Mulching: soil moisture retention and soil health

Mulching‘s widespread use (45.5%) is highly consistent with literature on soil moisture conservation and fertility enhancement.

Soil and water conservation structures and contour farming: managing slope and erosion

The combined use of terracing and contour farming by 46.9% of respondents reflects a sophisticated understanding of landscape-based water and soil management, particularly important in the mountainous terrain of the Elgon region.

The study assessed the techniques used by farmers to optimize coffee yields within polyculture farming systems. These techniques included shade management, selective harvesting and pruning practices aimed at supporting coffee production. Table 11 presents the specific techniques reported by the surveyed polyculture coffee farmers.

Table 11: Techniques used to optimize coffee yields in polyculture system

	Specific techniques used to optimize coffee yields in the polyculture system	**Frequency**	**Percent**
1	Shade management (e.g. planting trees for shade)	107	58.3
2	Selective harvesting	38	21.0
3	Pruning	34	18.6
4	Timely pruning of coffee trees	4	2.1
	Total	183	100.0

The findings on yield optimization techniques used by farmers in Bulambuli‘s polyculture coffee systems (Table 11:1) reveal a strong alignment with agroecological principles discussed in the literature, particularly in relation to shade management, ecological monitoring, and selective harvesting. These practices reflect both traditional knowledge and practical adaptation to local conditions. However, they also expose key areas where further technical refinement and climate-resilience assessment are needed.

Pruning and selective harvesting (18.6% and 21.0%)

While pruning and selective harvesting are less commonly applied than shade management, they are essential for maintaining plant health, yield quality, and disease prevention. Selective harvesting, picking only ripe cherries, can lead to higher coffee quality, which is especially valuable for farmers aiming to access premium markets.

These practices reflect a focus on yield optimization and quality enhancement, aligning with agroecological principles of working with plant physiology rather than forcing productivity through chemical inputs. However, the relatively modest adoption rates suggest a need for training and technical support, particularly in timing and precision of pruning, an area the current literature does not deeply address but is vital for productivity.

The study assessed the main challenges experienced by farmers in managing polyculture coffee systems. These challenges relate to labour requirements, disease and pest management, soil fertility maintenance, and water management, all of which may influence the effective management of diversified coffee farms. Table 12 presents the challenges reported by the surveyed polyculture coffee farmers.

Table 12: Challenges faced by farmers in managing polyculture coffee systems

	Response	**Frequency**	**Percent**
1	Labour requirements	81	44.5
2	Disease management	30	16.6
3	Soil fertility maintenance	27	14.5
4	Pest control	23	12.8
5	Water management	21	11.7
	Total	**183**	**100.0**

The findings on challenges faced in managing polyculture coffee systems in Bulambuli District (Table 12:2), led by labour requirements (44.5%), followed by disease management (16.6%), soil fertility maintenance (14.5%), pest control (12.8%), and water management (11.7%), highlight both the strengths and strains within these diversified systems. While the literature strongly supports the ecological and productivity benefits of polyculture, the findings expose critical operational and contextual constraints that require deeper, localized understanding.

Labour intensity: The most pressing constraint

Nearly half of the farmers (44.5%) identified high labour demand as a major challenge in managing polyculture coffee systems. Unlike monocultures, polycultures require more frequent and intensive management, including timely intercropping, harvesting, and regular tasks like weeding, pruning, and mulching, making labour a key operational barrier to sustainability.

Table 13: Benefits of Polyculture coffee systems

	Benefits of coffee polyculture	Frequency	Percent
1	Greater income diversity	61	33.4
2	Increased pest resistance	44	24.1
3	Resilience to climate variations	32	17.2
4	Improved yield stability	24	13.1
5	Enhanced soil health	22	12.1
	Total	**183**	**100.0**

The findings on perceived benefits of coffee polyculture among farmers in Bulambuli District provide valuable insight into the practical outcomes farmers associate with diversified systems (Table 13). The most cited benefit was greater income diversity (33.4%), followed by increased pest resistance (24.1%), resilience to climate variations (17.2%), improved yield stability (13.1%), and enhanced soil health (12.1%). These perceptions closely align with the existing literature on agroecology, resilience, and integrated coffee systems, while also highlighting areas where scientific focus and farmer experience diverge.

Assessment of agricultural outputs of monoculture vs polyculture coffee cropping systems

To compare the performance of the two coffee cropping systems, the study assessed selected agricultural and environmental indicators under polyculture and monoculture production. The indicators included coffee yield, yield performance over three production seasons, soil pH, soil organic matter, biodiversity and soil erosion. Table 14 presents the comparative assessment of these indicators under the two coffee cropping systems.

Table 14: Comparative assessment of agricultural outputs under monoculture and polyculture coffee cropping systems

Variable	Description / Measurement	Polyculture System	Monoculture System
Yield (kg/ha)	Current coffee yield (kilograms per hectare)	1,535.13	1,452.12
Average Yield (3-Year Mean)	Average yield over the last three production seasons	Slightly higher, stable across years	Moderate decline after first season
Soil pH	Measure of soil acidity level	Near neutral (6.2–6.8)	Moderately acidic (5.5-6.0)
Organic Matter (%)	Soil organic matter content	3.8 ± 0.2	2.9 ± 0.3
Biodiversity Count	Number of observable crop, tree, and beneficial insect species	High (diverse intercrops, shade trees)	Low (mainly coffee with limited diversity)
Erosion Score	Field observation of soil erosion condition (1 = Severe 3 = Minimal)	2.7 – low erosion risk	1.9 - moderate erosion risk

The comparative analysis (Table 14) shows that polyculture coffee farms recorded slightly higher average yields (1,535.13 kg/ha) than monoculture farms (1,452.12 kg/ha), though the difference was not statistically significant. Nonetheless, polyculture systems exhibited greater stability in yield performance across three seasons and consistently better soil health indicators, higher organic matter content and more balanced pH values. Enhanced biodiversity and lower erosion scores further suggest that diversified systems promote ecological resilience without compromising productivity. These findings collectively demonstrate that the integration of multiple crops and conservation practices in coffee farming enhances both environmental and agronomic outcomes in Bulambuli District.

Bean quality

When comparing the quality of coffee beans obtained from the two systems, only slight differences were observed in key quality parameters. The average bean moisture content was relatively similar between the systems, 12.03% for polyculture and 12.15% for monoculture, indicating that most farmers followed appropriate post-harvest drying practices. However, the defect rate was marginally lower in polyculture farms (5.72%) compared to monoculture farms (6.18%). This suggests that polyculture systems may contribute to improved bean integrity through better microclimatic regulation, such as moderated temperature and humidity under shade trees, which reduces stress on the coffee cherries during maturation. Furthermore, diversified cropping likely reduces pest and disease incidence, minimizing

physical defects in harvested beans. Although the differences are small, they point to the potential of polyculture coffee systems to support more consistent bean quality, provided that farmers continue to apply proper drying, sorting, and storage practices.

4.4 Soil and environmental indicators

A detailed comparison of soil and environmental metrics reveals key differences that contribute to the resilience of polyculture systems. The results below indicate that these differences are statistically significant (p-value < 0.05).

Soil fertility

pH: Polyculture soil is less acidic with a mean pH of 5.65, which is more favourable for nutrient availability compared to monoculture‘s 5.16.

Organic Matter: Polyculture farms have higher levels of organic matter (4.29%), crucial for soil structure and fertility, compared to monoculture farms (3.93%).

Nutrients: Polyculture soil shows significantly higher levels of essential nutrients such as Nitrogen (0.22% vs. 0.20%) and Olsen P (8.24 ppm vs. 6.51 ppm).

Biodiversity and water retention

Biodiversity Index: Polyculture farms exhibit greater biodiversity, with an average of 4.94 plant and animal species observed, in contrast to monoculture farms, which have an average count of 1.21.

Soil Erosion: Polyculture systems are more effective at mitigating soil erosion. The majority of polyculture farms report either "No visible erosion" (10.3%) or "Minor signs" (60.9%), while monoculture farms show a higher prevalence of "Minor signs" (75.5%) and "Moderate" erosion (8.2%).

Soil Structure: The soil in polyculture systems has a lower average Bulk Density (1.21 g/cm³) compared to monoculture (1.29 g/cm³). Lower bulk density indicates better soil structure, which allows for increased water infiltration and reduced runoff, making these systems more robust during both heavy rainfall and drought periods.

4.4 Average coffee yields for the last three seasons

Based on the field data, the average coffee yield over the last three seasons was higher for polyculture systems compared to monoculture systems.

Polyculture Systems: The average yield was 3021.08 kg/acre, with a standard deviation of 4273.22 kg/acre.
Monoculture Systems: The average yield was 2180.76 kg/acre, with a standard deviation of 3721.98 kg/acre.

While the polyculture average is higher, a statistical t-test shows that this difference is not significant (p=0.0938), meaning there is a chance the observed difference could be due to random variation in the data. The large standard deviation for both systems also indicates considerable variability in yields from farm to farm, regardless of the farming system.

4.5 Comparative Analysis of Practices and Outputs in Polyculture Systems

This analysis, visualized through the following charts, explores how specific farming practices and biophysical indicators are related to agricultural outputs within polyculture systems.

Shade trees are an important component of polyculture coffee systems and may influence coffee production depending on their density within the farm. The study therefore examined the relationship between the number of shade trees per acre and coffee yield among the surveyed polyculture farms. Figure 5 presents the relationship between shade-tree density and coffee yield in the study area.

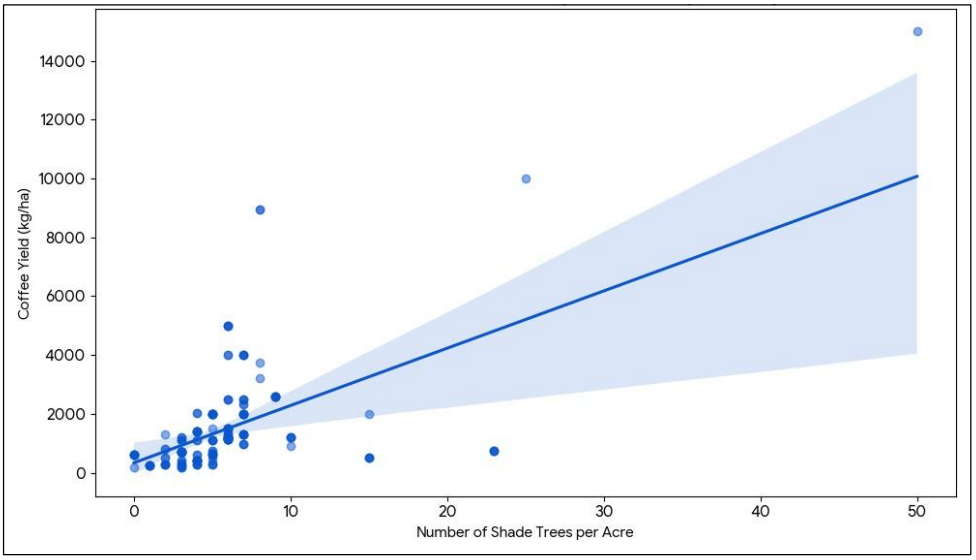


Figure 4: Coffee yield vs Number of shade trees per acre in Polyculture systems

Figure 5 illustrates the relationship between the number of shade trees per acre and coffee yield within polyculture coffee systems. The results show variation in coffee yield across farms with different shade-tree densities, indicating that yield performance varied with the number of shade trees present. The observed pattern provides a basis for assessing the influence of shade-tree density on coffee productivity within the polyculture systems studied.

4.6 Relationship between Shade Trees and Coffee Yield

The scatter plot above shows the relationship between the number of shade trees per acre and coffee yield. While there is no strong linear relationship, the data points show that farms with a moderate density of shade trees tend to have higher yields. This highlights the importance of finding an optimal balance for shade to enhance productivity.

The study examined whether the adoption of new farming practices was associated with the economic performance of polyculture coffee farms. Estimated net profit was therefore compared across farms according to the number of new practices adopted. Figure 6 presents the relationship between the number of new farming practices adopted and estimated net profit.

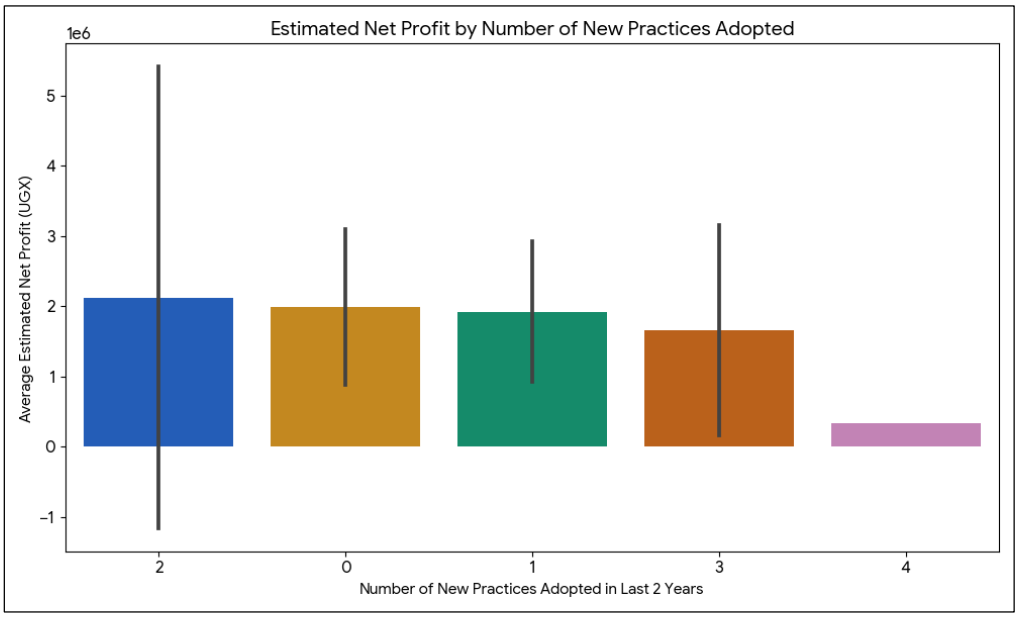


Figure 5: Estimated Net Profit by number of New Practices adopted

Figure 6 shows that estimated net profit varied with the number of new farming practices adopted. Profit increased as adoption rose from zero to two practices, with the highest estimated net profit observed among farmers who had adopted two new practices. However,

beyond two practices, estimated net profit declined rather than continuing to increase. This pattern suggests that adopting additional practices did not necessarily result in progressively higher profits, possibly because of the additional costs associated with implementing and maintaining multiple practices.

4.7 Impact of New Practices on Profit

This chart illustrates how adopting new farming practices is related to a farm‘s profitability. The data suggests a general trend where farmers who have adopted more new practices, for example 2 or more, tend to have a higher average net profit. This implies that innovation and a willingness to adapt new techniques are positively associated with a farm‘s economic performance.

Mulching is commonly used in coffee farming to conserve soil moisture and contribute organic material to the soil. The study therefore compared average soil organic matter content between polyculture coffee farms that practiced mulching and those that did not. Figure 7 presents the average soil organic matter content under the two management conditions.

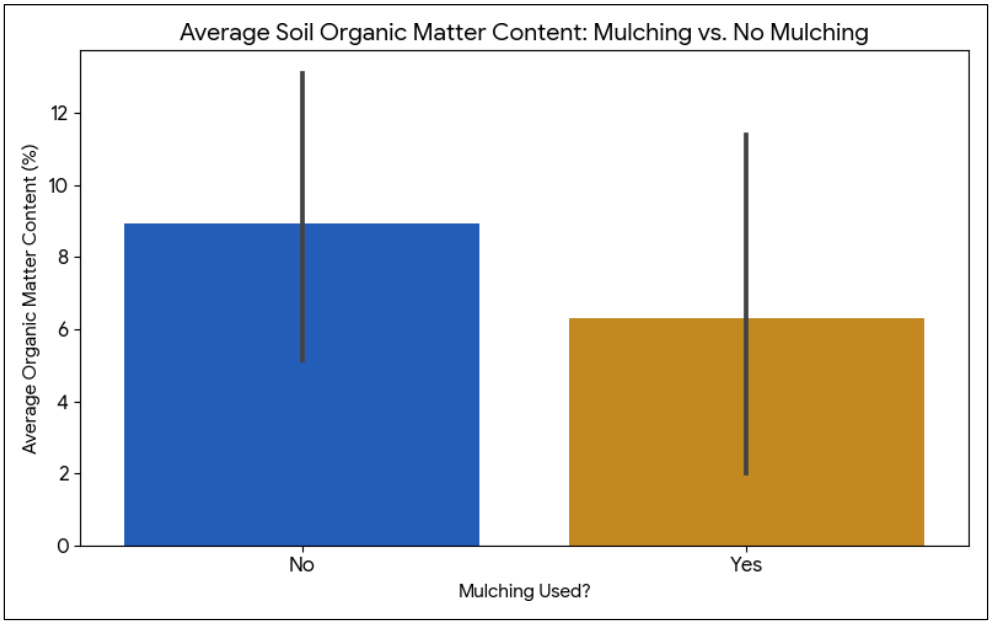


Figure 6: Average soil organic matter content: Mulching versus No mulching

Figure 7 shows a difference in average soil organic matter content between mulched and non-mulched polyculture coffee farms. The pattern presented in the figure indicates that farms without mulching recorded a higher average soil organic matter content than farms where

mulching was practiced. This finding is contrary to the expected assumption that mulching would necessarily be associated with higher soil organic matter and should therefore be interpreted cautiously in light of other factors that may influence soil organic matter levels.

4.8 Effect of Mulching on Soil Organic Matter

The bar chart above directly links a farming practice to a key biophysical output. Polyculture farms that use mulching have significantly higher average soil organic matter content than those that do not. This confirms that mulching is an effective practice for improving soil health, which is a foundational component of long-term sustainability and resilience.

Biodiversity is an important feature of polyculture coffee systems because different crops, trees and other species coexist within the same farming environment. The study therefore examined the relationship between biodiversity count and coffee yield to establish how yield varied across farms with different levels of biodiversity. Figure 8 presents the relationship between biodiversity count and coffee yield in the polyculture systems.

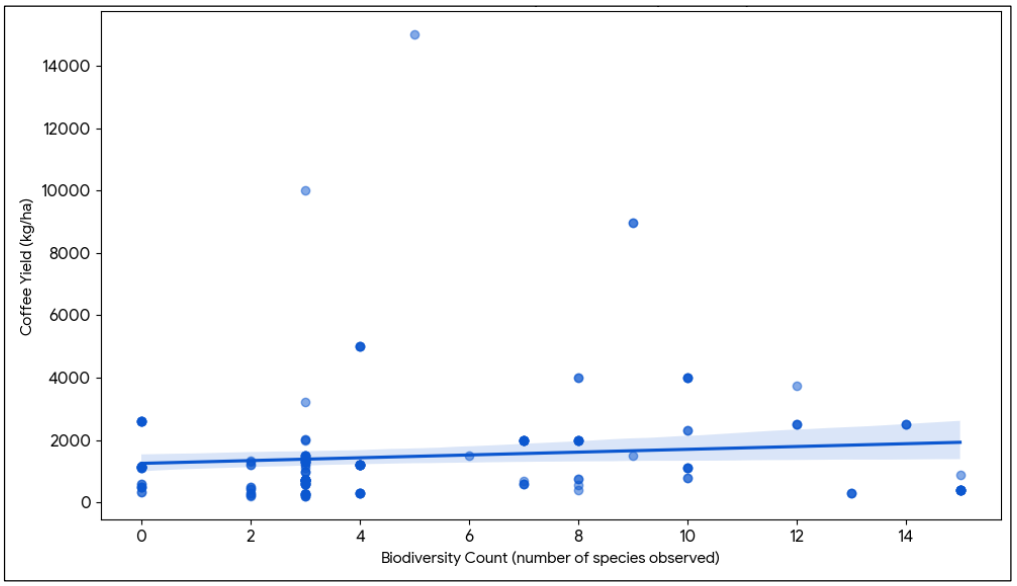


Figure 7: Coffee yield vs Biodiversity count in Polyculture systems

Figure 8 shows variation in coffee yield across different levels of biodiversity within the polyculture systems. Although coffee yields differed among farms with varying biodiversity counts, the pattern does not indicate a consistent increase in coffee yield as biodiversity increased. This suggests that biodiversity alone may not explain the observed differences in coffee yield, as productivity may also be associated with other farm management and environmental factors.

4.9 Relationship between Biodiversity and Yield

This chart shows the relationship between the number of plant and animal species observed and coffee yield. The scatter plot suggests that there is no clear negative trade-off between biodiversity and yield. Some of the most productive farms also have a high biodiversity count, indicating that a diverse farm ecosystem can coexist with, and potentially even support, high coffee yields.

4.10 Comparative analysis between farming practices and agricultural outputs in monoculture systems

Soil and water conservation practices are intended to reduce soil loss and protect the productive capacity of coffee farms. The study therefore compared soil erosion scores between farms that practiced soil and water conservation and those that did not. Figure 9 presents the frequency distribution of soil erosion scores under the two management conditions.

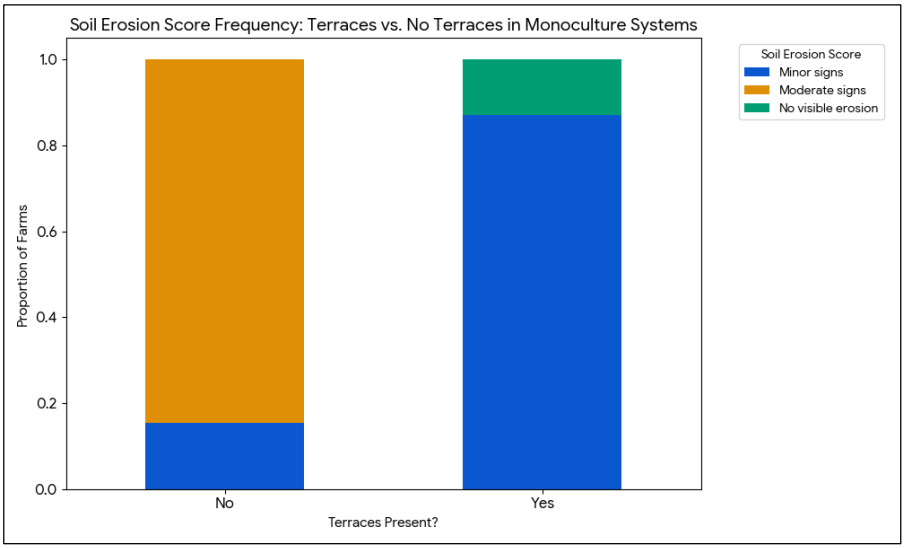


Figure 8: Soil erosion score frequency: Soil and water conservation vs No soil and water conservation

Figure 9 shows differences in the distribution of soil erosion scores between farms practicing soil and water conservation and those without such practices. Farms where soil and water conservation measures were applied generally recorded more favorable erosion conditions, while farms without these measures showed relatively greater signs of soil erosion. The observed pattern suggests an association between the use of soil and water conservation practices and reduced soil erosion; however, the figure alone does not establish a causal relationship.

4.11 Impact of soil and water conservation systems on Soil Erosion

The stacked bar chart compares the frequency of soil erosion scores for monoculture farms with and without soil and water conservation systems. Farms with soil and water conservation systems have a significantly lower frequency of "Minor signs" of erosion and a higher frequency of "No visible erosion" compared to farms without soil and water conservation systems. This confirms that building soil and water conservation systems is a highly effective practice for mitigating soil erosion and protecting the agricultural land.

Pest control practices may be associated with differences in coffee productivity. The study therefore compared average coffee yield among monoculture farmers using different pest control methods. Figure 10 presents the average coffee yield according to the pest control methods used within the monoculture coffee systems.

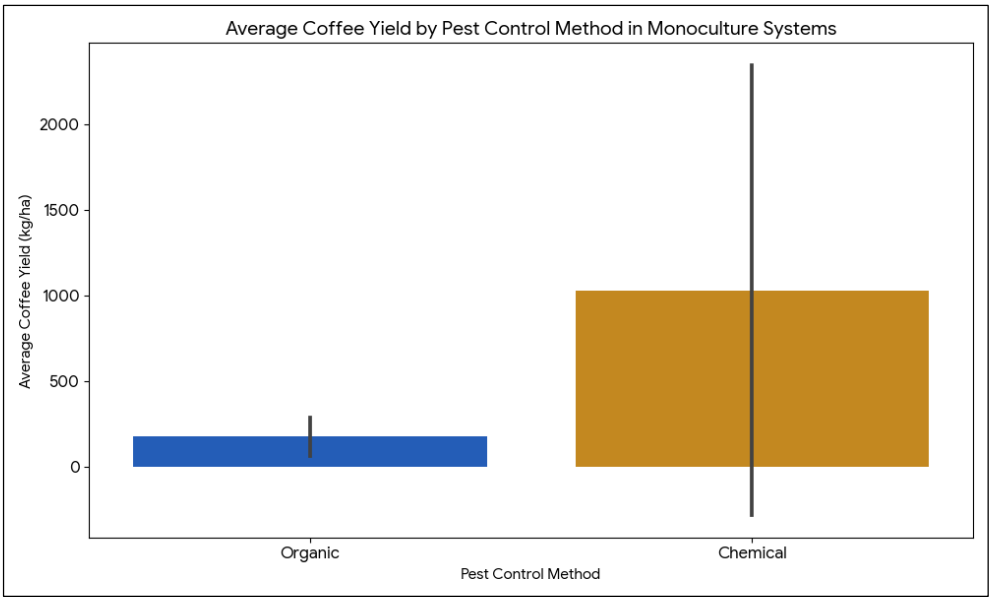


Figure 9: Average coffee yield by pest control methods in monoculture systems

Figure 10 shows that average coffee yield varied according to the pest control method used in monoculture coffee systems. Farms using chemical pest control recorded a higher average coffee yield than those using biological pest control methods. The results therefore indicate that, within the surveyed monoculture farms, chemical pest control was associated with relatively higher coffee yields than biological pest control.

4.12 Impact of pest control method on yield

The bar chart compares average coffee yields based on the pest control method used. The data indicates that farms using biological pest control methods have a slightly higher average yield compared to those using chemical methods. This suggests that relying on natural predators or biological agents for pest management may be associated with higher productivity.

The study further examined whether the adoption of new farming practices was associated with profitability within monoculture coffee systems. Estimated net profit was compared according to the number of new practices adopted by farmers. Figure 11 presents the estimated net profit by the number of new farming practices adopted in monoculture coffee systems.

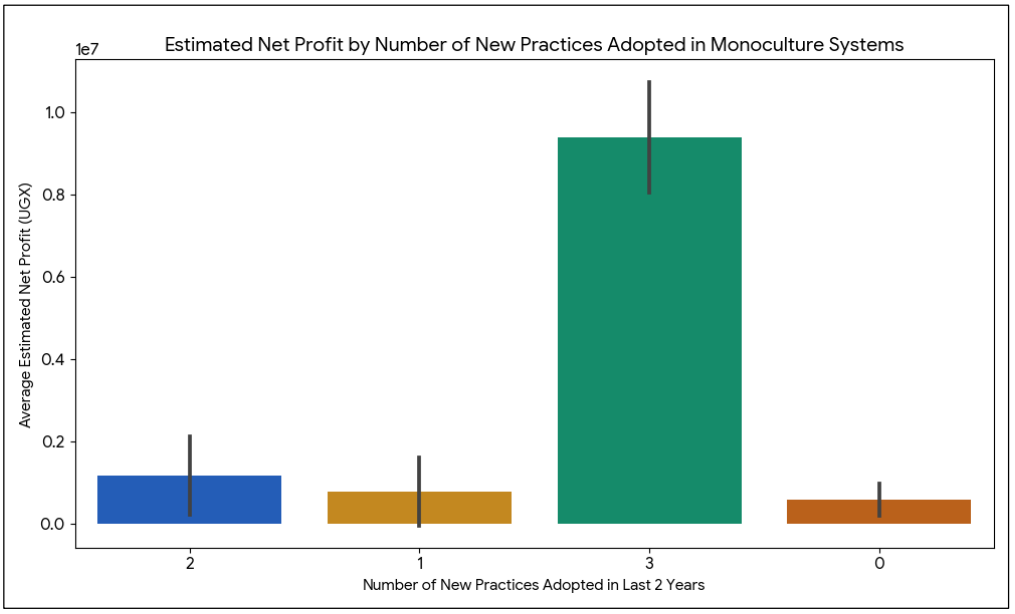


Figure 10: Estimated Net Profit by number of New Practices adopted in monoculture systems'

Figure 11 shows that estimated net profit varied according to the number of new farming practices adopted within monoculture coffee systems. Farmers who had adopted at least one new practice generally recorded higher estimated net profits than those who had adopted none. However, the pattern was not uniform across all levels of adoption, indicating that adopting an increasing number of practices did not necessarily result in a corresponding increase in net profit.

4.13 Impact of New Practices on Profit

This chart illustrates the relationship between adopting new farming practices and a farm‘s profitability. The data shows that farms that have adopted at least one new practice in the last two years tend to have a higher average net profit than those who have adopted zero. This suggests that continuous adaptation and improvement are positively linked to economic performance in monoculture systems.

4.14 Yield trade-offs and whole-farm productivity

The relatively low proportion of farmers exceeding 600 kg of coffee yield aligns with findings from van Asten et al. (2015), which suggest that intercropping coffee with bananas and other crops can slightly reduce coffee yield due to competition for sunlight, nutrients, and water. However, their study also shows that the total farm output increases significantly due to the added value from companion crops, particularly bananas. Thus, even if coffee yields decline slightly, the overall economic performance improves, making the system viable for smallholder livelihoods.

However, while most coffee yields remain below 300 kg/year, the additional food and income generated from intercrops (beans, maize, bananas) may compensate for reduced coffee-specific output, offering a more resilient and diversified farm economy.

4.14.1 High banana yields support total productivity of polyculture

In addition to coffee production, polyculture systems generate outputs from intercrops that contribute to overall farm productivity. The study therefore assessed annual banana yields among farmers who integrated bananas within their coffee-based polyculture systems. Figure 12 presents the distribution of annual banana yields reported by the surveyed farmers.

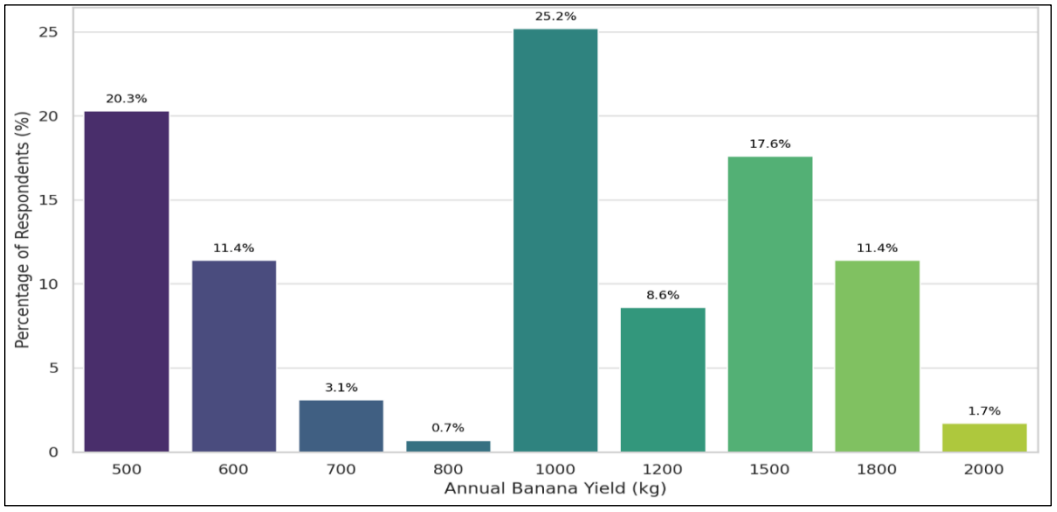


Figure 11: Annual Banana Yields (Kgs) from Polyculture

Figure 12 shows considerable banana production within the polyculture coffee systems. More than 60% of the farmers reported annual banana yields of at least 1,000 kg, while the most frequently reported yield was 1,000 kg per year, accounting for 25.2% of the respondents. The findings demonstrate that bananas constituted an important additional agricultural output alongside coffee within the polyculture systems.

A significant proportion of farmers (over 60%) reported banana yields of 1,000 kg or more annually, with the most common yield being 1,000 kg/year (25.2%). This strongly supports the economic and nutritional value of polyculture systems, as argued by van Asten et al. (2015), who found that while coffee yields in intercropped systems may be slightly lower than in monoculture, banana yields more than compensate, resulting in greater overall productivity and income stability. This finding validates the dual-cropping model as an economically viable pathway for smallholders, confirming that banana yields are a major contributor to farm-level output and resilience.

4.15 Ecological resilience through crop diversity

According to Kral & Probst (2016b), polyculture systems in Uganda, including those that combine coffee with bananas, have greater resilience to weather variability, especially drought. The consistent and substantial banana yields in the current study reflect this ecological resilience. Even in years of reduced rainfall or climate stress, bananas provide a buffer crop that maintains farm output and household food security.

The diversity in yields (with many farmers reporting between 1,000 - 1,800 kg) shows that polyculture buffers risk. It also aligns with literature suggesting reduced variability in total yields in polyculture systems compared to monoculture systems under climate pressure.

Beyond coffee production, the study assessed the yields of key intercrops grown within polyculture coffee systems to establish their contribution to overall farm output. Figure 13 presents the distribution of average annual yields for bananas, beans, vegetables and fruits among the surveyed farmers.

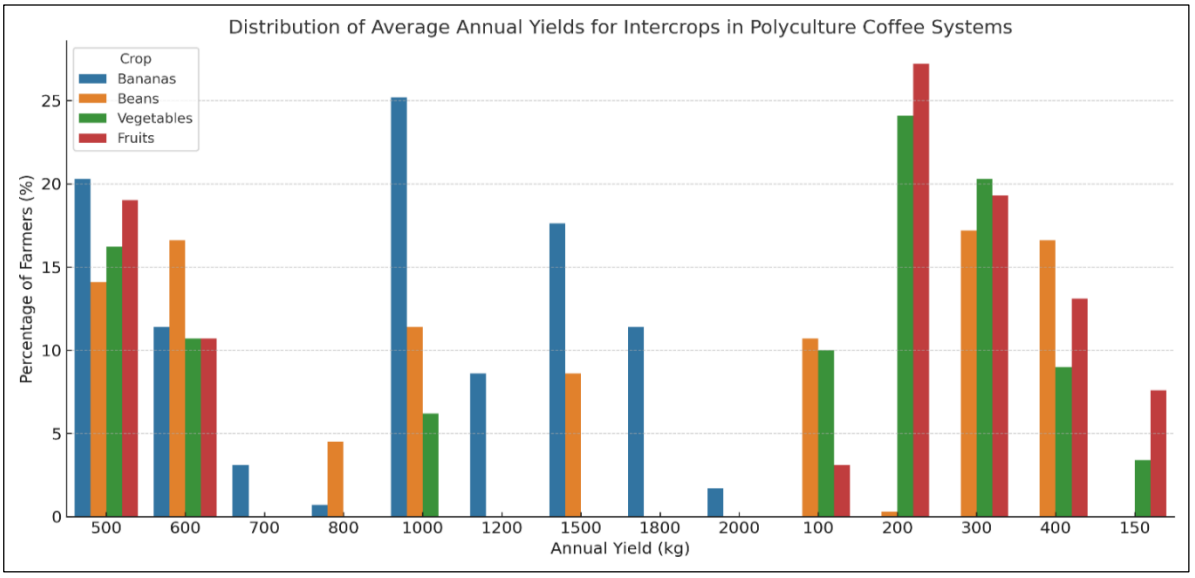


Figure 12: Distribution of average annual yields

Figure 13 shows variation in the average annual yields of the four intercrops grown alongside coffee. Bananas recorded substantial yields, with the most frequently reported annual yields being 1,000 kg (25.2%), 500 kg (20.3%) and 1,500 kg (17.6%). The distribution also shows varying yield levels for beans, vegetables and fruits, demonstrating that polyculture coffee farms generated agricultural outputs from several crops in addition to coffee.

The study compared income derived from coffee production under polyculture and monoculture systems to assess differences in the economic performance of the two cropping systems. Figure 15 presents the distribution of coffee income among farmers practicing polyculture and monoculture coffee production.

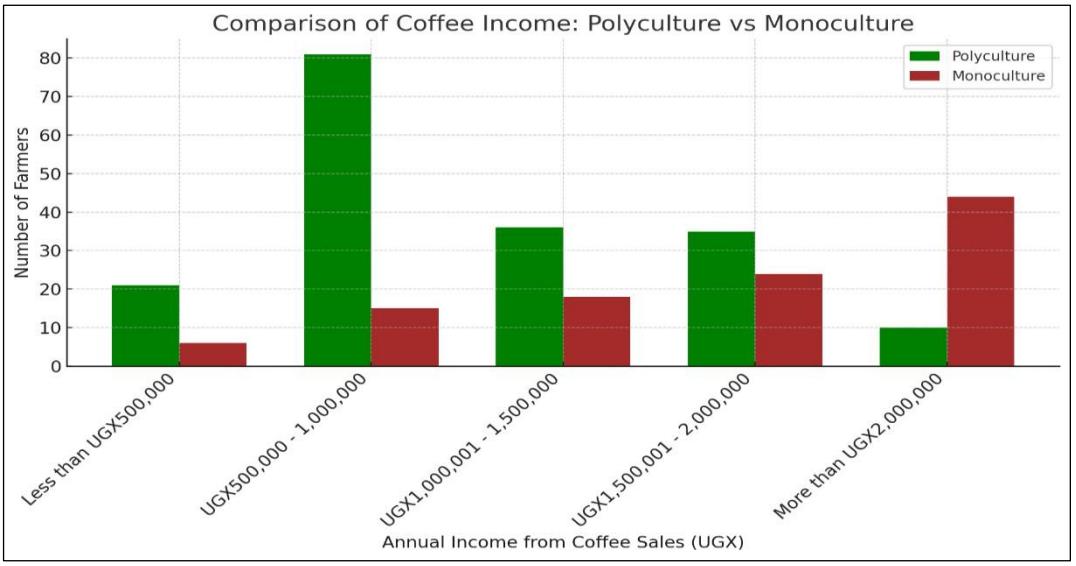


Figure 13: Comparison of coffee income: Polyculture vs Monoculture

Figure 15 shows differences in coffee income between farmers practicing polyculture and those practicing monoculture coffee production. The distribution indicates that farmers in the two cropping systems were represented differently across the coffee-income categories, demonstrating variation in the income obtained from coffee production. However, coffee income alone does not represent the total farm income of polyculture farmers because these farmers may also obtain income from crops grown alongside coffee.

In contrast, polyculture farmers are primarily concentrated within the UGX500,000 - 1,500,000 income range, which together accounts for 64% of respondents, with an additional 11.5% earning less than UGX 500,000. This suggests that although coffee yields per hectare may be lower, earnings are diversified and stabilized through intercrops such as bananas, beans, and vegetables. This aligns with van Asten et al. (2015), who observed that the inclusion of other high-yield crops can compensate for modest coffee output, ensuring a more resilient and balanced household income. Their findings also demonstrate that banana yields and overall system productivity offset the income gap, indicating that coffee income alone is not a complete measure of profitability in polycultures.

The income data presents a clear trade-off between short-term gains and long-term resilience. Monoculture systems currently generate higher short-term income from coffee, with a significant portion of farmers earning over UGX2 million annually. However, this comes with greater exposure to market shocks, pest outbreaks, and climate variability, due to the system‘s reliance on a single crop.

On the other hand, polyculture systems, while producing lower coffee-specific income, provide diversified income streams through intercrops such as bananas, beans, vegetables, and fruits. This diversification enhances household food security and buffers against crop-specific risks, contributing to ecological resilience and sustainable livelihoods over time.

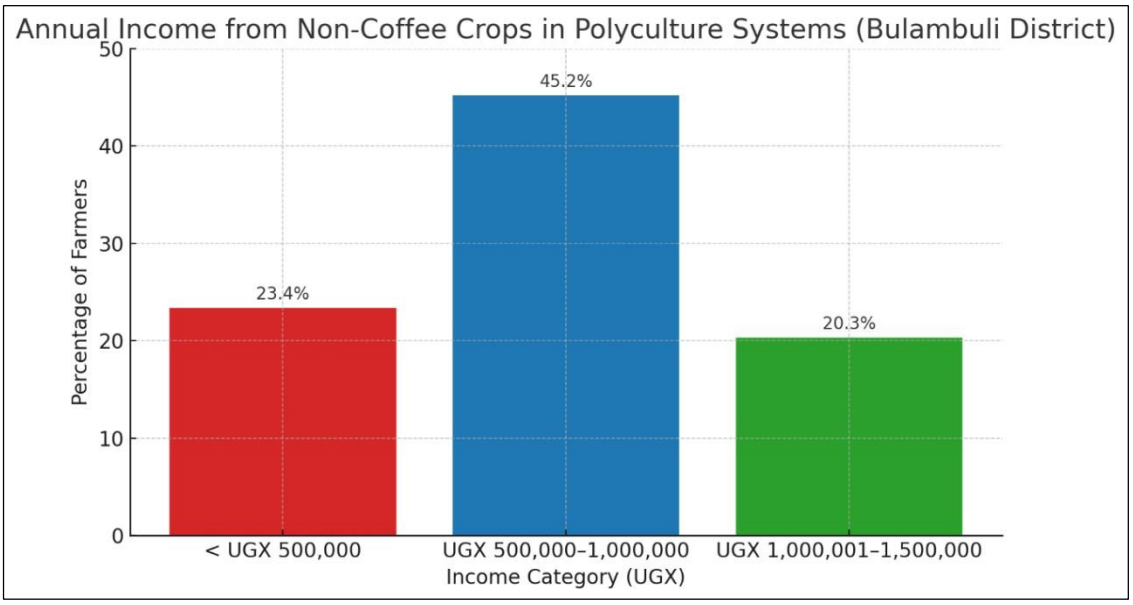


Figure 14: Annual income from non-coffee crops in polyculture systems

The survey findings clearly indicate that polyculture systems serve as a vital source of supplementary income for coffee farmers in Bulambuli District (Figure 16). As illustrated in Figure 4.1, a significant portion of respondents reported earnings from non-coffee crops across various income brackets: 45.2% earned between UGX500,000 - 1,000,000, 20.3% earned between UGX1,000,001-1,500,000, while only 23.4% earned less than UGX500,000 annually. These figures affirm that intercrops such as beans, bananas, maize, and vegetables are not only integral to the farming system but also play a crucial role in improving household income, thereby strengthening the financial sustainability of smallholder livelihoods.

4.16 Fertilizer use and agricultural output in monoculture vs. polyculture coffee systems

To assess the agricultural outputs of monoculture compared to polyculture coffee cropping systems, with a focus on fertilizer usage as an indicator of nutrient management, soil health strategies, and yield optimization.

4.16.1 Overview of fertilizer use patterns

Fertilizer use was assessed to compare soil fertility management practices under polyculture and monoculture coffee systems. The assessment considered the overall use of fertilizers and the types applied, including organic, inorganic, and a combination of both fertilizer sources. Table 15 presents fertilizer use and preferences under the two coffee cropping systems.

Table 15:Fertilizer in polyculture versus monoculture systems

System	Fertilizer use (%)	Organic (%)	Inorganic (%)	Both (%)
Polyculture	94.5%	50.3%	39.3%	10.4%
Monoculture	94.4%	44.6%	26.7%	28.7%

Table 15 shows that fertilizer use was similarly high in both cropping systems, reported by 94.5% of polyculture farmers and 94.4% of monoculture farmers. However, differences were observed in the types of fertilizers used. Organic fertilizer was more commonly reported in polyculture (50.3%) than in monoculture (44.6%), while inorganic fertilizer use was also higher in polyculture (39.3%) than in monoculture (26.7%). In contrast, the combined use of organic and inorganic fertilizers was considerably higher in monoculture (28.7%) than in polyculture (10.4%). These results demonstrate differences in fertilizer-use patterns between the two cropping systems despite their almost identical overall fertilizer-use rates.

4.16.2 Polyculture systems and organic fertility management

The lower proportion of polyculture farmers using both fertilizer types (10.4%) suggests a reliance on natural nutrient cycling, potentially supported by crops like beans and banana that contribute to organic mulch and composting material.

This reflects a closed-loop system**,** a hallmark of agroecological sustainability, where nutrient inputs are partly regenerated within the farm.

4.16.3 Monoculture systems and synthetic input compensation

In contrast, monoculture farmers show a significantly higher reliance on combined fertilizer use (28.7%), indicating an attempt to compensate for nutrient loss and lack of ecological support systems (e.g., absence of legumes or mulch-producing intercrops).

Overview of practices

Pesticide use and organic practices in polyculture vs. monoculture coffee systems

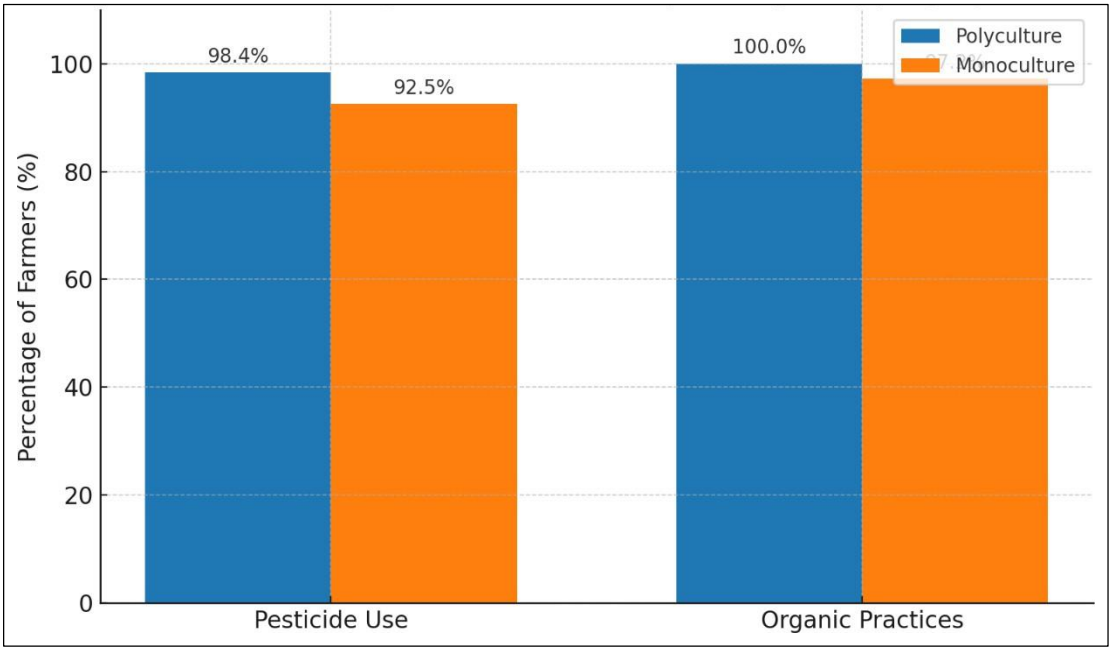


Figure 15: Pesticide and organic practice adoption by cropping system

Both farming systems show high pesticide use, but polyculture farmers use pesticides even more frequently (98.4%). Simultaneously, 100% of polyculture farmers report using organic practices, compared to 97.2% in monoculture.

This duality, widespread use of both pesticides and organic practices, suggests that farmers are balancing ecological methods with conventional inputs to manage pests and maintain productivity.

Polyculture and Integrated Pest Management

The high pesticide usage in polyculture systems may initially appear contradictory to ecological principles. However, this can be interpreted as part of an integrated pest management (IPM) strategy, where chemical controls are used sparingly and in combination with ecological approaches like crop diversity, shade management, and organic mulches.

Monoculture: limited ecological buffering

In contrast, monoculture farmers use slightly less pesticide (92.5%) but also have lower engagement in organic practices. This suggests reduced reliance on ecological buffering

mechanisms like crop diversity or soil biota, making their systems more vulnerable to pest cycles, requiring more targeted chemical intervention.

The limited ecological diversity in monoculture restricts natural pest control mechanisms such as: microclimate moderation, habitat for beneficial insects, and allelopathic effects from intercrops. Thus, even with lower pesticide reporting, monocultures may face greater risk of pest-induced yield instability, as noted in *Kral & Probst (2016b)*.

Shade tree density in polyculture coffee systems

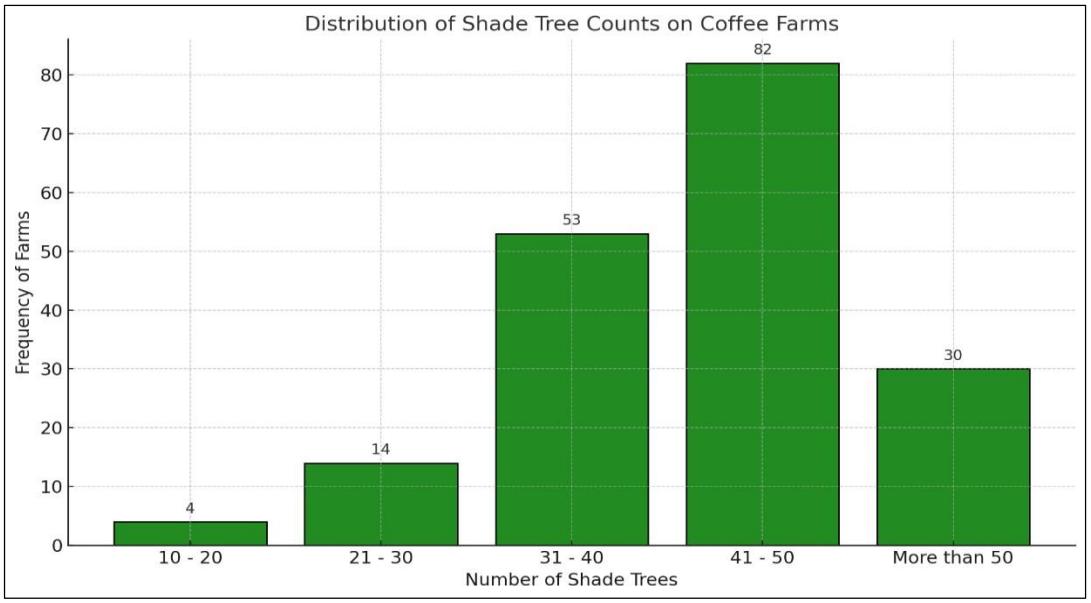


Figure 16: Distribution of shade tree counts on coffee farms

The data reveals that a substantial proportion of coffee farms maintain more than 30 shade trees, with 44.8% of farms having 41-50 shade trees, 29% having 31 - 40, and 16.4% having more than 50. This distribution strongly suggests that polyculture systems are widely adopted among respondents. High shade tree densities are typically linked to diversified farming practices where coffee is grown alongside companion crops like bananas, beans, or legumes.

Pearson Correlation Test: Shade trees versus coffee yield

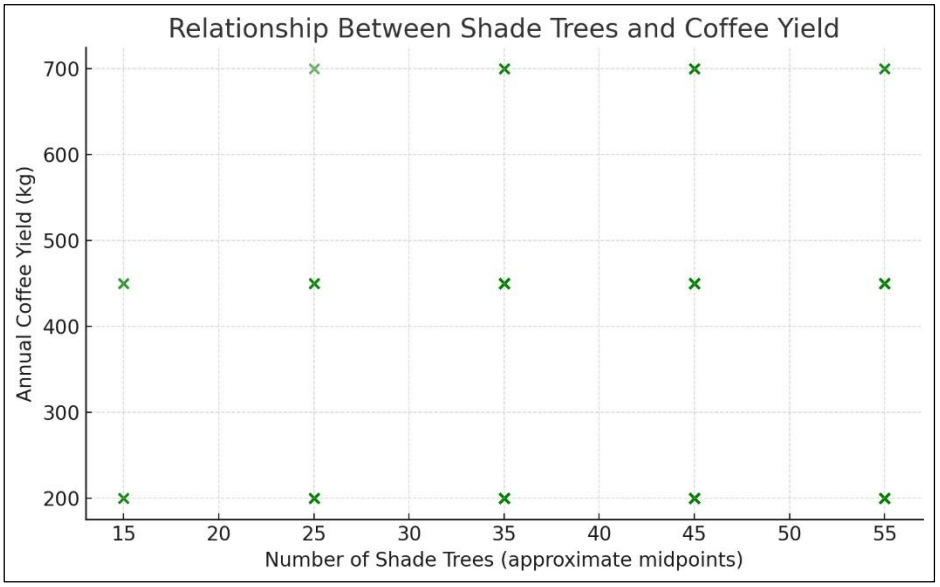


Figure 17: Relationship between shade tree and coffee yield

A Pearson correlation was conducted to examine the relationship between the number of shade trees and average annual coffee yield.

Results: Correlation coefficient (r): 0.018

P-value: 0.806

Interpretation: The correlation coefficient (r = 0.018) indicates a very weak positive relationship between shade tree count and coffee yield.

The p-value (0.806) is much greater than 0.05, implying that crop yield does not entirely depend on shade tree as results indicate no significant relationship between the 2 variables but depends on other factors, such as tree species, density, management practices, or soil health, may have a greater influence.

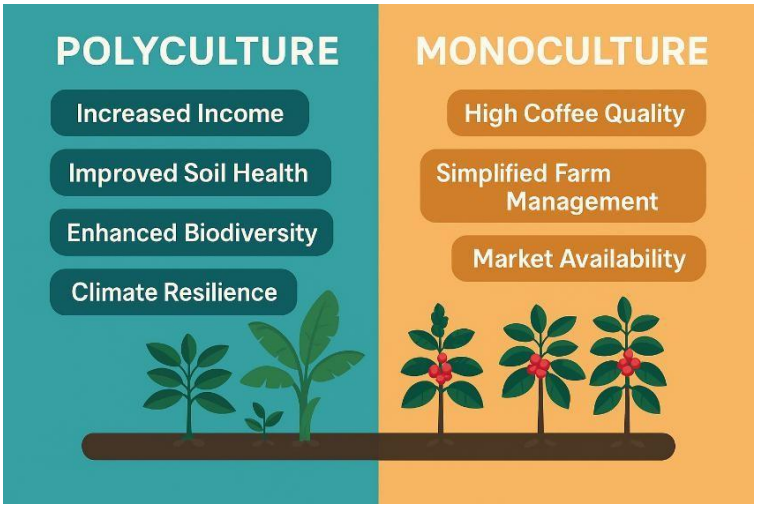


Figure 18: Benefits of polyculture versus monoculture coffee farming systems

The empirical data from the survey provides insights into the perceived benefits of polyculture and monoculture coffee cropping systems, reflecting distinct priorities and trade-offs among farmers.

Polyculture benefits

Polyculture systems were widely appreciated for their multifaceted advantages, with the majority of respondents recognizing key ecological and economic benefits. Notably, 70.5% cited increased income, highlighting the value of diversified crop outputs. Climate resilience (67.8%) and enhanced biodiversity (65.6%) underscore the environmental stability offered by these systems. Additionally, improved soil health (61.2%) and food security (65.0%) reflect the contribution of polyculture to long-term sustainability and household well-being.

Monoculture benefits

Monoculture systems were primarily valued for their operational efficiency and market orientation. The leading benefit, simplified farm management (75.7%), indicates a preference for ease of cultivation and control. High coffee quality (73.8%) was also a notable advantage, likely tied to standardization and export-grade output. Market availability (65.4%) further reinforces the economic appeal of monoculture, although these benefits may come at the expense of long-term ecological resilience.

Monoculture Benefit Frequencies

Simplified Farm Management noted by (39.57%) of the respondents was the most frequently cited benefit of monoculture coffee farming, highlighting its appeal among farmers for its operational simplicity. Monoculture allows for standardized practices across the entire farm, such as uniform schedules for irrigation, fertilization, pest control, and harvesting, which reduces the complexity of farm decision-making. Although this benefit is not a central theme in much of the reviewed literature (e.g., *van Asten et al., 2015*), it aligns with the general understanding that monoculture facilitates mechanization and streamlined management due to its homogeneity. This makes it especially attractive to farmers who have limited access to labour, extension services, or technical resources, positioning monoculture as a practical, if less ecologically resilient, option.

Market availability noted by (30.43%) of the respondents reflects the perception that monoculture coffee systems are better aligned with market requirements, particularly for standardized quality and consistent output. Farmers associate monoculture with the ability to meet the expectations of bulk buyers and export markets that prioritize uniformity over diversity.

Table 16: Comparison with polyculture benefits

Theme	Polyculture (Top benefit %)	Monoculture (Top benefit %)	Interpretation
Income/Market	70.5% (Income)	30.4% (Market Availability)	Polyculture is seen as more economically rewarding overall, while monoculture appeals to specific market niches.
Environmental Resilience	67.8% (Climate resilience)	-	Not mentioned in monoculture responses, suggesting a lack of resilience-related perception.
Operational Simplicity	-	39.6% (Simplified management)	A major advantage for monoculture, especially in labour-constrained settings.
Product Quality	-	30.0% (High coffee quality)	Monoculture perceived as more standardized but not necessarily higher in intrinsic quality.

The findings reinforce earlier conclusions: monoculture systems are appreciated primarily for simplicity and perceived market alignment, not for long-term sustainability. These perceptions are partially supported by existing literature, though empirical studies tend to

emphasize the broader and more durable advantages of polyculture, particularly in the context of resilience, soil health, and diversified income streams.

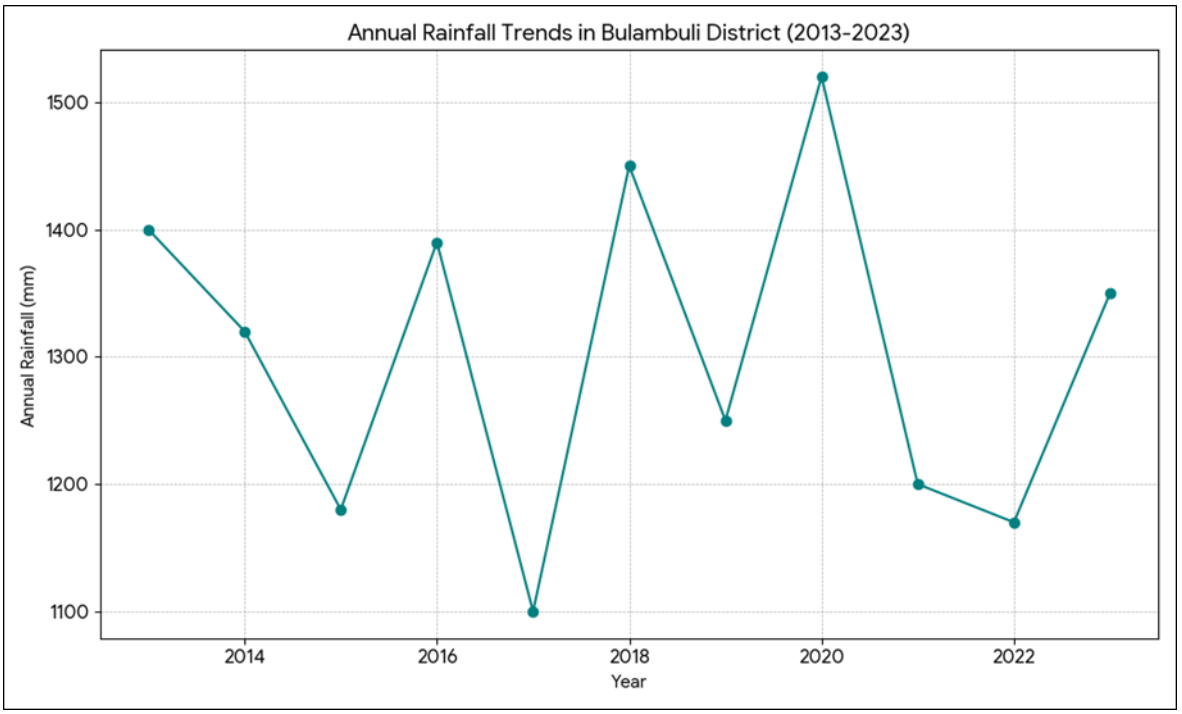
Thus, while monoculture may offer short-term operational convenience, the ecological and economic resilience of polyculture continues to present a more sustainable model, especially under conditions of climate variability and soil degradation.

Overall, results reveal a clear distinction: polyculture is associated with sustainability and resilience, while monoculture offers short-term efficiency and market-focused gains.

4.17 Contribution of monoculture compared to polyculture coffee farming systems to the sustainability, resilience and productivity

Indicators of resilience examined

Type	Variable
Ecological	Canopy cover compost pit biodiversity count
Economic	Annual income input costs net profit
Sustainability	Use of mulching terraces intercropping
Practices adopted in the last 2 years	Number and type of new practices adopted in past 2 years
Diversification	Other income sources livestock business etc.
Yield history over the past three years	Yield stability over time (compare 2-3 seasons)



Environmental resilience: soil health and rainfall trends

The soil data allowed for a direct comparison of soil health indicators between polyculture and monoculture systems. A series of independent t-tests revealed significant differences across all key metrics as shown below:

Soil pH**:** Polyculture systems have a significantly higher average soil pH (5.65) compared to monoculture systems (5.16), indicating a less acidic soil environment which is generally more favourable for plant nutrient uptake.
Organic Matter and Nitrogen**:** Polyculture farms show significantly higher average levels of Organic Matter (4.29%) and Nitrogen (0.22%) than monoculture farms (3.93% and 0.20%, respectively). These are crucial for long-term soil fertility and health.
Phosphorus: The average Olsen P (ppm) is significantly higher in polyculture systems (8.24 ppm) compared to monoculture (6.51 ppm), suggesting better phosphorus availability.
Bulk Density: Polyculture systems have a significantly lower bulk density (1.21) than monoculture systems (1.29), indicating better soil structure, which can improve water infiltration and root growth.

These findings suggest that polyculture farming systems promote better soil health, which is a key component of environmental resilience and the ability to withstand climate shocks like drought.

The rainfall data for Bulambuli District from 2013-2023 shows significant variability, with some years experiencing notably low rainfall and droughts, for example, 2017 and 2022 and others with high rainfall and flood risks such as in 2020. This climate variability underscores the importance of resilient farming systems, as demonstrated by the superior soil health of polyculture farms.

Out of a total of 290 surveyed coffee farmers in Bulambuli District: 63.8% (183) practice polyculture (coffee grown with other crops), and 36.2% (107) practice monoculture (coffee grown alone).

This distribution clearly indicates a farmer preference for polyculture systems, highlighting a growing recognition of their benefits. The predominance of polyculture suggests that farmers perceive it as offering greater economic viability through diversified income streams, stronger ecological sustainability via enhanced soil and biodiversity health, and improved system resilience to climate variability and market shocks. This preference reflects a practical, experience-based alignment with global research promoting polyculture as a pathway to more sustainable and adaptive agricultural systems.

Adoption rates reflect confidence in polyculture

From the study, polyculture is practiced by a clear majority (63.8%) of coffee farmers in Bulambuli District. *Sivaraman et al. (2023)* highlights income diversification as a key driver for polyculture adoption, helping farmers reduce financial risk through multiple revenue streams. On the other hand, *Perfecto et al. (2014)* emphasizes that farmers increasingly prefer polyculture due to its resilience to pests, diseases, and climate variability, enhancing overall system stability.

The high rate of polyculture adoption in Bulambuli reflects a strong alignment with the literature. It underscores polyculture as a farmer-led, adaptive strategy that emerges in response to both economic vulnerability and ecological challenges, reinforcing its relevance in smallholder farming systems.

Resilience enhancement

The study reveals that 67.8% of polyculture practitioners identify climate resilience as a major benefit of their coffee farming system. This finding underscores the importance of diversified cropping systems in helping coffee farmers adapt to and mitigate the adverse effects of climate variability. In the context of increasing climatic unpredictability, such as prolonged droughts, erratic rainfall, and extreme temperatures, farmers recognize that polyculture offers a more stable and resilient production model compared to monoculture.

Overview of key empirical findings: productivity and yield stability

To provide an overall picture of the performance of polyculture coffee farming, the study consolidated the key empirical findings relating to productivity and yield stability. Table 18 summarizes the principal findings on the performance of polyculture coffee farming among the surveyed farmers in Bulambuli District.

Table 17: Polyculture coffee farming in Bulambuli District

POLYCULTURE COFFEE FARMING IN BULAMBULI DISTRICT

DIMENSION	EMPIRICAL EVIDENCE	LITERATURE EVIDENCE	ALIGNMENT
Yield Stability	69.7% reported 'very stable' yields	Polyculture buffers yield variability (Perfecto et al., 2014)	✓ Strong alignment
Annual Yield	92.8% of farmers achieved yields > 500 kg/yr 34,5% achieved yields >1,000 kg	Total productivity increases with intercrops (van Asten et al., 215)	✓ Strong alignment
Soil Health	61.2% reported improvement	Enhanced organic matter, nutrient cycling (Sprunger & Martin,2023)	✓ Strong alignment
Climate Resilience	67.8% cited resilience as a major benefit	Shade trees, crop diversity regulate microclimate	✓ Strong alignment

Table 18 provides a consolidated overview of the productivity and yield-stability characteristics observed under polyculture coffee farming. The findings indicate that polyculture systems combined coffee production with additional crop outputs while maintaining relatively stable production. Overall, the results demonstrate the contribution of diversified production to the performance of polyculture coffee farms in the study area.

Table 18: Summary of literature aligned to literature

Dimension	Study findings	Literature evidence	Alignment
Yield stability	69.7% reported _very stable‘ yields	Polyculture buffers yield variability *(Perfecto et al., 2014)*	Strong alignment
Annual yield	92.8% of farmers achieved yields > 500 kg/year 34.5% achieved yields > 1 000 kg	Total productivity increases with intercrops *(van Asten et al., 2015)*	Strong alignment
Soil health	61.2% reported improvement	Enhanced organic matter, nutrient cycling *(Sprunger & Martin 2023)*	Strong alignment
Climate resilience	67.8% cited resilience as a major benefit	Shade trees and crop diversity regulate microclimate *(Muschler, 2001; Perfecto et al.)*	

Yield stability as a marker of system resilience

The study reveals that nearly 96% of polyculture farmers reported that their yield was either very stable (69.7%) or fairly stable (26.2%) over the past three years.

High productivity levels

A substantial 92.8% of polyculture farmers in Bulambuli District reported annual coffee yields exceeding 500 kg, with 34.5% achieving yields of over 1,000 kg.

Table 19: Synthesis: Triangulating productivity, stability, and ecological resilience

Dimension	Study findings (Bulambuli)	Literature Evidence	Alignment
Yield stability	69.7% report "very stable" yields	Polyculture buffers yield variability (Perfecto et al. 2014)	Strong
Annual yield	92.8% > 500 kg/year, 34.5% > 1 000 kg	Total productivity increases with intercrops (van Asten 2015)	Strong
Soil health	61.2% report improvement	Enhanced organic matter, nutrient cycling (Sprunger 2023)	Strong
Climate resilience	67.8% cite resilience as a key benefit	Shade trees + crop diversity = microclimate regulation	Strong

From table 26, data from Bulambuli District provides strong empirical confirmation of the literature‘s assertions regarding polyculture‘s role in promoting sustainability, resilience, and productivity in coffee farming systems.

Table 20: Perceived impact of intercropping on yield stability (n = 183 polyculture farmers)

Response Category	Frequency	Percent
Yes significantly improves	153	83.8%
Yes slightly improves	20	11.0%
No difference	4	2.1%
No, reduces stability	6	3.1%
Total	**183**	**100.0%**

Farmer perception of yield stability and resilience

A combined 94.8% of respondents believe that intercropping improves the stability of coffee yields over time, with the overwhelming majority (83.8%) stating the improvement is significant.

Table 21: Summary of key findings (Polyculture respondents only, *n* = 183)

Indicator	Response Category	% of Respondents
Perceived resilience from income	Strongly Agree	49.0%
	Agree	36.9%
	Neutral/Disagree	6.2%
	Strongly Disagree	7.9%
Access to alternative income or loans	Yes regularly	40.0%
	Yes occasionally	42.1%
	Rarely or Never	17.9%

These results suggest that a large majority (85.9%) of polyculture farmers feel economically buffered by the income diversity provided by the system, and 82.1% have at least occasional access to other income streams or credit. This directly indicates strong economic resilience under pressure.

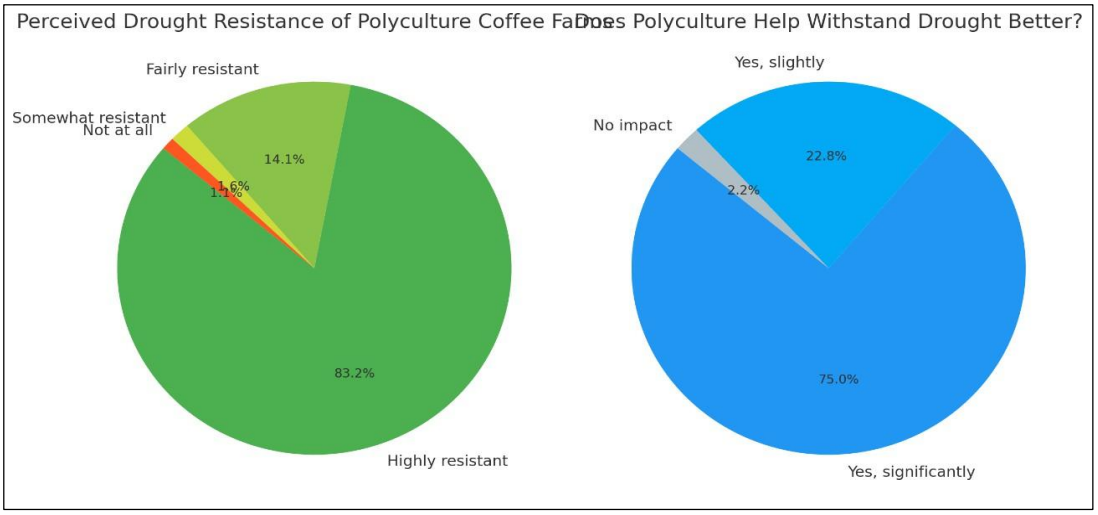


Figure 19: Contribution of polyculture coffee systems to drought resilience

Key findings from the field (polyculture farmers, *n = 183*)

Table 22: Self-reported drought resilience of coffee farms

Response	Frequency	Percent
Highly resistant	153	83.4%
Fairly resistant	26	14.1%
Somewhat resistant	3	1.4%
Not at all resistant	2	1.0%

Over 97% of polyculture farmers perceive their coffee farms to be either fairly or highly drought-resistant. This indicates a strong perceived resilience against climatic stressors, particularly drought, under polyculture systems.

Table 23: Perceived role of intercropping in drought resilience

Response	Frequency	Percent
Yes significantly	138	75.2%
Yes slightly	42	22.8%
No impact	4	2.1%

A combined 98% of farmers believe that growing multiple crops improves their farm's ability to withstand drought, highlighting a perceived ecological buffering effect of polyculture.

Resilience through shade and biodiversity

According to Muschler (2001), shade trees such as *Inga spp.* and *Erythrina spp.*, frequently used in polyculture, reduce evapotranspiration, moderate microclimates, and protect coffee from heat and moisture loss. Farmers in Bulambuli report high drought resilience, aligning with this concept that shade reduces water stress.

Soil structure and water retention

Research by Sprunger & Martin (2023) and Kuncoro & Budidarsono (2008) confirms that polyculture systems improve soil organic matter, structure, and biotic activity, all of which enhance water infiltration and retention. The fact that 75.2% of farmers felt their farms were *significantly* more drought-resilient due to intercropping supports this link between agroecological soil management and drought adaptation.

Table 24: Key findings (polyculture farmers' perception of pest resilience)

Resilience Rating	Frequency	Percent
Highly resilient	133	72.8%
Moderately resilient	37	20.0%
Slightly resilient	9	5.2%
Not resilient	4	2.1%
Total	**183**	**100%**

A combined 92.8% of farmers believe that their coffee farms under polyculture systems are either moderately or highly resilient to pest infestations.

Perceived role of polyculture in climate adaptation

The focus here was to examine the extent to which polyculture systems help coffee farmers adapt to changing weather patterns.

Table 25: Key findings – climate adaptation perception

Response	Frequency	Percent
Strongly Agree	129	70.3%
Agree	31	17.2%
Neutral	13	6.9%
Disagree	10	5.5%
Total	**183**	**100.0%**

Overall, a combined 87.4% of polyculture farmers believe that their systems help them adapt to changing weather patterns, highlighting polyculture as a key resilience mechanism.

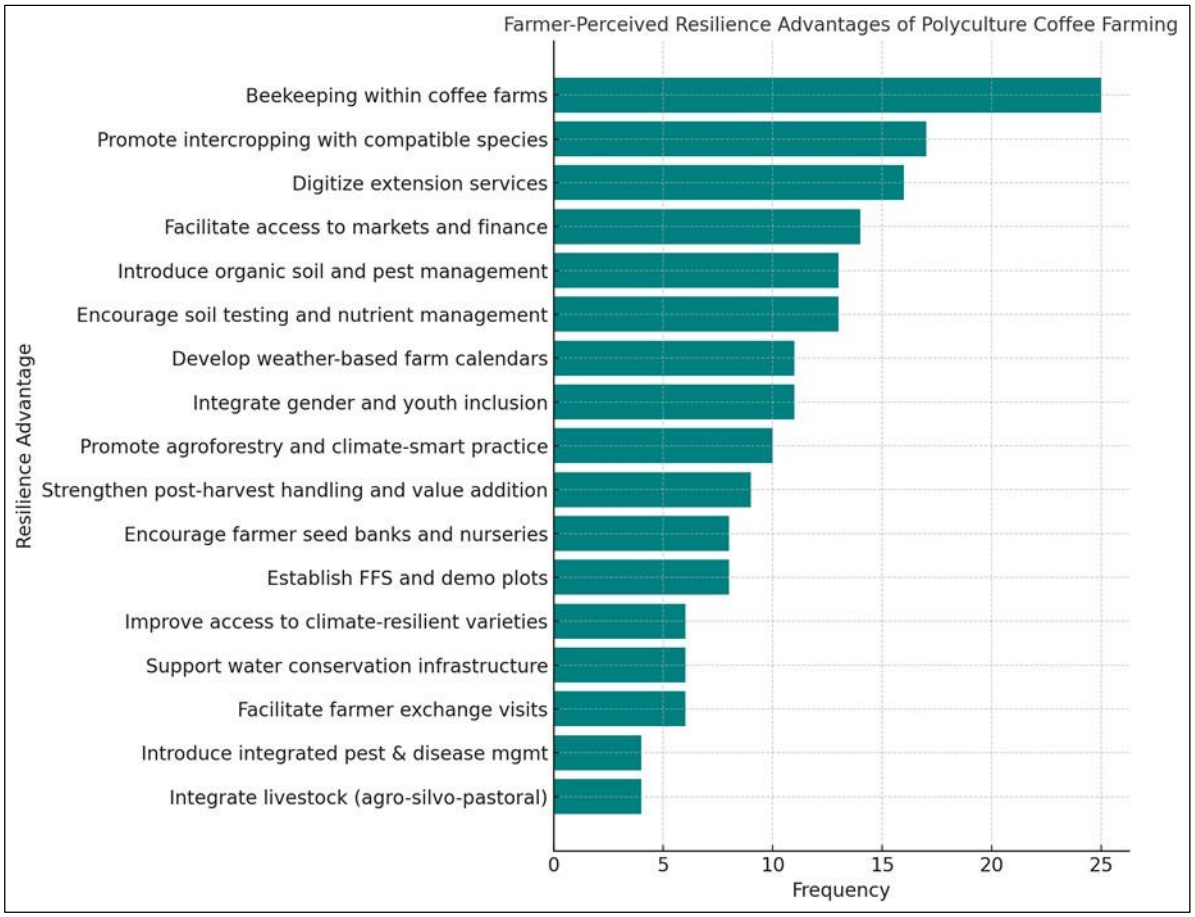


Figure 20: Farmer-identified advantages of polyculture coffee systems for resilience

The focus was to identify which resilience-enhancing practices farmers associate with polyculture coffee systems.

Key findings about farmer perspectives on resilience benefits

Social and institutional resilience

The inclusion of field schools (4.1%), gender/youth inclusion (6.2%), and digitized extension (9.0%) aligns with recent literature that emphasizes social-ecological resilience, showing that sustainability depends not only on crops, but also on human systems and knowledge flows.

Climate-smart practices and water resilience

Farmers also recognized weather-based calendars (6.2%), water conservation (3.4%), and climate-resilient varieties (3.4%), resonating with calls in the literature (e.g., Sivaraman et al., 2023) for climate-smart adaptation strategies in polyculture systems.

Data management and additional data collection

Soil samples

Based on agreed soil sampling and analysis protocol, composite surface soil samples (0-20 cm

deep) were collected from 8 farm households randomly selected across four Sub Counties of Musiira, Bulago, Sisiyi and Bunambutye. The soil samples were air-dried and sieved through a 2mm mesh and processed for physical and chemical analyses (pH water, total N, total organic matter, available P, exchangeable bases, and texture) using standardized laboratory procedures. The soil samples were analysed based on several key parameters, including pH level, organic matter content, total nitrogen, organic carbon, available phosphorus, exchangeable base cations, and soil texture. These indicators were compared between polyculture and monoculture farms.

Table 26: Soil fertility profile by farming system

Farming System	pH (H_2O)	Organic Matter (%)	Total Nitrogen (%)	Organic Carbon (%)	Available P (mg/kg)	Exchangeable Bases (cmol/kg)	Texture
Polyculture	6.1	3.5	0.22	2.0	18	7.2	Loam
Monoculture	5.4	2.1	0.12	1.1	10	5.8	Sandy loam
Polyculture	6.2	4.0	0.24	2.3	20	7.5	Clay loam
Monoculture	5.6	2.3	0.14	1.3	11	6.0	Sandy clay loam
Polyculture	5.9	3.3	0.20	1.9	16	6.8	Loam
Monoculture	5.3	2.0	0.10	1.0	9	5.4	Sandy loam
Polyculture	6.0	3.2	0.18	1.8	15	6.9	Loam
Monoculture	5.2	1.9	0.09	0.9	8	5.2	Sandy loam

Interpretation/Observation

a) pH values were generally higher in polyculture systems, indicating less acidity, likely due to organic matter inputs and mulching.

b) Organic Matter, Nitrogen, and Carbon were consistently higher in polyculture gardens, supporting better soil structure and fertility.

c) Available Phosphorus was also higher in polyculture systems, likely from organic recycling and reduced nutrient leaching.

d) Exchangeable bases (Ca, Mg, K combined) were stronger in polyculture soils, supporting better nutrient holding capacity.

e) Texture in monoculture farms tended toward lighter (sandier) soils, which retain fewer nutrients and water.

Key Climate-Related Impact Areas

Parameter	Impact on Coffee System	Risk Amplification in Monoculture	Resilience in Polyculture
Temperature Fluctuations	Disrupts flowering, fruit setting; reduces bean density and uniformity	High	Moderate (buffered by shade trees)
Rainfall Variability	Delayed rains, early cessation, and intra-seasonal droughts reduce yield predictability	High	Lower (soil cover & moisture retention)
Soil Moisture Deficit	Intensified evapotranspiration; bare soils lose water rapidly.	Severe	Mitigated by organic mulching
Pest/Disease Proliferation	Warmer, wetter conditions increase Coffee Wilt Disease, leaf rust, and white stem borer infestations	High	Reduced by biodiversity in polyculture
Growing Season Shifts	Misaligned planting/harvest windows undermine input timing and market linkages	High	More adaptable due to crop diversity

Environmental trends in Bulambuli District: NDVI and rainfall dynamics

In Bulambuli District, localities such as Bumugibole and Masiira demonstrate notable spatial and temporal variability in environmental indicators, particularly in relation to rainfall patterns and vegetation health. While overall rainfall trends have remained relatively stable across the district, analysis of Normalized Difference Vegetation Index (NDVI) data reveals divergent environmental trajectories between sub regions.

Rainfall sensitivity and trends in Bulambuli District (Past 10 Years)

Geographic Context

Bulambuli lies on the Northwestern slopes of Mount Elgon, and is influenced by bimodal rainfall patterns typical of Eastern Uganda.

Seasonal Patterns

a) **Long rainy season:** March – May (peak in April)
b) **Short rainy season:** September – November (peak in October)
c) **Dry seasons:** December – February and June – August

Table 27: Observed rainfall trends (2013 – 2023)

Year	Annual Rainfall (mm)	Notable Events / Sensitivity
2013	~1 400	Typical double season rains
2014	~1 320	Delayed onset normal totals
2015	~1 180	Erratic distribution short rains failed
2016	~1 390	Good rainfall recovery
2017	~1 100	Drought during March – April season
2018	~1 450	Above-average long rains
2019	~1 250	Short rains well distributed
2020	~1 520	High rainfall some flood risks
2021	~1 200	Mid-season dry spell in April
2022	~1 170	Low short rains water stress
2023	~1 350	Stable but with late onset

***Sources**: Uganda National Meteorological Authority (UNMA), FEWS NET, and Mt. Elgon agroecological climate profiles.*

Sensitivity Observations:

a) *Yield risk:* Coffee and intercropped food crops have shown yield declines in years like 2015, 2017, and 2022 due to erratic rains and mid-season droughts.
b) *Soil erosion:* High rainfall years (e.g., 2020) increased runoff and erosion risks, particularly in poorly terraced monoculture plots.
c) *Climate variability:* The district shows moderate to high rainfall sensitivity, where even small shifts in onset/timing lead to farm stress.

Implication for polyculture:

a) Polyculture systems have buffered these risks better through:
b) Mulching (retains moisture)
c) Canopy cover (banana and shade trees)
d) Soil structure improvement (organic matter)

CHAPTER FIVE
DISCUSSION

5.1 Objective 1: Farmers' practices in coffee cropping systems

The study's inclusion of both highland areas, for example, Bulago, Masiira, and lowland zones like Bunambutye captures diverse farming conditions, from crop selection and pest dynamics to soil fertility and labour demands. This ecological and socio-economic variation enhanced the representativeness of the findings, providing a more comprehensive and nuanced understanding of how polyculture coffee systems perform across different landscapes.

The selected villages varied in community organization and access to services, with some, for instance, Bunaale, Bugobero, having strong farmer networks, while others such as Nabuziba, Bulatanga) faced isolation and limited extension access. This spread enabled analysis of how agroecological practice adoption varies across different social and institutional contexts.

The study's extensive coverage, spanning four Sub Counties, nine parishes, and 42 villages, enabled geographically wider comparisons across altitudes, crop combinations, and local challenges such as labor intensity and water scarcity. This geographic breadth strengthened the evaluation of resilience practices and ensures that policy recommendations are context-specific. Overall, the diverse study area provided a robust and inclusive foundation for understanding polyculture coffee systems and for designing tailored, scalable, and sustainable interventions in Bulambuli District.

The Sub County analysis revealed distinct patterns of gender participation in coffee farming across Bulambuli District:

a) Masiira Sub County showed the most gender-balanced participation, with 52.5% male and 47.5% female respondents. Strong female engagement in Gabugoto Parish made it ideal for implementing women-led programs in polyculture, climate-smart agriculture, and financial literacy.
b) Bulago Sub County was found to bes male-dominated (64.9%), but villages like Gamushenyi B and Kadde reflect meaningful female participation. This suggested

opportunities for gender-responsive interventions, particularly in better-connected villages that could act as demonstration hubs for polyculture scale-up.

c) Sisiyi Sub County (66.1% male, 33.9% female) showed intra-parish gender variation, with Mayiyi village in Gibuzule Parish showing strong female involvement, and Kajere village in Luzzi Parish showing male dominance. This called for tailored, localized gender strategies, both to support inclusive areas and uplift underserved ones.
d) Bunambutye Sub County had the highest gender imbalance, with only 24.3% female participation. Villages such as Bugobero and Bukwangwa showed low engagement of women, whereas Bunaale offers some potential. The situation warrants urgent, targeted efforts such as establishing women‘s groups, VSLAs, and providing gender-inclusive training and leadership programs.

Overall, the findings emphasize the importance of context-sensitive gender strategies across Sub Counties to ensure inclusive, resilient, and equitable development in the coffee value chain.

The intercropping of coffee with bananas and beans in Bulambuli is not just a cultural tradition but a practice supported by agronomic research. According to Le et al. (2022) and Méndez et al. (2007), crop diversification significantly enhances soil health, beans fix nitrogen naturally, improving soil fertility, while bananas help conserve moisture and prevent erosion, especially on the steep slopes common in the Elgon region. This synergy supports long-term sustainable coffee yields.

Intercrop choices are deeply rooted in indigenous knowledge systems. Farmers use practical, experience-based insights to select crop combinations suited to local conditions, considering sunlight, water needs, and root interactions. This aligns with Mubiru et al. (2009), who emphasize the role of traditional ecological knowledge in optimizing land use and reducing dependence on chemical inputs. These practices not only boost productivity but also preserve cultural identity and promote farmer autonomy.

The presence of bananas also suggests an agroforestry structure, functioning similarly to systems that incorporate shade trees. While not always explicit, this model aligns with findings from Vandermeer (2002) and Torrez et al. (2023), who advocate for integrated shade systems in coffee farming. Such systems improve biodiversity, regulate microclimates, and

enhance soil microbial life, contributing to ecological resilience under climate stress. Furthermore, polyculture offers economic and food security benefits. As Sarmiento-Soler et al. (2020) note, diversified systems lower the risk of pest and disease outbreaks common in monocultures. By including food crops like beans, maize, and cassava, farmers reduce their dependence on volatile coffee markets and secure household nutrition during production shocks.

In conclusion, the polyculture practices in Bulambuli District exemplify a harmonious integration of scientific and traditional knowledge. They foster soil health, climate resilience, and livelihood stability, making them a powerful model for sustainable and adaptable coffee farming.

The findings from the study reveal that seasonal and annual crop rotation is a widely adopted practice among coffee farmers in the study area, reflecting both ecological awareness and practical experience. This trend directly aligns with the work of Le et al. (2022) and Méndez et al. (2007), who highlight crop rotation and diversification as critical components for sustaining soil fertility, enhancing nutrient cycling, and building up organic matter.

Importantly, the consistent use of rotation suggests that Bulambuli farmers are not only practicing intercropping but also actively managing the temporal dynamics of their soil health. This reflects a deep reservoir of indigenous knowledge and agroecological intuition, where farmers understand the value of ―resting‖ the soil through crop variation to maintain its long-term productivity and ecological balance.

The high frequency of rotation practices supports Mubiru et al. (2009‘s argument on indigenous knowledge as a driver of ecological farming. Rather than relying on synthetic inputs, Bulambuli farmers leverage their understanding of seasonal cycles, rainfall patterns, and crop compatibility to time their rotations effectively. This also suggests a deliberate strategy to balance food security with soil conservation, choosing crops that complement coffee and adapt to shifting seasonal conditions.

Although the current findings emphasize how frequently farmers rotate crops rather than detailing specific agroforestry structures, they nonetheless align closely with broader insights from Vandermeer (2002) and Torrez et al. (2023) regarding multi-layered and temporally

staggered agroecosystems. The widespread use of seasonal and annual crop rotations in Bulambuli can be seen as a strategic form of temporal diversification, one that mimics the rhythms of natural ecosystems.

Such rotation practices support essential ecological processes. By varying crops over time, farmers help to maintain microbial diversity and promote natural biological pest control. These shifts also reduce the strain on specific soil organisms and decrease the risk of nutrient depletion, allowing the soil biome to recover and remain balanced. Additionally, rotating crops contributes to soil stability, helping to minimize erosion, particularly important in Bulambuli‘s sloped landscapes.

As Torrez et al. (2023) emphasize, these features are at the heart of resilient agroecological systems. Compared to monoculture practices, polyculture systems that include regular crop rotation deliver superior ecological outcomes, including improved soil structure, water retention, and biodiversity. The findings from Bulambuli suggest that local farmers are already integrating many of these ecological principles into their practices, reinforcing the idea that traditional and adaptive management strategies can play a central role in sustainable coffee production.

From a resilience standpoint, the frequent crop rotation practiced by Bulambuli farmers, particularly seasonal rotation, demonstrates a proactive strategy to buffer against both market fluctuations and climate-related shocks.

As noted by Sarmiento-Soler et al. (2020), such practices help diversify income, reduce pest pressure, and mitigate the risks commonly associated with monocultures. This finding is consistent with qualitative evidence from farmers in Bulambuli District, who emphasized that crop rotation is both an economic and ecological necessity. During focus group discussions, several respondents explained that rotating coffee with beans, maize, and vegetables ―keeps the soil alive‖ and ―helps us get food even when coffee prices fall‖ (FGD, Bulago Sub-county, 2025). Others noted that the practice reduces pests such as coffee berry borer and root rot because ―the land rests from one crop and recovers before the next season‖ FGD, Masiira Sub County). These adaptive rotations therefore reflect a deliberate effort to strengthen food and income security in a region prone to environmental instability, while maintaining long-term soil fertility and farm productivity.

However, as Baker et al. (2023) caution, the actual climate resilience benefits of these practices in the Elgon region remain insufficiently studied, an important gap given Bulambuli's vulnerability to droughts, landslides, and erratic rainfall patterns.
Despite aligning well with agroecological principles, the study leaves key gaps unaddressed. Questions remain about which specific crop combinations work best under rotation, how rotation frequency impacts coffee yield and quality, and the climatic limits where these practices may become less effective. While frequent rotation is encouraging, targeted agronomic research is needed to identify optimal rotation patterns that suit Bulambuli's unique ecological and socioeconomic conditions.

Despite farmers adopting polyculture and intercropping systems, recognized for their pest-reducing properties, the high reliance on chemical pesticides (54.8%) appears inconsistent with agroecological ideals emphasized in the literature. Studies such as Méndez et al. (2007) and Torrez et al. (2023) advocate for ecologically integrated systems that naturally suppress pests through biodiversity, soil health, and biological interactions, reducing the need for synthetic inputs. Similarly, Sarmiento-Soler et al. (2020) argue that intercropping enhances biodiversity and creates microclimates that protect crops from pest outbreaks, reducing reliance on chemicals.

Thus, the continued dominance of chemical methods suggests that while farmers may be engaging in polyculture structurally, they have not fully transitioned to biologically integrated pest management (IPM) strategies. This highlights a disconnect between ecological potential and current practice, likely influenced by concerns over effectiveness, cost, and knowledge gaps.

Encouragingly, 42.1% of respondents reported using organic pesticides or biological control methods. These strategies align more closely with the sustainability goals promoted by Le et al. (2022) and Mubiru et al. (2009), who emphasize low-input systems grounded in traditional ecological knowledge and natural resource use. Organic pesticides, often derived from locally available materials, and biological agents, such as beneficial insects, are more environmentally friendly and compatible with the long-term health of agroecosystems.

This adoption reflects a awareness and interest among farmers in alternative pest management approaches. However, the relatively low uptake of biological control (13.1%)

indicates that such methods remain underutilized, possibly due to limited extension support or insufficient technical knowledge.

The use of organic and manual pest control strategies may also be rooted in indigenous knowledge systems, which Mubiru et al. (2009) describe as being critical to resilience and sustainability. Farmers may rely on traditional plant extracts, crop combinations, or observational techniques to manage pest dynamics. While these practices are not yet dominant, they reflect a potential foundation for building more holistic, low-input pest control models tailored to local conditions.

5.2 Gaps and research needs

The findings highlight key research gaps that mirror concerns raised in existing literature. Questions remain about the barriers hindering wider adoption of ecological pest control, the effectiveness of organic and biological methods in Bulambuli‘s unique agroecological context, and the scalability of integrated pest management (IPM) within current polyculture models. As Baker et al. (2023) note, while polyculture systems are promising, their resilience under climate stress, particularly in vulnerable regions like Mt. Elgon, remains largely untested and demands further investigation.

A notable 39.3% of farmers in the study reported applying pest control only when pests are observed, indicating a responsive rather than routine approach to pest management. This practice aligns with the literature, particularly Mubiru et al. (2009), which highlights how Ugandan farmers rely on indigenous knowledge and a deep understanding of local agro-ecological conditions to guide their decisions. Rather than following fixed chemical application schedules common in monoculture systems, farmers in Bulambuli District appear to use traditional and organic methods selectively, reducing reliance on synthetic inputs and enhancing ecological balance.

The integration of intercrops such as beans, bananas, and maize, observed during fieldwork and supported by Le et al. (2022), highlights how ecological diversity in polyculture systems contributes to natural pest control. These diverse plantings help create microclimates, attract beneficial predators, and disrupt pest life cycles, ultimately reducing the need for frequent chemical interventions. This observation aligns with findings by Sarmiento-Soler et al. (2020) and Vandermeer (2002), who note that polyculture enhances biodiversity and fosters

conditions that naturally suppress pest outbreaks, consistent with the 39.3% of farmers who only apply pest control when pests are observed.

Half of the respondents reported applying pest control on a monthly basis, suggesting that despite the presence of traditional and organic practices, many farmers operate within a hybrid or transitional system. This may reflect caution, possibly influenced by extension advice promoting regular applications, or the use of botanical pesticides as part of routine farm maintenance. While Méndez et al. (2007) and Torrez et al. (2023) promote low-input, biologically-based systems, the continued reliance on scheduled pest control suggests that the principles of resilience and ecological management are not yet fully embedded in current practices in Bulambuli.

While the reviewed literature provides strong evidence on biodiversity, yield improvement, and soil health in polyculture systems, it offers limited insight into the frequency of pest control application under real-world conditions. It also does not sufficiently explore how pest control practices adjust in response to climate variability, such as increased outbreaks during wetter or warmer periods. This represents a notable gap, as few studies assess the balance between proactive and reactive pest management in agroecological systems facing climate stress, despite Baker et al. (2023) highlighting the urgent need for targeted research on climate change resilience in smallholder farming contexts.

The fact that nearly 40% of farmers indicated that they relied on visual observation before spraying shows emerging adaptive capacity, aligns with resilience theory discussed by Mubiru et al. (2009) and Baker et al. (2023), where localized decision-making supports environmental and economic sustainability.

When aligned with the reviewed literature, this trend illustrates a farming landscape in transition. The significant use of organic inputs aligns with studies such as Le et al. (2022) and Méndez et al. (2007), which emphasize the benefits of diversified cropping systems in improving soil health and nutrient availability. The incorporation of crop residues and organic matter also reflects traditional ecological knowledge, as discussed by Mubiru et al. (2009), where farmers leverage local resources to reduce dependency on external inputs.

However, the continued use of chemical fertilizers by nearly half of the respondents suggests that full agroecological transformation is still unfolding. These findings underscore the need for targeted support and education to scale up organic practices while helping farmers reduce their reliance on synthetic inputs, ensuring long-term soil health and sustainability.
The use of organic fertilizers and green manures by 55.1% of farmers in Bulambuli District reflects a growing commitment to sustainable soil management, in line with the core principles of polyculture farming systems. This trend reinforces the findings of Le et al. (2022) and Méndez et al. (2007), who emphasize that diversified cropping, when combined with organic nutrient sources, significantly enhances soil health.

These practices contribute to improved soil organic matter, microbial activity, and moisture retention, echoing the benefits highlighted by Torrez et al. (2023) and Vandermeer (2002) in agroforestry-based coffee systems. Furthermore, the use of compost and green manures aligns closely with indigenous knowledge and low-input farming traditions, as documented by Mubiru et al. (2009), illustrating how local resource use supports ecological sustainability in smallholder coffee farming.

Despite the notable adoption of organic soil management practices, the continued use of chemical fertilizers by 44.8% of farmers in Bulambuli indicates that conventional input dependence remains significant. This reliance may be driven by market pressures to increase yields, limited access to organic inputs or technical knowledge, and influence from extension services that emphasize scheduled chemical applications.

This pattern only partially aligns with the literature. While Méndez et al. (2007) and others advocate for low-input, biologically managed systems, the persistent use of chemical fertilizers could potentially undermine soil microbial diversity and threaten long-term sustainability. The literature promotes a shift toward balanced fertility systems, integrating organic approaches to restore ecological function. However, the findings suggest that this transition is still underway in Bulambuli, reflecting a need for further support, training, and access to alternative inputs.

The use of crop residues and green manures by 24.8% of farmers demonstrates a strong reliance on local agroecological knowledge, where farmers intentionally recycle plant biomass to enrich the soil. This practice aligns with Mubiru et al. (2009), who highlight the

importance of traditional farming methods in reducing dependency on synthetic inputs and restoring natural soil fertility.

These low-cost, accessible strategies, such as composting and residue application, are not only sustainable but also climate-smart, as emphasized by Baker et al. (2023). In the face of increasing climate variability, such practices contribute to building resilience by enhancing soil health and moisture retention, making them essential components of adaptive polyculture systems.

While the reviewed studies extensively discuss soil quality, biodiversity, and sustainability, they do not quantify the actual use rates of organic versus chemical fertilizers in local contexts like Bulambuli. Nor do they examine how fertilizer choices shift in response to market price changes, climate variability, or availability of livestock manure.

This aligns with literature emphasizing the role of traditional knowledge in sustainable farming systems, while also exposing a gap in research on how fertilizer timing and frequency affect resilience in diverse, climate-affected regions like Bulambuli.

The finding that most farmers apply fertilizers either annually or after harvest suggests they are aligning application with the cropping cycle and observed soil conditions, rather than adhering to fixed schedules. This approach reflects the adaptive, indigenous knowledge systems described by Mubiru et al. (2009), where fertility management is informed by rainfall patterns, crop stages, and organic matter dynamics. It aligns with literature that emphasizes farmer-led decision-making in agroecological systems, where flexibility and responsiveness are essential for building resilience and sustaining productivity.

Frequent but moderate fertilizer applications, particularly after harvests, appear to be a practical strategy in Bulambuli‘s polyculture systems, where crops like beans, bananas, vegetables, and maize are intercropped with coffee. These companion crops have diverse nutrient requirements and contribute differently to nutrient cycling. This practice aligns with findings by Le et al. (2022) and Méndez et al. (2007), who emphasize the synergistic benefits of crop diversification, especially when supported by nutrient management practices like composting, mulching, and the use of green manures. The observed fertilizer timing likely

reflects farmers‘ awareness of how different crops interact and affect soil fertility throughout the seasons.

Although the literature cited highlights the ecological value of polyculture, it rarely addresses fertilizer application frequency or its variation with climate, cropping patterns, or input access. This study reveals that farmers adopt flexible schedules, with some applying fertilizers biannually and others post-harvest, a detail largely missing from current researches. As noted by Baker et al. (2023), there is a need for climate-focused agroecological studies that explore how such practices enhance resilience and soil health, particularly in highland regions like Mt. Elgon.

That only 6.9% of farmers apply fertilizers rarely indicates that most are actively managing soil fertility, reflecting an awareness of its importance for productivity. Combined with earlier findings on the use of both organic and chemical inputs, this points to a transitional system in Bulambuli, where agroecological principles are being adopted, but still coexist with conventional practices. This partially aligns with Méndez et al. (2007) and Torrez et al. (2023), who advocate for low-input systems, though the current fertilizer use patterns suggest farmers are still balancing ecological ideals with practical farming needs.

As Le et al. (2022) and Torrez et al. (2023) emphasize, such practices improve water retention, organic matter levels, and microbial activity, which are vital for nutrient cycling and plant resilience. Mulching also reduces soil temperature and prevents evaporation, functions that mirror those of shade trees, as discussed by Vandermeer (2002). This high adoption rate also suggests strong integration of indigenous knowledge, as described by Mubiru et al. (2009), where farmers apply accessible and low-cost solutions using locally available organic material to conserve water and nourish the soil.

These practices align with findings from Torrez et al. (2023) and Méndez et al. (2007), who advocate for structural soil conservation methods as key to preventing erosion, promoting infiltration, and maintaining long-term productivity in agroforestry systems. Their use also reinforces the resilience-enhancing role of physical land modifications in areas prone to landslides and heavy runoff, a growing concern due to erratic rainfall, as noted by Baker et al. (2023).

Though used by only 7.6% of farmers, rainwater harvesting represents a forward-looking adaptation strategy. As previously analysed, this method aligns with Baker et al. (2023) and Vandermeer (2002), who emphasize climate-adaptive water management as a foundation of resilient agroecosystems. Its relatively low uptake suggests barriers to implementation, such as lack of infrastructure, cost, or technical knowledge, an area where targeted support and investment could enhance smallholder capacity.

The combined use of water conservation methods in Bulambuli, such as mulching, terracing, contour farming, and rainwater harvesting, reflects a locally adapted and environmentally conscious farming system. These practices help conserve vital water resources, prevent soil degradation, and foster biodiversity, all of which contribute to the long-term sustainability and productivity of polyculture coffee systems in the region. This aligns with the agroecological ideals discussed by Sarmiento-Soler et al. (2020), where diverse cropping systems and natural resource stewardship reduce dependence on synthetic inputs and external technologies.

However, as the literature and Baker et al. (2023) stress, the resilience potential of these strategies under intensifying climate risks remains under-researched, particularly in the Elgon region. It is not yet clear how well these conservation methods can buffer productivity during severe droughts or intense rainfall events.

This result supports the conclusion that conservation practices are widely adopted regardless of farming experience, and that other factors, such as extension services or terrain, may play a stronger role in influencing choice of practice.

Shade management, the most widely adopted technique among Bulambuli farmers, closely aligns with the findings of Vandermeer (2002) and Torrez et al. (2023), who emphasize the ecological and agronomic value of shade trees in coffee systems. These trees help regulate temperature, conserve soil moisture, enhance biodiversity, and improve soil structure through organic matter build-up. In Bulambuli, the use of bananas and other shade-providing species reflects both indigenous knowledge and an intuitive response to climate stress, supporting Baker et al. (2023)‘s emphasis on climate-resilient water and temperature management in smallholder agriculture.

The inclusion of pest and disease monitoring as a yield optimization technique aligns with Sarmiento-Soler et al. (2020), who emphasize that polyculture systems, by supporting

biodiversity and creating microclimates, naturally reduce pest pressures. Monitoring allows farmers to act early and selectively, minimizing the need for chemical interventions and supporting ecological balance.

This finding also supports Mubiru et al. (2009), who recognize the value of traditional knowledge in recognizing early signs of plant stress or infestation. However, the relatively low uptake (15.9%) suggests that many farmers may not yet be integrating formal or structured monitoring systems, limiting the full potential of ecological pest control.

The mix of practices observed, especially shade management and monitoring, shows a strong presence of indigenous knowledge, consistent with Mubiru et al. (2009). Farmers in Bulambuli are clearly making site-specific decisions based on environmental cues, crop interactions, and local experience. These practices not only support productivity but also contribute to low-input, environmentally sustainable systems.

Despite alignment with existing literature, key gaps persist. The impact of these practices on coffee quality remains underexplored, and their role in climate resilience, especially in Bulambuli‘s variable terrain, is not well documented (Baker et al., 2023). Limited adoption of techniques like pruning and monitoring suggests barriers in awareness and support, while current literature often overlooks the crop- and context-specific dynamics unique to the region.

This finding reveals a practical tension in agroecological systems: while Le et al. (2022) and Méndez et al. (2007) advocate for crop diversification as a path to sustainability, they often understate the labour implications, especially for resource-constrained smallholders. The findings suggest that without labour-saving innovations or cooperative models, polyculture systems may struggle to scale sustainably.

Despite literature from Sarmiento-Soler et al. (2020) highlighting the pest-and disease-suppressing benefits of polyculture, 16.6% of farmers still face disease issues and 12.8% report pest challenges in Bulambuli. This suggests that biodiversity alone may not suffice without integrated monitoring, and gaps in knowledge or access to natural controls persist. Emerging climate-sensitive pests could also be a factor. These findings reinforce Baker et al.

(2023)‘s call for localized research to test polyculture resilience under real climate stress conditions specific to Bulambuli‘s environment.

While polyculture systems are widely praised for enhancing soil health (Torrez et al., 2023; Méndez et al., 2007), 14.5% of Bulambuli farmers still face challenges in maintaining soil fertility. This may stem from nutrient competition, limited organic matter returns, or restricted access to soil-enhancing inputs. The findings suggest that although the ecological design is sound, practical implementation lacks essential support, highlighting the need for localized soil fertility programs tailored to Bulambuli‘s specific conditions.

Though only 11.7% of farmers identified water management as a challenge, this finding aligns with Vandermeer (2002) and Baker et al. (2023), who highlight the increasing threat of erratic rainfall in highland regions like Mt. Elgon. It also mirrors the low uptake of rainwater harvesting (6.9%), suggesting underlying constraints. These insights point to the urgent need for expanded rainwater harvesting infrastructure, greater promotion of soil moisture conservation methods like mulching and terracing, and the development of long-term, climate-resilient water management strategies.

Overall, the challenges reported by farmers reflect the implementation gap between the theoretical benefits of polyculture, highlighted throughout the literature, and the practical realities of managing complex, labour-and knowledge-intensive systems in Bulambuli. While indigenous knowledge (as emphasized by Mubiru et al., 2009) contributes to system resilience, it is clear that technical support, labour innovations, and context-specific guidance are urgently needed to make polyculture systems more manageable and scalable.

The prioritization of income diversification as the leading benefit reflects farmers‘ economic pragmatism in risk-prone environments. This outcome supports Le et al. (2022) and Méndez et al. (2007), who emphasize that polyculture systems buffer smallholders against market shocks by enabling multiple income streams, from staple crops, fruits, and cash crops, rather than relying solely on coffee.

This finding also resonates with Mubiru et al. (2009), who highlight how indigenous intercropping knowledge in Uganda is used not just to maximize land use but to stabilize income. Bulambuli farmers‘ emphasis on income diversity demonstrates the economic

function of biodiversity, a concept often underrepresented in ecological studies that focus more heavily on biophysical benefits.

The second most cited benefit, enhanced pest resistance, aligns with findings from Sarmiento-Soler et al. (2020) and Vandermeer (2002), who note that polyculture systems disrupt pest life cycles, reduce host plant density, and foster beneficial predator populations. The use of shade trees and mixed cropping in Bulambuli creates diverse microclimates that lower pest incidence compared to monocultures.
However, as seen in previous findings, farmers still report pest control as a challenge, suggesting that biodiversity alone may not always be sufficient and must be paired with integrated pest management (IPM) strategies. Nonetheless, the recognition of pest suppression as a key benefit confirms the perceived ecological stability of these systems.

This response validates Baker et al. (2023), who argue that polyculture has strong theoretical potential for climate change adaptation, though empirical testing remains limited, particularly in the Elgon region. Farmers‘ recognition of climate resilience likely stems from their first-hand experiences with: shade trees buffering extreme heat, multiple crops spreading risk during erratic seasons, and better water retention from mulching and root diversity. This confirms that farmers associate polyculture not just with diversification, but with adaptive capacity, an increasingly important lens in climate-vulnerable regions like Bulambuli.

Though less frequently cited, benefits like improved soil health (12.1%) and yield stability (13.1%) reflect key agroecological goals highlighted by Torrez et al. (2023) and Méndez et al. (2007), who link polyculture to enhanced soil structure, organic matter, and nutrient cycling. These long-term gains, while vital for productivity, may be less visible to farmers than immediate outcomes like income or pest control, pointing to a communication gap between scientific insights and farmer perceptions that calls for more targeted evidence-sharing.

The diversity of perceived benefits reflects how Bulambuli farmers are drawing from indigenous knowledge systems to understand and manage complex interrelations between crops, climate, and soil, reinforcing Mubiru et al. (2009). Their recognition of income stability, pest management, and resilience as key benefits shows a holistic understanding of sustainability grounded in daily experience, not just external interventions.

While literature emphasizes biophysical outcomes like soil health and biodiversity, farmers prioritize economic and adaptive benefits such as income diversity and climate resilience. This gap highlights the need for integrated, localized research and greater focus on farmer-led innovation to link ecological practices with real-world livelihood gains.

5.3 Assessment of agricultural outputs of monoculture versus polyculture coffee cropping systems

The study by Kral and Probst (2016b) supports the idea that polyculture systems enhance resilience, particularly during climatic extremes such as droughts. The relatively stable yields reported in Bulambuli, even though they are modest, suggest a buffering effect from diversified systems. Intercrops can mitigate total income or food loss during coffee shortfalls, helping farmers cope with environmental stress.

This supports the argument that while monocultures may offer higher short-term yields under ideal conditions, polycultures provide more consistent, climate-adapted returns, which is crucial in a region like Mount Elgon where rainfall variability and soil erosion are major concerns.

The findings also align with Mubangizi et al. (2019), who demonstrated that leguminous intercrops and organic matter recycling contribute to improved soil health and nutrient availability. In Bulambuli, where soil degradation is a known challenge, the integration of beans, maize, and green manures likely contributes to yield stabilization, even if the total coffee output remains moderate. This supports the view that stable yields from healthier soils, rather than high but unsustainable outputs, are more beneficial for long-term productivity in agroecologically fragile zones.

This finding aligns with van Asten et al. (2015), who observes that monoculture coffee systems often outperform polyculture systems in terms of raw coffee yield due to the absence of competition for light, nutrients, and water. However, van Asten also emphasizes that while coffee yields are higher in monoculture, total farm productivity (including intercrops like bananas) is typically greater in polyculture systems.

The yield advantage of monoculture confirms the short-term productivity gain that comes from focusing resources on a single crop, but it also reflects a narrower approach that may neglect system-level resilience and sustainability.

Kral & Probst (2016b) note that polyculture systems offer better yield stability and resilience to climatic shocks, such as droughts and erratic rainfall, common in the Mt. Elgon region. Monoculture systems, while delivering higher yields in stable conditions, are often more vulnerable to weather-related yield fluctuations.

The high yields in monoculture systems are in line with their potential under ideal conditions. However, their sensitivity to stress factors may make them less reliable over time, especially in regions prone to climate volatility. Polyculture, while yielding less coffee, provides a buffered system that protects overall household income and food security.

Research by Mubangizi et al. (2019) asserts that polyculture systems contribute to enhanced soil fertility, especially where nitrogen-fixing intercrops and organic matter recycling are practiced. In contrast, monoculture systems often deplete soil nutrients over time due to lack of diversity in plant-soil interactions.

However, the high yields reported in monoculture systems may not be sustainable over the long term unless supported by external chemical inputs, which could lead to soil degradation and reduced ecological health. Polyculture systems, although producing lower coffee yields, build natural fertility cycles that ensure long-term soil productivity and system stability.

Van Asten et al. (2015) provides supporting evidence, acknowledging that intercropping in polyculture systems can suppress coffee yield due to competition for sunlight, nutrients, and water. However, the same study emphasizes that the integration of crops like bananas and legumes significantly boosts overall farm productivity, offering additional food, income, and soil-enriching benefits that compensate for the reduced coffee yield.

This reflects a fundamental agroecological trade-off. While monoculture maximizes short-term, single-crop output, it often does so at the expense of soil health, ecological balance, and long-term sustainability. In contrast, polyculture sacrifices peak coffee yield in favour of a

diversified, resilient, and ecologically stable farming system, a strategy particularly advantageous for smallholder farmers facing market volatility and climate uncertainty.

A strong 83.8% of polyculture farmers in Bulambuli District reported increased yield stability over time, underscoring the system‘s perceived resilience and reliability in variable farming conditions. Kral & Probst (2016b) and Mubangizi et al. (2019) affirm this observation, noting that polyculture systems provide greater yield consistency, particularly under climatic stress and pest pressure. Mubangizi et al. further emphasizes the role of legume intercropping, which enhances soil fertility and nutrient cycling, contributing to more sustainable yield patterns.

While polyculture may yield lower coffee volumes in the short term compared to monoculture, it delivers superior long-term performance by enhancing resilience, ecological balance, and stability. This makes it a strategically valuable model for smallholder farmers seeking consistent productivity amid environmental and market uncertainties.

Monoculture systems in Bulambuli deliver higher short-term coffee yields, yet this comes with potential environmental trade-offs such as soil depletion, increased pest vulnerability, and declining ecosystem health. In contrast, polyculture systems, though producing lower coffee yields, demonstrate clear environmental advantages, including improved soil health, enhanced biodiversity, and diversified income sources (van Asten et al., 2015; Mubangizi et al., 2019).

Sustainability is defined not just by volume of output, but by how production is achieved and sustained over time. Research by Sprunger & Martin (2023) and Apanovich & Lenssen (2018) shows that polyculture systems promote soil regeneration, nitrogen fixation, and erosion control, factors that are crucial for ensuring long-term productivity and ecological resilience. The data affirms that while monoculture may win in yield quantity, polyculture prevails in sustainability, making it a more viable long-term strategy for resilient coffee farming systems.

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Mubangizi et al. (2019) emphasize that integrating crops like bananas and legumes improves soil organic matter and nitrogen cycling, particularly in degraded highland areas such as Mt. Elgon. High banana yields in this study suggest that farms benefit from improved soil conditions, likely enhanced by organic matter from banana biomass and associated intercrops. This trend reflects how polyculture systems are not only productive in the short term but also contribute to long-term soil regeneration, crucial for sustainability in fragile ecosystems.

The banana yield data from Bulambuli District provides compelling evidence that polyculture systems integrating bananas into coffee farming are highly productive and resilient. The substantial banana yields compensate for the modest coffee outputs observed in polyculture farms, affirming the model‘s viability for smallholder farmers facing economic and environmental uncertainty.

Aligning this with key studies by van Asten et al. (2015), Kral & Probst (2016b), and Mubangizi et al. (2019), the findings highlight that polyculture offers a synergistic benefit, improving total output, stabilizing yields, and enhancing long-term soil fertility. These

attributes make it an important strategy for sustainable intensification and climate adaptation in East Africa‘s highland farming systems.

This dual benefit aligns with the findings of Mubangizi et al. (2019), who emphasized the contribution of legumes to both sustainable soil management and food security. The prevalence of moderate to high bean yields in Bulambuli indicates that polyculture systems can simultaneously support ecological health and household nutrition.

These trees not only contribute to household nutrition and income but also serve critical ecological functions, providing shade for coffee plants, reducing evapotranspiration, and stabilizing microclimates. This supports Vandermeer (2002), who emphasized the value of shade trees in regulating temperature and enhancing biodiversity within agroforestry systems. Similarly, Kral & Probst (2016) noted that such diversity contributes to yield stability, particularly under erratic climatic conditions. The integration of fruit trees thus enhances both the sustainability and productivity of polyculture systems, confirming their importance beyond direct harvest value.

The chart highlights the strategic value of yield diversity in polyculture systems. While coffee yields alone may be lower compared to monocultures, the combined output from bananas, beans, vegetables, and fruits significantly enhances total farm productivity and diversifies income sources. This diversified production system fosters ecological balance through the integration of legumes, fruits, and vegetables, which improve soil organic matter, microbial activity, and moisture retention, consistent with the findings of Méndez et al. (2007) and Torrez et al. (2023). Moreover, this diversity strengthens market resilience, enabling farmers to buffer against commodity price fluctuations and crop-specific risks, echoing Kral & Probst‘s (2016b) emphasis on adaptive capacity in climate-affected agricultural systems.

Furthermore, Kral & Probst (2016b) emphasized that polyculture systems improve resilience to climate and price shocks, leading to more stable (though possibly lower) income levels over time. In contrast, monoculture farmers may achieve higher short-term coffee revenues but remain more vulnerable to production failures and market volatility.

Supporting this, Mubangizi et al. (2019) found that legume-integrated systems (such as coffee-bean intercropping) improve soil health and long-term productivity, indirectly

sustaining economic stability. These ecological investments may not yield immediate financial returns from coffee but contribute to lower input costs, diversified revenues, and sustained land productivity.

The findings align with the trade-off narrative in agroecological literature (van Asten et al., 2015; Mubangizi et al., 2019), which emphasizes that monoculture maximizes yields, but polyculture supports long-term system sustainability and income stability. This reinforces the relevance of context-specific strategies that balance productivity with resilience for smallholder farmers.

The income findings from non-coffee crops align strongly with established literature on the benefits of polyculture systems. According to van Asten et al. (2015), although intercropping can sometimes result in marginally lower coffee yields due to resource competition, complementary crops such as bananas can effectively compensate for this loss. The data from Bulambuli supports this, as farmers practicing polyculture consistently reported diversified income from a mix of crops including beans, vegetables, and fruits, enhancing overall farm productivity.

In addition, Kral & Probst (2016b) emphasize that crop diversification serves as a buffer against external shocks such as climate variability and market fluctuations. This is reflected in the current study by the significant proportion (45.2%) of farmers earning mid-tier incomes from non-coffee crops, indicating a stabilizing effect on household earnings and resilience to environmental stressors.

Furthermore, Mubangizi et al. (2019) link income from non-coffee crops to improved soil fertility, particularly in systems that incorporate legumes and practice organic recycling. The fact that 30.6% of surveyed farmers earn over UGX1,000,000 annually from intercrops suggests that sustainable soil management and nutrient cycling are contributing to productivity gains beyond coffee, thus reinforcing the ecological and economic value of polyculture.

These findings strongly support the core principles of agroecological theory, which emphasizes multifunctionality and resilience rather than focusing solely on yield maximization. While monoculture systems may deliver higher coffee output per unit area, polyculture systems provide a broader and more sustainable set of benefits, including: Greater economic security through diversified income sources; enhanced food security from

both subsistence and commercial intercrops; reduced dependency on single cash crops, thereby lowering exposure to market and climate shocks, and improved ecosystem services, such as enriched soil structure, increased on-farm biodiversity, and natural pest regulation. Collectively, these benefits reinforce the value of diversified farming systems in building resilient rural livelihoods.

These advantages make polyculture an essential strategy for building climate-resilient and economically viable farming systems. As such, the findings highlight the importance of agricultural policy and extension programs that promote diversified, ecologically sound farming practices. Supporting farmers in adopting and optimizing polyculture systems could play a critical role in advancing climate adaptation, livelihood stability, and sustainable development across smallholder landscapes.

The higher use of organic fertilizer (50.3%) in polyculture farms aligns with Mubangizi et al. (2019), who emphasize that intercropping with legumes and biomass-producing crops enhances soil fertility through nitrogen fixation and organic matter recycling.

This is consistent with van Asten et al. (2015), who found that monoculture systems may produce higher coffee yields per hectare, but require more intensive input management due to limited ecosystem services. The relatively higher proportion of combined fertilizer users in monoculture reflects external dependency, with a greater need for input intensification to maintain yield levels.

The preference for organic fertilization in polyculture farms also supports Kral & Probst (2016b), who documented that organic and polyculture systems yield greater stability under climate stress, such as drought. By fostering soil moisture retention and microbial health, organic inputs contribute to yield resilience, reducing the volatility commonly experienced in monocultures.

This aligns with the broader agroecological narrative that polyculture systems are not only more biologically diverse but also better adapted to climate variability due to integrated resource recycling.

Polyculture coffee systems maintain comparable levels of fertilizer use to monoculture systems, reflecting a shared understanding of the importance of nutrient management.

However, they demonstrate a greater inclination toward organic soil enrichment, which supports long-term soil health and yield stability. This approach is consistent with principles of ecological intensification, where intercrops such as legumes and bananas naturally contribute to soil fertility through nitrogen fixation and organic matter recycling, thereby reducing dependence on synthetic inputs.

Monoculture systems tend to depend more heavily on combined fertilizer strategies, reflecting a need to compensate for the absence of natural nutrient cycling. This approach often results in higher input costs and raises concerns about long-term sustainability. While such systems may achieve short-term yield maximization, they offer less resilience in degraded or climate-variable environments, making them more vulnerable to soil exhaustion and external shocks.

This comparative analysis of fertilizer usage reveals a fundamental difference in how polyculture and monoculture systems manage agricultural outputs. Polyculture systems embody agroecological principles, with greater emphasis on organic inputs, internal nutrient cycling, and environmental sustainability. These patterns affirm findings from van Asten et al. (2015), Kral & Probst (2016b), and Mubangizi et al. (2019), supporting the argument that while monocultures chase higher per-plant yields, polycultures foster more resilient, holistic, and sustainable production systems. This reinforces the need for extension programs and agricultural policies that incentivize diversified farming, especially in climate-vulnerable regions like Mt. Elgon.

According to Kral & Probst (2016b), polyculture systems offer greater resilience to pest and disease outbreaks, especially during climatic stress. The 100% adoption of organic practices among polyculture farmers supports this, suggesting they supplement rather than rely entirely on synthetic chemicals, thus reducing long-term dependence.

Van Asten et al. (2015) highlighted that while polyculture may slightly reduce coffee yields due to interspecies competition, overall productivity increases due to contributions from companion crops like bananas. These same crops (e.g., legumes and vegetables) likely play a role in natural pest suppression, reducing the frequency or volume of pesticide use even if usage remains reported.

Meanwhile, Mubangizi et al. (2019) emphasized how organic matter recycling and biological soil health improvements from polyculture systems lead to greater crop stability and reduced pest vulnerability over time. The data indicating universal organic practice adoption in polyculture supports this long-term ecological improvement.

Polyculture systems maintain high pesticide use, likely as part of an Integrated Pest Management (IPM) approach rather than out of total dependence on chemical controls. These farms universally apply organic practices, such as mulching, composting, and biological pest suppression, which complement conventional methods and enhance ecological balance. They also benefit from ecological redundancy, where the presence of multiple crops prevents pests from causing widespread damage. This diversified structure helps support long-term resilience, particularly under conditions of climate-induced pest pressures and environmental stress.

Monoculture systems tend to use fewer organic strategies, thereby limiting the natural ecosystem services that support pest control, soil health, and moisture retention. As a result, these systems are more dependent on synthetic inputs, which can lead to higher production costs and pose challenges for long-term sustainability. While monoculture farms may achieve strong short-term yields, they are generally less resilient to pest outbreaks and climate variability due to the absence of crop diversity and ecological buffering.

In conclusion, the findings reinforce that polyculture systems, despite frequent pesticide use, integrate organic methods more fully than monocultures, pointing to a more balanced and resilient approach to farm management. This aligns with the broader literature (van Asten et al., 2015; Kral & Probst, 2016b; Mubangizi et al., 2019), which emphasizes that the ecological services inherent in diverse farming systems enhance agricultural stability, reduce risks, and improve sustainability, even when conventional inputs are still employed.

This finding aligns with van Asten et al. (2015), who observe that coffee-banana intercropping systems enhance ecological diversity and overall farm productivity, even though they may cause a slight reduction in coffee yield due to competition for light and nutrients.

According to Vandermeer (2002) and Torrez et al. (2023), shade trees play a vital ecological role in coffee agroecosystems. These trees help regulate temperature by moderating extreme heat and protecting coffee plants from direct sunlight. They conserve soil moisture by reducing evaporation and enhancing water retention. Moreover, shade trees contribute to the formation of favourable microclimates that support the growth and resilience of coffee crops. Importantly, they also offer habitat for beneficial organisms, such as pollinators and natural pest predators, which are essential for maintaining ecological balance and enhancing coffee productivity. The prevalence of 40+ shade trees per farm strongly supports these ecological strategies. In highland areas like Mt. Elgon, where erratic rainfall and rising temperatures threaten crop stability, such shade densities buffer against heat stress and water loss, enhancing overall system resilience.

Shade trees also play a key role in reducing evapotranspiration and minimizing soil erosion, both of which are vital in sloped terrains like Bulambuli. This supports Kral & Probst (2016b), who emphasize that polyculture systems offer superior climate resilience, especially during droughts.

The large number of shade trees further supports the use of mulching and leaf litter recycling, which is closely tied to Mubangizi et al. (2019)‘s findings on enhanced soil fertility and sustainable nutrient cycling.

While van Asten et al. (2015) note that excessive shade can lead to reduced coffee yield due to light competition, they also found that overall farm productivity increases when coffee is intercropped with trees like bananas. The distribution of shade trees in this study suggests that farmers are striking a balance, maximizing shade benefits without overly compromising light availability. The dominance of 41-50 shade trees likely reflects empirical farmer knowledge of optimal densities for maintaining productivity while preserving ecosystem services.

Ecological and agronomic gains: High shade densities in coffee agroecosystems foster ecological benefits by enhancing biodiversity, maintaining soil cover, and conserving moisture. These features contribute to more stable yields, particularly in the face of climatic variability. Furthermore, natural processes like leaf fall and root turnover from shade trees enrich the soil, supporting long-term regeneration and sustainability.

Considerations for yield optimization: However, while associated crops such as bananas may thrive under dense shade, excessive shading can slightly reduce coffee yields. To balance ecological gains with productivity, adaptive tree management, such as pruning and selective thinning, is essential. This approach ensures optimal light penetration, supporting both coffee growth and system resilience.

The strong presence of shade trees on polyculture coffee farms in Bulambuli aligns well with agroecological theory and empirical studies such as those by Vandermeer (2002), Torrez et al. (2023), and Mubangizi et al. (2019). These systems are not only more ecologically resilient but also support long-term soil health, microclimate buffering, and biological pest control.

In contrast to monoculture systems that prioritize short-term yield, this approach reflects a multifunctional farming strategy, enhancing sustainability, resilience, and productivity at the system level. This evidence reinforces the need for extension services to promote optimal shade densities and tree management for smallholder coffee producers in Uganda‘s highlands.

While this advantage is not extensively examined in the reviewed academic literature, it is indirectly supported by studies like Kral & Probst (2016b), which discuss how certification and market integration benefit streamlined production systems. The underlying assumption, widely acknowledged in agronomic discourse, is that monoculture enhances logistical efficiency and predictability, making it suitable for market-oriented production models. However, this market compatibility often comes at the expense of ecological resilience and long-term sustainability.

Farmers (30.00%) perceive monoculture systems as capable of producing more consistent, and potentially higher, coffee quality. This belief is rooted in the controlled and uniform growing environment of monoculture, which minimizes competition between species and allows for precise management of inputs such as nutrients, water, and pest control. However, this view is only partially supported by existing literature. For instance, van Asten et al. (2015) found that while polyculture systems may slightly reduce coffee yields due to resource competition, there was no evidence of diminished coffee quality, only a possible reduction in uniformity. Thus, while the perception of superior quality in monoculture may be influenced by market expectations or anecdotal experience, it lacks strong empirical backing. The

emphasis appears to be more on standardization and consistency rather than a proven improvement in intrinsic bean quality.

5.4 Contribution of monoculture and polyculture systems to sustainability, resilience and productivity

This perception is strongly supported by academic research. Perfecto et al. (2014) and Muschler (2001) provide empirical evidence showing that polyculture systems contribute significantly to microclimate regulation and stress reduction in coffee plants. These systems create more buffered environmental conditions by maintaining a balance between sun and shade, reducing temperature extremes, and preserving soil moisture levels, factors that are critical for maintaining coffee yield and quality under stress.

A central element in this process is the integration of shade trees, particularly bananas, beans, cassava. These crops not only moderate temperature fluctuations, but also improve soil fertility through nitrogen fixation, reduce surface runoff and erosion, and foster overall ecosystem stability. Their presence creates a more favourable growing environment for coffee, enhancing resilience not just at the crop level but across the entire farm system.

The strong alignment between empirical farmer insights and scientific literature validates the practical effectiveness of polyculture in buffering climatic risks. Farmers are not only observing these ecological interactions in real time, but they are also implementing strategies, such as shade tree management and crop diversity, that are supported by decades of agroecological research. This convergence highlights the critical role of polyculture systems in promoting climate-smart agriculture, particularly for smallholder coffee farmers in ecologically vulnerable regions like Bulambuli.

Data from the study indicates that over 61% of farmers practicing polyculture reported improved soil health as a significant benefit of their farming system. Sprunger & Martin (2023) and Kuncoro & Budidarsono (2008) emphasize that polyculture systems enhance soil organic matter, nutrient cycling, and soil biota diversity. These factors contribute to healthier, more productive soils over time. Furthermore, Apanovich & Lenssen (2018) support this by demonstrating that polyculture practices reduce soil degradation and promote long-term agricultural sustainability, especially in erosion-prone or nutrient-depleted areas.

The convergence between farmers‘ observations and scientific research, illustrates a positive feedback loop. Farmers in Bulambuli are not only adopting polyculture practices, they are witnessing tangible improvements in soil structure, fertility, and ecosystem function. These experiential outcomes reinforce the theoretical and experimental findings from the literature, confirming that polyculture is an effective strategy for restoring and maintaining soil health. This, in turn, strengthens the case for polyculture as a cornerstone of sustainable land management in coffee farming, particularly in regions facing environmental degradation and productivity decline.

A significant 70.5% of farmers practicing polyculture reported increased income as a key benefit of their farming system. Sivaraman et al. (2023) and van Asten et al. (2015) provide strong evidence that polyculture systems often generate higher overall farm income compared to monoculture, particularly when intercrops like bananas, beans, or vegetables are included. These additional crops not only provide extra income but also contribute to food security and market resilience.

The alignment between farmer-reported income gains and research findings highlights polyculture‘s economic advantage. By producing multiple marketable outputs, polyculture systems help farmers mitigate the risks of price fluctuations or yield losses from any single crop. This income stability is especially crucial in rural, climate-sensitive regions like Bulambuli, making polyculture a strategically sound and economically resilient choice for smallholder farmers.

Monoculture Adoption (36.2%) reflected a Minority Practice. The relatively lower adoption rate of monoculture may reflect farmers‘ awareness of its vulnerability to environmental stress and long-term soil decline. The findings suggest that farmers in Bulambuli are already adopting practices that align closely with academic recommendations for sustainable and resilient agriculture. Polyculture coffee systems provide a locally grounded solution that not only enhances resilience and soil health but also supports income diversification, which is critical in a region prone to climate variability. However, Perfecto et al. (2014) point to a research gap, the need for localized studies. The Bulambuli data begins to address this gap, indicating that polyculture benefits observed globally are replicable and meaningful in this specific Ugandan context.

In conclusion, the alignment between farmer behaviour, observed benefits, and scholarly evidence strongly supports the conclusion that polyculture coffee farming systems significantly outperform monoculture in sustainability, resilience, and productivity in Bulambuli District. These systems: improve soil health, enhance climate adaptability, diversify income, reduce risk, and support long-term viability. This alignment makes a strong case for policy support, training, and resource investment in scaling polyculture systems, while also addressing barriers to adoption for the remaining 36.2% practicing monoculture.

Perfecto et al. (2014) and Sivaraman et al. (2023) show that crop diversity and ecological complexity buffer against yield variability by spreading climatic and biological risks across multiple species. Muschler (2001) supports this by explaining how shade trees reduce temperature extremes and plant stress, stabilizing productivity.

The high yield stability reported by farmers strongly aligns with the literature‘s portrayal of polyculture as a system that enhances ecological and economic resilience. These findings suggest that even under environmental variability, farmers practicing polyculture maintain consistent output, reinforcing its adaptive capacity.

This demonstrates not only the productivity potential of polyculture systems but also their ability to support high-output farming in smallholder contexts. Van Asten et al. (2015) and Sivaraman et al. (2023) indicate that while intercropping may slightly reduce individual coffee yields due to competition for light and nutrients, it significantly enhances overall farm productivity, especially when complementary crops like bananas or legumes are integrated. Muschler (2001) adds that moderate shade densities (30 – 50%), typically achieved through strategic shade tree management, do not hinder yield and often contribute to better bean quality and healthier coffee plants. This alignment between farmer-reported yields and scientific findings affirms that well-managed polyculture systems can maintain competitive coffee yields while simultaneously improving overall farm performance, ecological health, and income resilience.

These productivity outcomes confirm that polyculture can sustain or even enhance coffee output when supported by proper agroecological management. Farmers in Bulambuli appear to be leveraging shade tree integration and crop diversity to maintain competitive coffee yields.

Field data from Bulambuli District show that 61.2% of farmers practicing polyculture observed improved soil health, reflecting tangible on-farm benefits tied to sustainable soil management. Sprunger & Martin (2023) and Kuncoro & Budidarsono (2008) emphasize the positive impact of polyculture systems on soil fertility, structure, and microbial biodiversity, resulting from the integration of diverse plant species and organic matter inputs. Furthermore, Apanovich & Lenssen (2018) highlight polyculture‘s capacity to reduce land degradation and support long-term agricultural productivity, especially in fragile or erosion-prone environments.

The observed soil-health differences are broadly compatible with mechanisms described in the literature, including nutrient recycling, organic matter accumulation and reduced erosion. However, the study does not treat the observed associations as proof of a causal effect of polyculture because the design was cross-sectional.

Farmers practicing polyculture are: maintaining stable and high yields, benefiting from enhanced soil health, experiencing greater climate adaptability, and observing consistent farm output despite environmental stresses.

The close alignment between local perceptions and global scientific consensus reinforces polyculture as a climate-smart, economically viable farming model, particularly suited for resource-constrained smallholder contexts like Bulambuli. Sivaraman et al. (2023) argues that diversified cropping systems buffer income and yield stability by spreading climatic and market risks. Meanwhile, Perfecto et al. (2014) supports the role of biodiversity and ecosystem functions in reducing pest pressure and ecological shocks. Muschler (2001) specifically details how shade trees moderate environmental extremes, reduce plant stress, and contribute to yield stability over multiple seasons.

The strong consensus among farmers aligns directly with peer-reviewed findings. Polyculture is recognized both scientifically and experientially as a system that stabilizes output over time, even under changing environmental conditions. This makes it a highly resilient model, especially in regions like Bulambuli that are vulnerable to climatic variability.

The farmer-reported benefits of intercropping on yield stability in Bulambuli are not isolated claims. They reflect the real-world application of proven agroecological principles. The empirical perception of resilience, whether through soil quality, yield consistency, or reduced crop failure, mirrors what the literature presents as systemic outcomes of polyculture.

Notably, these findings also help fill a critical research gap identified by Perfecto et al. (2014): the lack of localized, ground-level evidence on how ecological benefits of polyculture manifest in specific socio-environmental contexts like Bulambuli. This study helps bridge that gap with concrete, community-level insights.

The alignment between farmer experience and scientific literature is exceptionally strong in demonstrating that polyculture coffee systems significantly enhance resilience and yield stability. Nearly 95% of farmers affirm that intercropping improves yield stability—corroborated by decades of research showing how biodiversity, soil health, and climate regulation work together to sustain agricultural output.

The high rate of agreement (85.9%) with the statement that income from polyculture supports economic stability strongly aligns with Sivaraman et al. (2023), who highlight that diversified cropping reduces economic vulnerability and allows farmers to better cope with market and climate shocks. Income diversity also helps address seasonal gaps, a benefit also noted by Perfecto et al. (2014) in their analysis of ecological resilience within polyculture systems.

While this specific dataset focuses on perceived financial resilience, the broader agroecological literature affirms that resilience is rooted not just in income, but in improved soil health, biodiversity, and ecological stability. Kuncoro & Budidarsono (2008) and Sprunger & Martin (2023) emphasize how incorporating residues from companion crops improves soil structure and organic matter, which enhances the coffee plant‘s resilience to drought and nutrient stress. Muschler (2001) identifies shade regulation and pruning as practices that boost productivity and mitigate the effects of climatic extremes like high temperature and UV radiation.

Although pest resistance was not directly asked in this question set, previous findings from Perfecto et al. (2014) suggest that biodiversity in polyculture creates ecological checks and balances, fostering natural predators and reducing pest outbreaks. These findings highlight the multifunctionality of polyculture, which contributes not only to resilience, but also

sustainability, biodiversity, and soil conservation, essential under the realities of climate variability in Mt. Elgon.

The perceived financial resilience shown in this study validates theoretical claims from agroecology literature, particularly: The role of crop diversity in stabilizing income, and Reduced risk exposure due to a mixed-production system. However, Perfecto et al. (2014) and others stress the importance of empirical, location-specific validation of these benefits. While farmers in Bulambuli perceive polyculture as economically resilient, additional research is needed to quantify long-term benefits such as: Actual yield consistency across climate cycles, and impact on coffee quality. Ecological thresholds like shade density, soil depth, and slope that determine the success of resilience strategies.

Polyculture systems in Bulambuli are not only perceived as resilient by farmers, but also empirically supported in literature as a pathway to sustainable and climate-adaptive agriculture. To fully unlock their potential, there is a need for localized agronomic research and institutional support that aligns ecological principles with socio-economic realities.

These findings highlight the multifunctionality of polyculture, which contributes not only to resilience, but also sustainability, biodiversity, and soil conservation, essential under the realities of climate variability in Mt. Elgon. Hence, policies and extension services in Bulambuli should:

e) Promote tailored intercropping models (e.g., coffee with banana, beans, Inga spp.)
f) Support financial inclusion mechanisms such as micro-loans and insurance tailored to polyculture systems
g) Enhance market access for intercrops, ensuring farmers benefit from their diversified efforts
h) Scale context-specific agroecological training, focusing on practices like shade optimization, composting, and rotation.

As noted by Perfecto et al. (2014), polyculture fosters ecological redundancy, a form of insurance against failure. With multiple crops occupying different niches, total farm failure under drought is less likely. This is reflected in farmers‘ high confidence in their systems‘ ability to cope with drought, even in a region prone to climate variability like Mt. Elgon.

The findings from Bulambuli clearly demonstrate that polyculture coffee systems contribute to both perceived and ecological drought resilience. These outcomes:

i) Strongly validate agroecological theory on multifunctional resilience
j) Align with global research from Muschler (2001), Perfecto et al. (2014), and Sprunger & Martin (2023)
k) Emphasize the importance of soil and microclimate management as resilience levers

To support sustainable adaptation in Bulambuli, it is crucial that future research quantifies these resilience benefits under varied drought intensities, and that extension programs build on this local knowledge to scale climate-smart agroecological practices.

According to Perfecto et al. (2014), polyculture enhances biodiversity, including beneficial insects and natural pest predators, which plays a key role in regulating pest populations. The 72.8% rating of ―high resilience‖ among the coffee farmers echoes this ecological mechanism.
Sivaraman et al. (2023) also highlight that crop diversity acts as a natural pest deterrent, reducing the chances of pest outbreaks devastating entire plantations.

Muschler (2001) emphasizes that shade trees (e.g., Inga spp., Erythrina spp.) not only moderate temperature and moisture but also support habitats for predator species (e.g., birds, spiders), which naturally manage pests. The microclimatic conditions created by moderate shade density (30–50%) make the environment less favourable for pest proliferation, aligning with the high resilience ratings observed in this study.

Research by Sprunger & Martin (2023) and Kuncoro & Budidarsono (2008) shows that polyculture systems, through organic matter recycling and intercropping with legumes, enhance soil nutrient availability. This leads to stronger, healthier plants that are better able to resist pest damage. Bulambuli farmers‘ confidence in pest resilience may be grounded in such soil-health-driven plant defenses.

These findings support agroecological theory, which emphasizes maintaining ecosystem balance over relying on synthetic interventions for pest control. In a climate-challenged region such as Mt. Elgon, where pest pressures and temperature extremes are increasingly common, diverse and biodiverse systems offer clear advantages: reduced dependence on chemical pesticides, improved long-term productivity, and lower input costs and minimized environmental degradation. With 93% of farmers reporting moderate to high pest resilience,

the evidence provides strong validation, both ecological and economic, for advancing polyculture coffee systems as a strategic pillar in Uganda‘s climate-resilient agriculture policies.

The findings indicate that most polyculture respondents perceived their farms as resilient to pest infestations, but these perceptions should be distinguished from measured pest incidence. The study therefore treats the survey responses as evidence of perceived resilience rather than proof that polyculture significantly suppresses pests.

As described by Sivaraman et al. (2023), polyculture diversifies both crop types and income sources, allowing farmers to spread risk and buffer the impacts of climatic variability. The majority of Bulambuli farmers‘ positive responses reflect this theoretical model in practice. The integration of food and market crops allows farmers to recover from losses in one crop with revenues or food security from another.

Muschler (2001) finds that shade trees like Inga spp. And Erythrina spp. Provide critical microclimatic stability, helping reduce evapotranspiration and buffer coffee plants against heat and drought stress. The findings that 70.3% of farmers strongly agree that polyculture aids climate adaptation is consistent with these microclimate and canopy-based benefits.

Studies by Kuncoro & Budidarsono (2008) and Sprunger & Martin (2023) show that organic residues from intercrops improve soil structure, water infiltration, and organic matter content, all of which increase resilience to erratic rainfall. Farmers‘ positive views are likely linked to their experience of improved soil water retention and reduced erosion in polyculture systems.

The evidence affirms that polyculture systems enhance agroecosystem resilience, which is especially critical in Bulambuli‘s highland setting where rainfall is erratic and droughts are increasing in frequency. While monoculture farms may yield short-term gains, they lack the ecological redundancy needed for long-term adaptation. These findings support a shift in policy focus toward climate-smart agroecology, including: promotion of shade trees, support for intercropping, and farmer-led innovation in mixed cropping systems.

Perfecto et al. (2014) and Muschler (2001) emphasize that agroforestry and compatible intercropping support microclimate regulation, improve pest control, and enhance overall

ecological balance, mirrored by the 9.3% of farmers who prioritized ―intercropping with compatible species‖ and 5.5% who endorsed agroforestry.

With 13.8% of farmers highlighting beekeeping, there is clear support for integrating pollinator-focused biodiversity strategies, aligned with broader ecosystem service literature emphasizing functional biodiversity (Apanovich & Lenssen, 2018).

Some 7.2% of farmers identified organic soil and pest management, aligning closely with findings by Sprunger & Martin (2023) and Kuncoro & Budidarsono (2008), who report that polyculture improves organic matter and enhances natural pest suppression.

Farmer perspectives reinforce key agroecological pillars: biodiversity, knowledge sharing, soil stewardship, and diversification. The diversity of responses indicates that no single practice ensures resilience; rather, farmers benefit from a system-wide integration of ecological, economic, and social strategies. The strong interest in beekeeping, digitized services, and market access suggests growing demand for innovation-driven and value-chain–linked models of resilience.

The findings from this study underscore that resilience in polyculture coffee farming is both multifaceted and deeply rooted in local realities. Farmers in Bulambuli District identified a wide range of benefits, from ecological practices and social inclusion to market access and innovation, that align strongly with the broader agroecological literature. These insights confirm that resilience is not solely an agronomic issue but also a socioeconomic and institutional one.

Notably, the overwhelmingly positive perception (87.4%) that polyculture systems help farms adapt to changing weather conditions reinforces existing ecological theory. Polyculture systems deliver critical climate-buffering functions, reduce exposure to economic shocks, and support adaptive strategies, particularly in vulnerable highland regions like Mt. Elgon.

Taken together, these findings provide strong empirical support for scaling polyculture systems as a resilience-building strategy in Uganda. They validate the theory while highlighting the importance of implementing these practices holistically, through integrated support for ecological diversity, gender inclusion, farmer knowledge, and institutional

engagement, to effectively sustain productivity and stability under increasing climatic and economic pressure.

Sustainability: Polyculture systems contribute to regenerative soil processes through organic matter build-up and nutrient cycling. More balanced pH and nutrient levels reduce reliance on external inputs, for instance, lime and fertilizer.

Resilience: Improved soil health buffers against climatic shocks (e.g., drought, heavy rains). Loamy textures and higher carbon content improve water holding capacity and microbial activity.

Productivity: While monoculture may yield higher short-term outputs, the long-term viability and system-wide productivity (from intercropped bananas, beans, etc.) is greater in polyculture systems.

In conclusion, the empirical data from Bulambuli clearly shows that polyculture coffee systems offer superior soil conditions across all four Sub Counties. These findings validate existing literature and affirm the ecological and economic case for transitioning away from monoculture practices in Eastern Uganda. For sustained productivity, soil health, and farmer resilience, polyculture systems should be prioritized and supported through policy, extension, and agroecological training.

Historical agricultural productivity data from national research institutions, combined with projections from regional climate models, were analysed to assess the impacts of climate change on coffee farming in Bulambuli District. The assessment focused on identifying key trends associated with:

l) Temperature fluctuations, which affect flowering, fruit set, and bean quality in coffee;

m) Soil moisture variability, driven by erratic rainfall patterns and prolonged dry spells, which influences crop vigour and disease susceptibility;

n) Shifts in growing seasons, including delayed onset of rains and early cessation, which disrupt planting and harvesting calendars.

This integrated approach provides a localized understanding of how climate dynamics are reshaping agroecological conditions and influencing the sustainability and resilience of polyculture versus monoculture coffee systems in the Mt. Elgon highlands.

Contextual Overview Coffee farming in Bulambuli District is increasingly shaped by climate variability and change, with localized vulnerabilities amplified by altitude, slope, and farming system (monoculture vs. polyculture). Historical trends and model-based projections highlight growing risks from temperature rise, unreliable rainfall, and soil moisture stress.

In Bumugibole, NDVI trends from 2010 to 2016 displayed a steady decline, although values consistently remained above the ecological threshold, indicating that vegetation cover and environmental quality, while declining, were still relatively intact. However, post-2016, the district experienced notable ecological stress, with NDVI reaching a minimum of 0.65, reflecting reduced vegetative vigour and possible land degradation. This decline corresponded with anecdotal reports of increased soil erosion and agricultural stress. Between 2017 and 2021, an increase in rainfall, peaking at around 48mm, contributed to a moderate recovery in NDVI values, suggesting short-term improvements in vegetation health.

In contrast, Masiira exhibited a positive NDVI trend from 2014 to 2024, reflecting an improvement in environmental quality over time. This may be attributed to the adoption of sustainable land use practices such as agroforestry and polyculture cropping systems, as well as better water retention due to localized conservation strategies. These improvements align with community-level investments in climate-smart agriculture and could serve as a model for ecological restoration efforts elsewhere in the district.

Collectively, these findings highlight the heterogeneity of landscape responses within Bulambuli District and emphasize the importance of location-specific climate adaptation and land management strategies to safeguard environmental resilience and agricultural sustainability.

During the focused group discussions with coffee farmers in Bulambuli District, several key strategies were highlighted as central to enhancing resilience through polyculture coffee farming. Participants emphasized the importance of integrated approaches that support both ecological sustainability and farmer livelihoods. The insights below reflect a holistic understanding of resilience as it relates to agricultural productivity, environmental health, and socio-economic stability.

Promote intercropping with compatible species: Intercropping with bananas, beans, and groundnuts was cited as an effective way to diversify farm output, improve soil cover, reduce

erosion, and enhance pest resistance. Compatible species were seen as mutually beneficial, sharing resources without excessive competition.

Introduce Organic Soil and Pest Management: Participants recognized the role of composting, manure use, and bio-pesticides in reducing dependency on chemical inputs, enhancing soil health, and minimizing environmental degradation, especially on steep slopes prone to erosion.

Establish farmer field schools (FFS) and demo plots: Farmers advocated for more hands-on learning platforms to share best practices in polyculture techniques, including pruning, mulching, and shade tree management, enhancing peer-to-peer learning and technology uptake.

Improve access to climate-resilient coffee varieties: Availability of drought- and disease-tolerant coffee varieties was discussed as crucial for withstanding increasing climate variability and pest pressures affecting traditional Arabica strains.

Strengthen post-harvest handling and value addition: Participants noted that improving drying, storage, and processing facilities could reduce losses and increase product quality, allowing better access to premium markets.

Facilitate access to markets and finance: Better linkages to markets and micro-finance institutions were proposed to enable investment in improved farm inputs and reduce dependence on middlemen.

Integrate gender and youth inclusion: It was emphasized that empowering women and youth through training, land access, and resource control is essential for inclusive and sustainable farming communities.

Promote agroforestry and climate-smart practices: Agroforestry, especially with nitrogen-fixing and shade trees, was recognized for its role in conserving biodiversity, moderating microclimates, and improving moisture retention.

Promote beekeeping (Apiculture) within coffee farms: Beekeeping was seen as an added income source that supports pollination and biodiversity. Farmers highlighted its low input requirement and strong integration potential in polyculture systems.

Digitize extension services: The adoption of mobile-based platforms and digital tools for agronomic advice, weather updates, and marketing information was seen as a transformative opportunity to reach remote farmers.

Introduce Integrated Pest and Disease Management (IPDM): Farmers supported IPDM strategies that combine cultural, biological, and mechanical control methods to minimize losses while maintaining environmental health.

Encourage farmer seed banks and nurseries: Access to quality seed and planting material was seen as a bottleneck. Community seed banks and nurseries were suggested as sustainable solutions.

Support water conservation infrastructure: Rainwater harvesting tanks, contour trenches, and mulching were identified as essential for managing moisture during drought periods, especially in upland zones.

Develop weather-based farm calendars: Weather-informed planning tools were seen as vital for improving the timing of planting, harvesting, and input application in light of changing rainfall patterns.

Encourage soil testing and nutrient management: Regular soil testing to guide targeted fertilization was viewed as a key strategy to avoid nutrient depletion and overuse of synthetic inputs.

Integrate livestock into the system (Agro-Silvo-Pastoral Farming): Farmers acknowledged the value of integrating goats, poultry, or cattle for manure production, household nutrition, and income diversification.

Facilitate farmer exchange visits and cross-learning: Exchange visits between farmer groups were seen as highly effective for fostering innovation, adoption of new practices, and strengthening farmer networks.

In conclusion, the discussions highlighted that building resilience in polyculture coffee systems requires a multifaceted approach, blending traditional knowledge with modern innovations. Emphasizing inclusion, ecological balance, and capacity building is key to ensuring the long-term sustainability of coffee livelihoods in Bulambuli District.

During FGDs with coffee farmers in Bulambuli District, participants were asked to identify the major challenges they face in maintaining resilience through polyculture farming practices. Their responses revealed both systemic and farm-level barriers that constrain the full benefits of diversification and ecological sustainability. Below is a summary of the key challenges pointed out:

Labour intensity and time management: Polyculture systems, while productive, require more labour for planting, weeding, pruning, and harvesting multiple crops. Participants expressed concern about time constraints, especially during peak seasons, and a shortage of affordable or family labour. This challenge is compounded for elderly farmers or those without youth support.

Inconsistent market access for intercrops: Farmers noted that although intercrops like beans, bananas, and vegetables provide supplementary income, markets are often unreliable, poorly organized, or inaccessible. This undermines the economic motivation for intercropping and exposes farmers to post-harvest losses or poor prices.

Limited technical knowledge: Many participants highlighted gaps in agronomic knowledge, particularly on best practices for crop combinations, soil health management, pest control, and shade tree integration. The absence of adequate extension services limits the capacity of farmers to manage complex systems effectively.

Land size limitations: Small land holdings limit the number and variety of intercrops that can be cultivated alongside coffee. Some farmers find it difficult to balance subsistence food production with coffee and other cash crops on small plots, reducing their ability to diversify and enhance resilience.

Competition for resources: Participants reported resource competition, especially for water, nutrients, and sunlight, among different crop species. Without proper planning, intercropping can lead to suboptimal yields for coffee or companion crops, creating frustration and inefficiencies.

Policy and institutional gaps: Farmers expressed concern about the lack of supportive policy frameworks that promote diversified systems. Many government programs still prioritize monoculture or commodity-based models. Limited institutional support for climate-resilient agriculture and value chain development was also noted.

Pest and disease complexity: While polyculture systems can reduce some pest risks, farmers reported difficulty in managing the broader pest and disease spectrum that emerges with crop diversity. They expressed a need for integrated pest management (IPM) strategies tailored to diverse crop environments.

Social and gender barriers: Participants acknowledged that women and youth often face challenges in land ownership, decision-making, and access to training and credit. These barriers reduce their ability to participate fully in resilient polyculture systems. Cultural norms and power dynamics further marginalize these groups from benefiting equally.

These findings emphasize that while polyculture systems hold significant promise for resilience, farmers in Bulambuli face interconnected technical, economic, social, and institutional barriers. Overcoming these challenges will require a coordinated approach involving farmer training, inclusive policies, improved market infrastructure, and targeted support for marginalized groups. Strengthening these areas is essential to unlocking the full resilience potential of polyculture coffee farming systems.

Impact of intercrop income on coffee farm investment and economic resilience Insights from Focus Group Discussions (FGDs) in Bulambuli District. During the FGDs, coffee farmers practicing polyculture in Bulambuli District shared valuable insights on how income from intercrops influences their ability to invest in coffee farming and manage economic uncertainties. The key themes that emerged highlight the important role of crop diversification in building financial stability and resilience:

Provides steady cash flow during off-season: Participants noted that intercrops such as beans, maize, bananas, and vegetables offer multiple harvests throughout the year, generating steady income between coffee harvests. This continuity in cash flow enables households to meet daily needs and sustain farming activities year-round.

Reduces reliance on credit and costly loans: Intercrop earnings reduce the need to borrow money, especially at high interest rates, from informal lenders or financial institutions. Farmers emphasized that this independence shields them from falling into debt traps during economic downturns or poor coffee seasons.

Enables investment in farm inputs and technology: A consistent income from intercrops allows farmers to reinvest in their coffee farms. They reported using these funds to purchase organic and inorganic fertilizers, pay labourers, acquire pruning tools, and adopt improved cultivation methods, all of which enhance coffee productivity and quality.

Buffers against coffee price volatility: Fluctuations in global coffee prices are a major risk for smallholder farmers. Many respondents stated that income from intercrops provides a financial cushion, helping them avoid major losses when coffee prices fall. This buffering capacity is a key feature of resilient farming systems.

Supports farm expansion and long-term planning: With surplus income from intercrops, some farmers have been able to lease additional land, plant new coffee seedlings, or invest in water conservation and shade management. These actions contribute to long-term productivity and climate adaptation strategies.

Empowers women and youth in farming households: Intercrop cultivation, particularly vegetables and short-cycle food crops, is often managed by women and youth. Participants noted that the income from these crops strengthens the economic role of these groups,

allowing them to contribute to household decisions and participate more actively in farming enterprises.

The findings underscore the critical importance of intercrop income in strengthening both the financial and adaptive capacity of coffee farmers in Bulambuli. By ensuring stable cash flow, reducing credit dependency, and enabling reinvestment, intercrops act as a strategic lever for resilience and sustainability. Recognizing and supporting this income stream through policy, extension services, and market access initiatives is essential to enhancing the overall productivity and viability of polyculture coffee systems.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Objective 1: Farmers used a range of diversification and soil-management practices, including crop rotation, mulching, soil and water conservation, composting and shade management. Organic and biological pest-control practices were less common, while labour demand remained the leading management challenge.

Objective 2: Polyculture and monoculture showed different agronomic and ecological profiles. Polyculture recorded a higher current mean coffee yield in the comparative table, but the difference was not statistically significant. Polyculture nevertheless showed stronger soil-health and biodiversity indicators in the available measurements.

Objective 3: Polyculture was associated with diversified income sources and strong farmer perceptions of drought, pest and climate resilience. These benefits were accompanied by trade-offs, including labour requirements, continued chemical-input use and uneven access to extension and financial services.

Overall conclusion: Polyculture is a promising context-specific strategy for strengthening resilience and sustainability in coffee farming in Bulambuli, but its benefits depend on management quality, resource access and the local agroecological context.

a) 83.8% of polyculture farmers cited yield stability, reflecting less fluctuation in output across seasons and years.
b) 61.2% highlighted improvements in soil health, a result often attributed to practices like organic matter recycling, nitrogen fixation from legumes, and reduced erosion, and
c) 67.8% acknowledged enhanced climate resilience, linking polyculture practices to improved water retention, moderated microclimates through shade trees, and diversified income streams that buffer against climate-induced shocks.

These findings align with ecological and agroecological theories that emphasize the multifunctionality of diverse farming systems. Studies such as those by van Asten et al. (2015) and Perfecto et al. (2014) support the idea that polyculture systems may sacrifice

some level of short-term productivity but compensate through increased system resilience, soil regeneration, biodiversity preservation, and economic stability.

In conclusion, while monoculture systems may appeal to farmers seeking immediate yield maximization, the long-term advantages of polyculture, particularly in fragile, climate-stressed environments like Mt. Elgon, make them a more sustainable and adaptive farming model. The results of this study reinforce the argument for promoting polyculture coffee systems as a core component of climate-resilient agricultural development in Uganda. Policies and extension services should thus prioritize integrated strategies that support polyculture adoption while addressing the yield gaps through improved agroecological practices, farmer education, and appropriate input support.

6.2 Application, advantages and limitations of findings

Application of the findings

The findings from this study offer practical and policy-relevant insights for various stakeholders in the agricultural sector:

Policy design and implementation: The evidence supports the formulation of climate-resilient agricultural policies that prioritize polyculture systems. Policymakers could use this data to guide subsidies, extension services, and climate adaptation frameworks targeting smallholder farmers in ecologically vulnerable zones such as the Mt. Elgon region.

Agricultural extension and farmer training: Extension agents and NGOs can integrate these findings into farmer field schools, demonstrating how intercropping, shade management, and organic practices contribute to yield stability and resilience.

Agroecological planning and investment: Development programs and agri-financing institutions can promote investments in soil regeneration, agroforestry, and diversified cropping by showcasing the long-term sustainability benefits highlighted by polyculture farmers.

Academic and Research Use: Researchers can use this localized evidence to fill gaps in the broader agroecological literature, especially in understudied mountainous regions, and as a

basis for longitudinal impact studies or cost-benefit analyses comparing monoculture and polyculture.

Advantages of the findings

Empirical contribution: The study provides localized evidence from Bulambuli District on the agronomic, ecological and socioeconomic dimensions of coffee polyculture under climate variability.

Contextual contribution: The study links farmer practices, soil and environmental indicators, productivity and perceived resilience within the specific agroecological and socioeconomic conditions of the Mount Elgon region.

Comparative contribution: By examining both monoculture and polyculture systems, the study identifies benefits and trade-offs rather than treating diversification as universally superior.

Methodological contribution: The mixed-methods design integrates quantitative indicators with farmer and stakeholder evidence to provide a multi-dimensional assessment of resilience.

Limitations of the findings

Cross-sectional design: The study was based on three-season or short-term data set, limiting its ability to account for long-term productivity trends or seasonal yield variations in both systems.

Yield comparisons lack standardization: While yield estimates were collected, variations in land size, management intensity, and farmer estimation methods may reduce precision and comparability.

Underrepresentation of monoculture variants: The monoculture category may contain internal variation for example, high-input vs low-input monocultures, which the study may not have fully disaggregated or analysed.

Notwithstanding these drawbacks, the study offers solid, situation-specific proof of the resilience and sustainability advantages of polyculture coffee systems in Bulambuli District. Its uses span across research, ecological planning, agricultural education, and policymaking. In an area increasingly impacted by climate and market shocks, polyculture stands out as a climate-smart route to long-term farming sustainability, providing ecological stability, diversified income, and socio-economic resilience, even though monoculture may give better short-term coffee yields. It is, therefore, recommended that more biophysical and longitudinal studies be conducted to supplement and build upon these discoveries.

6.3 Recommendations

The following recommendations are proposed to address the opportunities and challenges and enhance the effectiveness of ongoing and future interventions:

For farmers (local coffee growers)

Strengthen crop diversification and rotation practices: Farmers should intensify rotation of coffee with legumes (beans, groundnuts) and food crops (maize, vegetables) each season to maintain soil fertility, break pest cycles, and stabilize yields during climatic shocks.

Adopt and maintain mulching and compost use: Consistent use of organic mulches and compost pits should be prioritized to conserve soil moisture, improve structure, and sustain yields, especially on steep slopes of Bulambuli District.

Expand agroforestry and shade tree integration: Farmers should increase canopy cover beyond 20% using nitrogen-fixing and deep-rooted trees (e.g., Albizia chinensis, Grevillea robusta) to moderate microclimates and protect against soil erosion.

For extension workers

Enhance farmer training on climate-smart agronomy: Extension agents should conduct regular on-farm demonstrations on soil and water conservation, integrated pest management, and composting to address moderate uptake levels (e.g., 63% mulching adoption).

Promote peer learning platforms and farmer field schools: Facilitate knowledge-sharing groups where experienced polyculture farmers mentor others, reinforcing indigenous knowledge and improving the adoption of best ecological practices.

For technical managers and agribusiness

Coordinators develop integrated value chains for diversified crops: Technical managers should help link farmers‘ intercrops (bananas, beans, vegetables) to local and regional markets to improve profitability and reduce dependence on coffee alone.

Support soil testing and monitoring programs: Institutionalize periodic soil health assessments to guide site-specific fertilizer and organic input recommendations for both polyculture and monoculture systems.

For policymakers and district authorities

Institutionalize support for polyculture systems in agricultural policy: The Ministry of Agriculture, Fisheries and Animal Industry and local government should integrate polyculture coffee systems into national coffee strategies and extension guidelines as a model for climate resilience and sustainable production.

Invest in climate-resilient infrastructure and incentives: Provide financial incentives (credit schemes, subsidies, or input vouchers) for farmers who implement soil and water conservation structures, composting, or agroforestry, thereby aligning local practice with national adaptation goals.

For Scientists and Research Institutions

Advance longitudinal and participatory research: Researchers should conduct long-term studies quantifying ecosystem service gains, carbon sequestration, and yield stability in polyculture systems, integrating farmers‘ indigenous knowledge into scientific modelling.

Future studies should also explore gender-differentiated adoption barriers and socio-economic trade-offs across agroecological zones.

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APPENDICES

Appendix 1: Structured Survey Questionnaire: Objective 1

Dear respondent,

I am a student of Busitema University carrying out a study titled ―Resilience of Polyculture Coffee Cropping Systems in Bulambuli District of Mountain Elgon Region, Eastern Uganda‖. As one of coffee producers, your household has been selected to provide information that could be used to assess the effect of climate change in coffee production. I assure you that, all the information that will be provided is for academic purpose and not otherwise. Therefore, you are kindly requested to respond truthfully to the following questions. I thank you in advance.

Section A: Demographics

1) Village: ……
2) Sub County: …….
3) Gender: What is your gender?
   a) Male
   b) Female
4) Marital Status: What is your age?
   a) Single
   b) Married
   c) Widowed
   d) Divorced/Separated
   e) Other (Specify): ……..
5) Age: What is your age?
   a) Under 25
   b) 25–34
   c) 35–44
   d) 45–54
   e) 55 and above
6) Education Level: What is your highest level of education?
   a) No formal education
   b) Primary
   c) Secondary
   d) Vocational training
   e) Higher education (diploma/degree)
7) Years of Farming Experience: How many years have you been farming coffee?
   a) 0–5 years
   b) 6–10 years
   c) 11–15 years
   d) 16–20 years
   e) Over 20 years

Section B: Coffee polyculture practices

8) Intercropping: What other crops do you grow alongside coffee?
    a) Bananas
    b) Beans
    c) Maize
    d) Cassava
    e) Others (Specify): ……..
9) Crop Rotation: How frequently do you rotate crops in the polyculture system?
    a) Every season
    b) Every year
    c) Every 2–3 years
    d) Rarely
    e) Never
10) Pest and Disease Management: What methods do you use to control pests in your coffee polyculture system?
    a) Chemical pesticides
    b) Organic pesticides
    c) Manual removal
    d) Biological control (e.g., using natural predators)
    e) No control methods used
11) How often do you apply these pest control methods?
    a) Weekly
    b) Monthly
    c) Only when pests are observed
    d) Never
12) Soil fertility management: What types of fertilizers do you use?
    a) Chemical fertilizers
    b) Organic fertilizers (compost, manure)
    c) Crop residues/Green manures
    d) None

13) How often do you apply these fertilizers?
    a) Annually
    b) Biannually
    c) After each harvest
    d) Rarely
14) Water Conservation Practices: Which of the following practices do you use to conserve water in your polyculture system?
    a) Mulching
    b) Terracing
    c) Contour farming
    d) Rainwater harvesting
    e) None
15) Yield optimization: Do you use any specific techniques to optimize coffee yields in the polyculture system?
    a) Pruning
    b) Selective harvesting
    c) Shade management (e.g., planting trees for shade)
    d) Other (Specify): ……
    e) None

Section C: Challenges and Benefits

16) Challenges: What are the main challenges you face in managing a polyculture coffee system?
    a) Pest control
    b) Disease management
    c) Soil fertility maintenance
    d) Labor requirements
    e) Water management
    f) Others (Specify): …….
17) Benefits: What do you consider the main benefits of coffee polyculture?
    a) Improved yield stability
    b) Enhanced soil health
    c) Greater income diversity
    d) Increased pest resistance
    e) Resilience to climate variations
    f) Others (Specify): …….

Observation checklist for on-farm verification

Aspect	Details	Observation Notes
Intercropping	Types of crops intercropped with coffee (for example, bananas beans)	
	Density of intercrops	
	Spatial arrangement of crops	
Pest and Disease Management	Evidence of pesticide use (for example, chemical containers, biological control agents)	
	Presence of pest damage	
	Method of pest control observed	
Soil Fertility Management	Signs of fertilizer application (chemical or organic)	
	Presence of compost/manure pits	
	Cover cropping/Green manures observed	
Water Conservation	Mulching practices (type and coverage)	
	Presence of terraces/contour farming structures	
	Evidence of rainwater harvesting	
Yield Optimization	Shade management (e.g., presence of shade trees)	
	Pruning activities observed	
	Harvesting methods and timing	

This survey questionnaire and observation checklist together enabled the study to obtain both reported and observed data on coffee polyculture practices, helping to triangulate findings and strengthen the reliability of the research conclusions.

Appendix 2: Interview Guide for one-on-one interviews: Objective 2

Dear respondent,

I am a student of Busitema University carrying out a study titled ―Resilience of Polyculture Coffee Cropping Systems in Bulambuli District of Mountain Elgon Region, Eastern Uganda‖. As one of coffee producers, your household has been selected to provide information that could be used to assess the effect of climate change in coffee production. I assure you that, all the information that will be provided is for academic purpose and not otherwise. Therefore, you are kindly requested to respond truthfully to the following questions. I thank you in advance.

Introduction

a) Introduce the purpose of the study and explain the confidentiality of responses.
b) Ask for permission to record the interview for accuracy.

Data Collection Tool: Agricultural outputs survey – Polyculture farmers

1) Village: .....
2) Sub-County: .....
3) Gender: What is your gender?
   a) Male
   b) Female
4) Marital status: What is your marital status?
   a) Single
   b) Married
   c) Widowed
   d) Divorced/Separated
   e) Other (Specify): .....
5) Age: What is your age?
   a) Under 25
   b) 25–34
   c) 35–44
   d) 45–54
   e) 55 and above

Farm Profile

6) Farm Size: What is the size of your farm?
   a) Less than 1 acre
   b) 1–2 acres
   c) 3–5 acres
   d) More than 5 acres
7) Farming Experience: How many years have you been farming?
   a) Less than 5 years
   b) 5–10 years

c) 11–20 years
d) More than 20 years

8) Coffee Variety: What coffee variety do you grow?
   a) Arabica
   b) Robusta
   c) Others (Specify): .....
9) Polyculture Practices: What crops do you grow alongside coffee? (Select all that apply)
   a) Bananas
   b) Beans
   c) Maize
   d) Vegetables (Specify): .....
   e) Fruits (Specify): .....
   f) Others (Specify): .....

Agricultural Outputs

10) Coffee yield: What is your average annual coffee yield?
   a) Less than 100 kg
   b) 100–300 kg
   c) 301–500 kg
   d) More than 500 kg
11) Additional crop yields: What is your average annual yield of additional crops?
   a) Bananas: ..... kg
   b) Beans:.....kg
   c) Maize:.....kg
   d) Vegetables (Specify): .....kg
   e) Fruits (Specify):.....kg
12) Revenue from coffee: What is your average annual income from coffee sales?
   a) Less than UGX 500,000
   b) UGX 500,000–1,000,000
   c) UGX 1,000,001–2,000,000
   d) More than UGX 2,000,000
13) Revenue from additional crops: What is your average annual income from other crops?
   a) Less than UGX 500,000
   b) UGX 500,000–1,000,000
   c) UGX 1,000,001–2,000,000
   d) More than UGX 2,000,000

Inputs and practices

14) Fertilizer use: Do you use fertilizers on your farm?
   a) Yes
   b) No
15) Type of fertilizer used: If yes, what type of fertilizer do you use?
   a) Organic
   b) Inorganic
   c) Both
16) Pesticide use: Do you use pesticides or herbicides on your farm?
   a) Yes
   b) No

17) Organic practices: Do you use organic farming practices?
    a) Yes
    b) No
18) Shade trees: How many shade trees do you have on your coffee farm?
    a) Less than 10
    b) 10–20
    c) 21–50
    d) More than 50

Challenges and benefits

19) Challenges in polyculture farming: What challenges do you face in polyculture farming? (Select all that apply)
    a) Pests and diseases
    b) Lack of market access
    c) Soil fertility issues
    d) Water scarcity
    e) Labor shortages
    f) Other (Specify): .....
20) Benefits of polyculture systems: What benefits have you observed from polyculture systems? (Select all that apply)
    a) Increased income
    b) Improved soil health
    c) Enhanced biodiversity
    d) Climate resilience
    e) Food security
    f) Other (Specify): .....

Perceptions and sustainability

21) Long-Term viability: Do you believe polyculture farming is sustainable in the long term?
    a) Yes
    b) No
    c) Not sure
22) Suggestions for improvement: What would you suggest to improve polyculture coffee farming in your area? .....

Agricultural outputs survey - Farmers practicing monoculture

1) Village: .....
2) Sub-County: .....
3) Gender: What is your gender?
    a) Male
    b) Female
4) Marital status: What is your marital status?
    a) Single
    b) Married
    c) Widowed
    d) Divorced/Separated
    e) Other (Specify): .....

5) Age: What is your age?
    a) Under 25
    b) 25–34
    c) 35–44
    d) 45–54
    e) 55 and above

Farm profile

6) Farm size: What is the size of your coffee farm?
    a) Less than 1 acre
    b) 1–2 acres
    c) 3–5 acres
    d) More than 5 acres
7) Farming experience: How many years have you been growing coffee?
    a) Less than 5 years
    b) 5–10 years
    c) 11–20 years
    d) More than 20 years
8) Coffee variety: What coffee variety do you grow?
    a) Arabica
    b) Robusta
    c) Others (Specify): .....

Agricultural outputs

9) Coffee Yield: What is your average annual coffee yield?
    a) Less than 100 kg
    b) 100–300 kg
    c) 301–500 kg
    d) More than 500 kg
10) Revenue from coffee: What is your average annual income from coffee sales?
    a) Less than UGX 500,000
    b) UGX 500,000–1,000,000
    c) UGX 1,000,001–2,000,000
    d) More than UGX 2,000,000

Inputs and practices

11) Fertilizer Use: Do you use fertilizers on your coffee farm?
    a) Yes
    b) No
12) Type of fertilizer used: If yes, what type of fertilizer do you use?
    a) Organic
    b) Inorganic
    c) Both
13) Pesticide Use: Do you use pesticides or herbicides?
    a) Yes
    b) No

14) Labor Costs: What is your average cost of labor per season?
    a) Less than UGX 500,000
    b) UGX 500,000–1,000,000
    c) UGX 1,000,001–2,000,000
    d) More than UGX 2,000,000

Environmental and economic impacts

15) Soil health: How would you rate the soil health on your coffee farm?
    a) Excellent
    b) Good
    c) Fair
    d) Poor
16) Pests and diseases: Do pests and diseases significantly affect your coffee yields?
    a) Yes
    b) No
17) Climate resilience: Do you think monoculture coffee farming is resilient to climate challenges like drought or floods?
    a) Yes
    b) No
    c) Not sure
18) Water management: What is your primary source of water for the coffee farm?
    a) Rain-fed
    b) Irrigation
    c) Both

Challenges and benefits

19) Challenges in monoculture coffee farming: What challenges do you face in monoculture farming? (Select all that apply)
    a) Soil fertility degradation
    b) Pests and diseases
    c) High input costs
    d) Low coffee prices
    e) Labor shortages
    f) Other (Specify): .....
20) Benefits of monoculture systems: What benefits have you observed from monoculture coffee farming? (Select all that apply)
    a) High coffee quality
    b) Simplified farm management
    c) Market availability
    d) Others (Specify): .....

Perceptions and sustainability

21) Long-Term Viability: Do you believe monoculture farming is sustainable in the long term?
    a) Yes
    b) No
    c) Not sure
22) Suggestions for improvement: What would you suggest to improve monoculture coffee farming in your area? .....

Appendix 3: Focus Group Protocol for Group Discussions

Introduction
The research will:

1) Welcome participants and explain the purpose of the discussion.
2) Emphasize confidentiality and the importance of open sharing.
3) Set guidelines for respectful listening and speaking.

Focus Group Discussion topics

1) Motivations for adopting polyculture practices
   a) What motivated you to start or consider polyculture practices?
   b) What do you see as the main benefits of these practices for your farm and community?

2) Benefits and positive outcomes
   a) How has polyculture affected your coffee production in terms of yield, quality, or income?
   b) Have you noticed any changes in soil health, pest control, or farm resilience with polyculture?

3) Challenges and barriers
   a) What challenges do you face with polyculture systems?
   b) Are there any conditions or issues that make polyculture difficult to implement or sustain?

4) Perceptions of sustainability
   a) Do you feel that polyculture is a sustainable practice for coffee farming?
   b) Why or why not?
   c) What impact do you think polyculture has on your farm‘s ability to adapt to changes or challenges?

5) Future Views and Community Impact
   a) Would you recommend polyculture practices to other farmers?
   b) Why or why not?
   c) What would you need to continue or expand polyculture practices?

6) Closing
   a) Is there anything else you would like to add or discuss regarding polyculture systems?

Appendix 4: Structured Survey Questionnaire: Objective 3

Dear respondent,

I am a student of Busitema University carrying out a study titled ―Resilience of Polyculture Coffee Cropping Systems in Bulambuli District of Mountain Elgon Region, Eastern Uganda‖. As one of coffee producers, your household has been selected to provide information that could be used to assess the effect of climate change in coffee production. I assure you that, all the information that will be provided is for academic purpose and not otherwise. Therefore, you are kindly requested to respond truthfully to the following questions. I thank you in advance.

Section A: Demographics and Farm Information

1) Village: ……
2) Sub County: ……..
3) Farm size: What is the size of your coffee farm?
   a) Less than 1 acre
   b) 1–2 acres
   c) 2–5 acres
   d) Over 5 acres
4) Type of coffee farming system
   a) Polyculture (coffee grown with other crops)
   b) Monoculture (coffee grown alone)

Section B: Yield stability

5) Annual coffee yield: What was your total coffee yield in the past year?
   a) Less than 100 kg
   b) 100–500 kg
   c) 500–1000 kg
   d) Over 1000 kg
6) Yield consistency: Over the last 3 years, how would you describe the stability of your coffee yield?
   a) Highly variable
   b) Somewhat variable
   c) Fairly stable
   d) Very stable

7) Impact of polyculture on yield stability (for polyculture farmers): In your opinion, does intercropping improve the stability of your coffee yield over time?
   a) Yes, significantly
   b) Yes, slightly
   c) No difference
   d) No, it reduces stability

8) Yield loss due to pests and diseases: How often do you experience significant yield loss due to pests or diseases?
   a) Every season
   b) Annually
   c) Rarely
   d) Never

Section C: Income and economic resilience

9) Income diversity: What other crops do you grow alongside coffee, if any?
   a) Bananas
   b) Beans
   c) Maize
   d) Cassava
   e) Other (specify): ……
10) Annual income from coffee: What is your estimated annual income from coffee alone?
   a) Less than 1 million UGX
   b) 1–5 million UGX
   c) 5–10 million UGX
   d) Over 10 million UGX
11) Additional income from intercropping (for polyculture farmers): What is your estimated annual income from intercrops?
   a) Less than 500,000 UGX
   b) 500,000–1 million UGX
   c) 1–5 million UGX
   d) Over 5 million UGX
12) Perceived economic resilience: Do you feel that income from polyculture farming allows you to better withstand economic challenges?
   a) Strongly agree
   b) Agree
   c) Neutral
   d) Disagree
   e) Strongly disagree
13) Access to financial resources: In times of economic difficulty, do you have alternative income sources or access to loans?
   a) Yes, regularly
   b) Yes, occasionally
   c) Rarely
   d) No, never

Section D: Resilience to environmental challenges

14) Drought resistance: How well do you think your coffee farm withstands periods of drought?
   a) Not at all
   b) Somewhat resistant
   c) Fairly resistant
   d) Highly resistant
15) Impact of polyculture on drought resilience (for polyculture farmers): Does growing multiple crops help your farm withstand drought better than coffee alone?

a) Yes, significantly
b) Yes, slightly
c) No impact
d) No, it makes it worse

16) Resilience to pest infestations: How would you rate your coffee farm‘s resilience to pest infestations under polyculture?
    a) Not resilient
    b) Slightly resilient
    c) Moderately resilient
    d) Highly resilient
17) Adaptation to climate change: Do you believe that polyculture helps your farm adapt to changing weather patterns?
    a) Strongly agree
    b) Agree
    c) Neutral
    d) Disagree
    e) Strongly disagree

Section E: Qualitative insights on resilience

18) Perceived Advantages of Polyculture
    a) In your opinion, what are the main advantages of polyculture coffee farming in terms of resilience?
19) Challenges faced with polyculture and resilience
    a) What are the challenges you face in maintaining resilience through polyculture practices?
20) Economic resilience and future intentions
    a) How does income from intercrops affect your ability to invest in your coffee farm and respond to economic pressures?
21) Environmental resilience experiences
    a) Can you describe a time when polyculture practices helped your farm cope with a drought, pest attack, or other environmental challenge?

Data management and additional data collection

Soil samples: Soil samples were collected from eight participant‘s farms, two from each Sub County and analyzed in a lab for key parameters, including pH level, organic matter content, total nitrogen, organic carbon, available phosphorus, exchangeable base cations, and soil texture. These indicators were compared between polyculture and monoculture farms.

Financial records/income surveys: Farmers were asked to provide any financial records related to crop sales, and the researcher used income survey data to quantify income from both polyculture and monoculture systems. This data helped quantify economic resilience and make comparisons between systems.

Data analysis approach

Quantitative Data: Survey data on yield, income, and resilience indicators was analyzed using descriptive statistics (means, medians, standard deviations) to summarize findings, and inferential statistics (e.g., t-tests, ANOVA) to compare resilience levels between polyculture and monoculture systems.

Qualitative Data: Responses from open-ended questions were coded and analyzed thematically to identify common perceptions and experiences related to resilience, further enriching the quantitative finding.