EVALUATION OF AGROECOLOGICAL DIVERSITY AND SOIL PRODUCTIVITY OF SMALLHOLDER FARMS IN BUSIA COUNTY, KENYA

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A THESIS SUBMITTED TO THE SCHOOL OF AGRICULTURE AND BIOTECHNOLOGY IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTERS OF SCIENCE IN SOIL SCIENCE UNIVERSITY OF ELDORET, KENYA

2025

DECLARATION

Declaration by the Candidate

This thesis is my original work and has never been presented for the award of an academic degree in any other university and should not be copied, or reproduced in any format without written authority from the author and/or the University of Eldoret.

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DEDICATION

I dedicate this thesis to my daughter, Geneve Hera. At a very early age of 6 years, she supported me in various ways beyond her age. The support was through cooperation, teamwork, her quick grasp of house chores, gentle care she gave me every time I was sick and acceptance and resilience in embracing our lifestyle changes allowing me to pursue my studies.

To Collins Marita, thank you for encouraging me to pursue my master's degree the very moment I shared with you the thought. Your belief in me never wavered, and now you nudging me towards PhD.

I also dedicate this thesis to my dear friends, Sharon Komen, Sara Nura, Georgina Okeyo, Dailash Lagat, Dr. Harrison Churu & Dr. Livondo Luhaz. Your unconditional moral support, thought-provoking challenge approaches, academic guidance and presence throughout the journey meant a lot to me.

To my employers who supported my studies by allowing me the flexibility, a day or two out of the five work days, to follow up on my studies.

And lastly, I dedicate this thesis to Love. Love has the power to uplift, make us feel seen and to remind us we belong. Love encourages, endures and transforms.

To Love!

ACKNOWLEDGEMENT

I sincerely acknowledge the University of Eldoret, particularly the School of Agriculture and Biotechnology and the Department of Soil Science for the opportunity to pursue masters' studies. I am grateful to my supervisors Dr. Njoroge and Dr. Otinga for their support throughout this journey. I am also grateful to the County Government of Busia for granting me the green light and for providing experienced enumerators who played a key role in the data collection activity among the farming communities. Finally, I wish to acknowledge with special thanks the KU Leuven University and ETH Zurich University for their continued partnership with the University of Eldoret, an alliance that made my scholarship possible and supported both my studies and research.

ABSTRACT

Agroecological biodiversity signifies the above ground variety and variability of different biological elements in agricultural systems; crops, livestock, tree species, and farm activities. Soil productivity relates to how capable a soil is concerning supporting plant growth and maintaining agricultural production over an area and time. The term, therefore, is synonymous with physical features of the soil in question as well as chemical, which include fertility, organic matter, and microbial activity. This research initiated in 2024, was fundamentally designed to critically assess the influence of agroecological biodiversity on soil productivity within the context of smallholder farming systems in Busia County, Kenya. The overarching goal was to empirically determine if diversification practices, specifically those aligned with established agroecological principles, yield a measurable, positive effect on soil productivity indicators. To quantify the degree of agroecological biodiversity practiced by farmers, the study employed the FAO's Tool for Agroecology Performance Evaluation (TAPE) framework. This structured approach integrated four key, interlinked indicators; crop, livestock, tree, and diversified farm activities, to derive a composite agroecological biodiversity score for each participating farmer and the study area as a whole. The requisite sample size (n=210) was purposively acquired from the Ministry of Agriculture, livestock and Fisheries of Busia County's smallholder farmer population using Fisher's formula to ensure statistical representativeness. The specific criterion for inclusion was documented exposure to, and current implementation of, agroecological biodiversification practices since 2020, facilitated either by government agencies or private development entities. A random sampling technique was then strategically applied to select farmers. Six distinct administrative wards were initially identified for the study. In wards where the number of eligible farmers exceeded 35 (n>35), a simple random sampling procedure was executed using Microsoft Excel to select the final participants. For wards containing fewer than 35 farmers, or where selected farmers were unavailable or declined consent to participate, a snowball sampling method was utilized. This ensured that the target sample size of n=210 was achieved across the study area. Primary data collection was executed via a structured questionnaire survey administered using the mobile data collection platform, KoboCollect. The survey instrument was comprehensive, capturing essential information on farmer demographics, detailed inventories of crops cultivated, livestock held, and trees planted, the range of farm activities undertaken, and critically, actual maize yield data from the most recent harvesting season. The data was analysed through mixed methods evaluation using both Microsoft Excel and R software. Most of the households were male headed, with most (67.0%) in the age category of 18–35 years and 42.7% having attained tertiary education. Agriculture (87.9%) accounted as a major source of income. The observed agroecological diversity pattern showed unsustainable extents of practice: crops scored 40.5%, livestock 31.25%, trees 45.5%, and farm activities 41.75%. Despite observed diversification such as predominance of kienyeji poultry, maize cultivation, and single-species tree systems; soil productivity remained predominantly low, with most farms falling under SPI Class V (0–19%). Correlation analysis of agroecological biodiversity with soil productivity results in an R value of -0.0383, implying no significant relationship between agroecological biodiversity and soil productivity. These findings imply that although to a minimal extent

agroecological diversification exists, soil productivity is not directly influenced by it. However, the diversification might promote the resilience of soil over time, as influenced by climate change or from some other secondary intervention on soil vitality. Farm-specific interventions such as soil testing are recommended to address productivity challenges, while future research should explore the resilience benefits of agroecological biodiversity.

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AE	Agroecology
AEB	Agroecological Biodiversity
AED	Agroecological Diversity
FAO	Food and Agriculture Organization of the United Nations
SPI	Soil Productivity Index
TAPE	Tool for Agroecology Performance Evaluation

CHAPTER ONE

INTRODUCTION

1.1 Introduction

The world's population and agricultural output have been two concurrent phenomena that have received a lot of attention over the last few decades because they have the potential to pose risks to social, economic, and environmental sustainability (Sher et al., 2024). The population of the world is expected to increase by an estimated 83 million people per year and reach an estimated 9.7 billion in 2050, with emerging nations accounting for a large portion of this growth (Sher *et al.*, 2024). Agriculture is the mainstream for almost every sector (Saru, 2022) (KNBS, 2024). Around 37% of the land area is used for agriculture in the world with Africa having the second largest agricultural land (1.1Billion hectares) (World Bank Group, 2019) (FAO, 2019a).

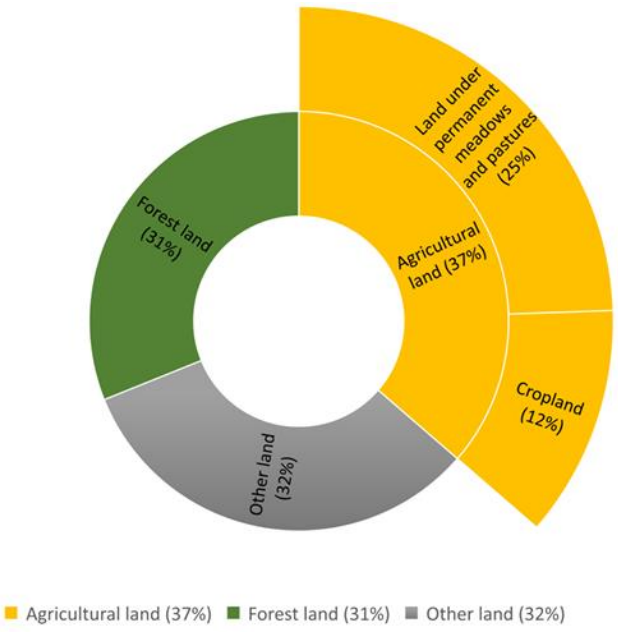

Figure 1 Global land area composition in 2019 (FAO, 2021a)

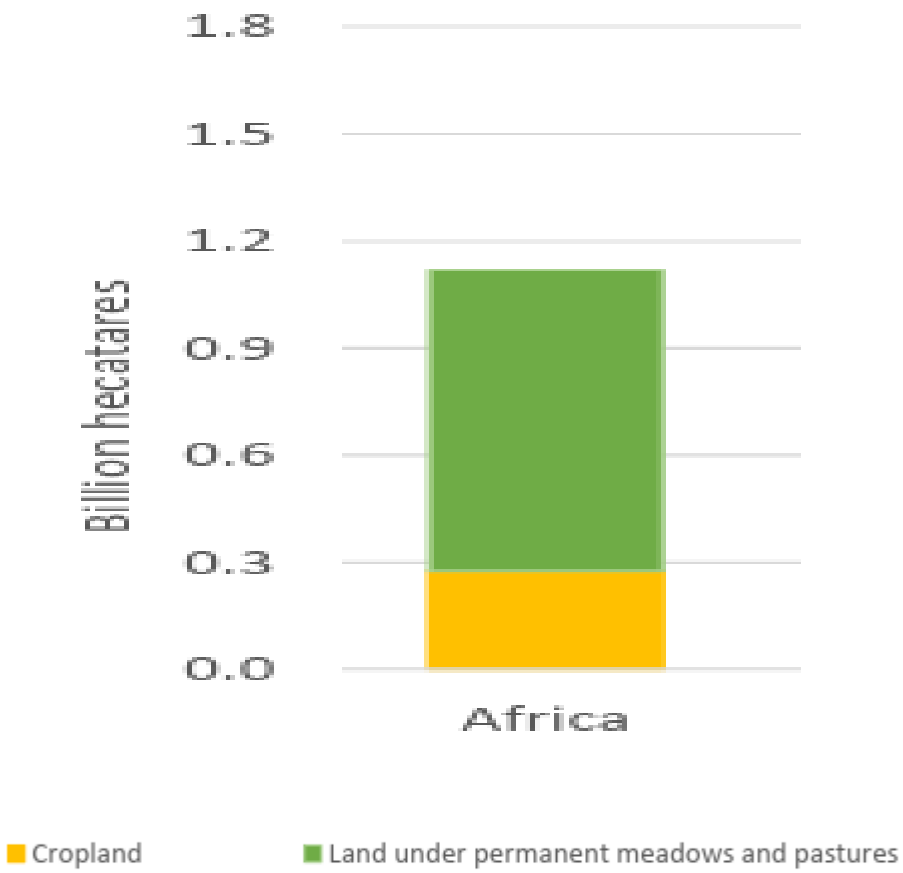

Figure 2: Agricultural land by component in Africa, 2019 (FAO, 2021a)

The world is faced with the twin challenge of feeding a projected population of 10 billion by 2050 while engaging in food system approaches that are environmentally and socially sustainable (Ndoli et al., 2021). Over the last six decades, a productivism paradigm focusing on increasing production to achieve food security emerged (Brandão & Rist, 2020). Historically, a significant proportion of the world's agricultural systems has relied on monocultures, which involve in the continuous cultivation of a single crop species on a given piece of land (Ryan, 2021). While

monocultures can allow for efficient production of high yielding crops, they often trigger the cost of reduced soil health, reliance on synthetic inputs, and increased vulnerability to pests, diseases, and climate extremes (Renwick et al., 2020) (Zou et al., 2024). Acknowledging the limitations and risks associated with monocultures, there has been a growing realization of the potential benefits of implementing diverse and dynamic farming systems (Elouattassi et al., 2023).

Agroecology has been argued to be a food system approach that could enhance the resilience of smallholder food security (Kliem & Sievers-Glotzbach, 2022; Madsen et al., 2021). The precise definition of agroecology remains a subject of ongoing scholarly discussion and lacks universal consensus (Dagunga et al., 2023). Originating as a scientific discipline in the 1920s, agroecology is fundamentally the application of principles from both agronomy (the science of soil management and crop production) and ecology (the study of interactions within agroecosystems, encompassing land, crops, and trees) to the practice of food production (Carlile & Garnett, 2021; Wezel et al., 2009). This foundational science subsequently evolved into a social movement in Latin America during the 1980s, before its most recent development as a cohesive set of agricultural practices rooted in ecological principles (Dagunga et al., 2023; Wezel et al., 2009). Agroecology offers a distinct and compelling alternative to the conventional agricultural paradigm. Proponents champion its capacity to foster diversified and resilient food production systems. Furthermore, it serves a critical role in environmental protection by significantly minimizing ecological footprints through its reduced reliance on costly, often environmentally damaging, external inputs. This

minimal dependence also renders it particularly accessible to marginalized and resource-poor farmers (Epule et al., 2022).

As a field of inquiry, agroecology has spurred a notable surge in research focused on sustainable methodologies, including the strategic diversification of cropping systems, the intentional mimicry of natural processes to optimize productivity and nutrient cycling, and the implementation of Integrated Pest Management (IPM), often incorporating valuable Indigenous knowledge systems (Rosset & Altieri, 2017; Vikas & Ranjan, 2024). The 1970s marked a pivotal period, witnessing a substantial shift toward an ecosystem-based approach to agriculture, characterized by a significant proliferation of agroeconomic literature adopting an agroecological perspective (Juncos, 2021; Rosset & Altieri, 2017).

Smallholder farms constitute the vast majority of the world's agricultural landscape, representing approximately 84% of all farms globally. These farms are crucial to global food security, responsible for an estimated 70 to 80% of the world's food production, while also contributing about 60% of household income for their owners (Fan & Rue, 2020; Hazell, 2020; Lowder et al., 2019; Musafiri et al., 2020). Despite their indispensable role, smallholder farms are acutely vulnerable to the impacts of extreme climatic events. They frequently face considerable yield gaps due to their heavy reliance on rain-fed agricultural techniques and often possess limited socioeconomic and institutional capacity to adapt and mitigate risks (Ibáñez et al., 2022). Moreover, the majority of them grapple with a myriad of challenges, including unpredictable weather patterns (Ofori et al., 2021), land fragmentation due to

population pressure (Giller et al., 2021), high costs of technologically advanced inputs (Assefa et al., 2020), and endemic soil fertility decline (TerAvest et al., 2015).

Consequently, smallholder agriculture is crucial for maintaining biodiversity and achieving sustainable food security (Guarín et al., 2020). Agroecological biodiversity (above-ground) in this study meant the variability and variety of crops, livestock, trees, and activities as practiced on the farm by smallholder farmers. Smallholder farmers can conserve and use agroecological biodiversity in their farming practices to enhance agricultural productivity (Zuza et al., 2024). This can be done by growing more than one crop species, rearing of different animal species and breeds, planting different trees species and varieties and conducting various farm activities (product or service rendering) at a time. This is a commonly practiced production strategy observed among smallholder farmers throughout sub-Saharan Africa (Isbell et al., 2021). It improves soil health which translate to improve soil productivity (Labeyrie et al., 2021).

Crop diversification improves soil organic matter through crop residue left on the farm from leaf falls and after harvesting. Soil organic matter is essential in maintaining soil health. It improvises nutrient availability through biological nitrogen fixation in the soil from leguminous plants and by decomposition of crop residues which with time releases back nutrients into the soil as humus. It improves soil moisture retention capacity by reducing evaporation by the broad leaved crop varieties and through the improved soil particle aggregation from the organic acids that act as a soil particle binding agent. This additionally mitigates soil erosion and improves soil-water

infiltration capacity through the improved soil aggregation which forms stable soil structures, leading to steady yields (Mupangwa et al., 2021). Eventually, these mechanisms translate to improved and sustainable soil productivity which leads to increased food production.

Livestock diversity is a key component of a sustainable agricultural system that provides many benefits, such as soil health resilience, income earning, food security, and nutrition(Sekaran et al., 2021). Heterogeneous livestock systems promote soil health via the utilization of well decomposed manure. Manure has soil macro and micro nutrients thus increasing soil nutrient status, organic acids that are a binding agents of soil aggregates thus improving soil aggregation, building a resilient soil structure. With improved soil aggregation, the soil moisture is retained for a longer period. Water percolation and infiltration rates are also improved, improved soil pH and temperature buffering capacity. Even though of its relevance, livestock variety and variability potential in smallholder systems if mostly unutilized due to land scarcity, insufficient feeds and minimal access to veterinary services (Valbuena et al., 2015). Due to commonly perceived expenses in rearing livestock, smallholder farmers focus on one or two species (i.e., cattle or poultry). The challenges related to resource availability to enhance upscaling livestock diversity require to be looked into which are inclusive of improving grazing land availability, extension services and fodder production that support execution of integrated livestock management systems.

For agricultural productivity, ecosystem resilience and sustainability, tree diversity is crucial (Keprate et al., 2024). Ecosystem services such as soil health restoration, slope

stabilization, microclimate regulation and carbon capture are provided by trees provide. (Singh et al., 2024) .As per agroforestry, biodiversity conservation is supported by trees through habitats for species, pest control, pollination and breeding spots (Udawatta et al., 2019). Evidence shows that increased tree diversity can make farming systems more productive through increased soil organic matter, brought about by incorporation of green leaf manure and compost manure; reduced soil erosion, and the stimulation of the nutrient cycle (Mbow et al., 2014). However, tree diversity remains limited in smallholder agriculture (Nyaga et al., 2015). Insecure land titles, a lack of knowledge about agroforestry practices, competition for space with crops, and limited tree planting (Rahman, 2017).

Hence, the enhancement of tree diversity through specific policies such as the government campaign to plant 15 billion trees in ten years from 2022 in a bid to reach 30% tree cover in Kenya, extension services and incentives such as bonuses, recognition programs, carbon credit, and professional development is a key component in the promotion of sustainable agriculture and rural livelihoods through tree diversification. The complementarity between field crops, livestock, and trees represents the agroecological principles of emphasizing biodiversity and the interdependence of ecosystem components (Gliessman, 2015).

The Food and Agriculture Organization (FAO) has developed the Tool for Agroecology Performance Evaluation (TAPE) as a holistic model for quantitatively assessing agroecology across numerous dimensions (Wordofa et al., 2024). TAPE extends beyond a mere evaluation mechanism, serving as a critical evidentiary and

guiding framework for establishing the presence and scope of agroecological practices within any given crop or agricultural system (Lucantoni et al., 2023). The framework's inherent flexibility allows it to accommodate a wide spectrum of production systems, varying implementation levels, and potential uses, enabling diverse practical interpretations (Namirembe et al., 2022).

Its applications are manifold:

- Policy Advocacy: TAPE furnishes policy advocates with comprehensive data, facilitating a deeper understanding of agroecology's contributions to the Sustainable Development Goals (SDGs).
- Farmer Empowerment and Decision-Making: The tool supports farmers in making informed resource allocation decisions by providing a self-assessment mechanism that promotes the interpretation and utilization of their performance results (Mottet et al., 2020).

Piloting and implementation of the tool have been undertaken in several African nations, including Benin, Ethiopia, Kenya, and Madagascar (FAO, 2025). Despite its meticulously structured assessment process, the TAPE framework possesses certain limitations in application. These constraints necessitate strategic modifications to ensure its optimal relevance and utility when deployed in specific, localized contexts that demand tailored performance metrics (Mottet et al., 2020) (Anthonioz, 2021). Additionally, however much the tool has been used and the results shared, there is still scarce documentation to its experience or its application critical (Namirembe et al., 2022). This called for the need of conducting this study to assess the impact of

agroecological biodiversity, an advocated practice toward soil health and food security, on soil productivity.

1.2 Statement of the problem

There has been tremendous growth of prominence globally and in Kenya on Agroecological diversification in the recent years as a potential tool to enhance soil productivity. Despite the prominence, there is limited scientific evidence, in relation to agroecological biodiversity, demonstrating how soil productivity is improved on smallholder farming systems particularly in Kenya. Smallholder farming systems face persistent soil fertility decline, water stress, and declining agricultural production. To illustrate, there is a declining productivity trend with maize crop in Kenya at a rate of 0.07t/ha per decade highlighting a deeper concern of soil productivity loss. To arrest this, there has been intensified and diversified interventions resulting into an increased use of external inputs and heterogeneity of smallholder farming systems. Regardless of the solutions, low soil productivity still persists. This study sought to determine the impact of agroecological diversification practice on soil productivity in smallholder farming systems in Busia County.

1.3 Objectives

1.3.1 General Objective

To assess agroecological diversity among smallholder farms in Busia County using modified version of the FAO TAPE Tool and assess its effectiveness on soil productivity.

1.3.2 Specific Objectives

To assess the extent of agroecological biodiversity aligned practices of smallholder farmers in Busia County

To evaluate the effectiveness of smallholder agroecological diversification on soil productivity

1.4 Research question

What is the status of agroecological biodiversity practice among smallholder farmers in Busia County?

How does agroecological diversification among smallholder farmers influence soil productivity in Busia County?

1.5 Justification of the study

Diversity in the ecosystem promotes productivity, sustainable and resilience in agriculture. However, evidence related to the performance and impacts of agroecological diversity aligned practices within localized settings in Kenya is very scanty, especially in the areas dominated by smallholder farms, such as the Busia County area. The FAO Tool for Agroecology Performance Evaluation (TAPE) provides a globally standardized approach to assessing agroecological biodiversity, but localizing and contextualizing it have yet to be thoroughly explored in Kenya.

The justification of this study is to provide empirical data regarding the indicators of agroecological diversity and the understanding of diversities link to soil productivity. After identifying context-specific indicators through TAPE tool and determining their extent and effects in Busia County, the study will contribute to better evidence-based agricultural policies, extension strategies, and farmer practices for sustainable land use and improved livelihoods. This will also enhance efforts to scale up agroecological biodiversity in Kenya and other similar agroecological zones of Sub-Saharan Africa (Mottet et al., 2020; Namirembe et al., 2022).

1.6 Significance of the Study

This research utilized the FAO Tool for Agroecology Performance Evaluation (TAPE) to understand the extent and nature of agroecological diversity among smallholder farmers in Busia County. With this localization of a globally accepted tool, the research has also increased the relevance of using this tool within the smallholder farmers' context and thus enabled assessment of agroecological practices in a much more accurate and context-specific manner. The results of the research will be expected to guide policymakers and development partners on how well agroecological biodiversity interventions work, thereby adding value to action and strategy formulation advocating for more sustainable agriculture. Results are also expected to inform agricultural extension services to develop more specific and relevant farmer support programs. Smallholder farmers themselves will have greater contributions by better understanding their ecological performance at farm level, which will eventually help them adopt and optimize the principles of agroecology. This study also adds to the global repository of knowledge in sustainable agriculture, where this localized

information can be tackled by a developing country perspective for comparative analysis and international policy dialogues.

1.7 Limitations of the Study

There were limitations encountered during the study. The county ministry of Agriculture, Livestock and Fisheries (MoALF) had a misinterpretation of agroecology, same to the local enumerators. This was addressed by conducting a rigorous, thorough and comprehensive four day training. The training was inclusive of evaluating exercises to gage their understanding and see fit if ready for the field. This was then followed by a pilot survey whereby nearby farmers, who were not part of the selected, were administered the survey to help the enumerators have a feel of the activity prior actualizing it.

Secondly, an anticipated constraint to success of the research was language and cultural barriers which was arrested by deliberately choosing to work with local enumerators who were conversant with the native language of the farmers and understood and respect culture of the smallholder farmers

Thirdly, a few times, weather challenges were experienced where by rainfall interrupted the data collection, hindering movement and also effective communication due to the sound pollution from the rain drops hitting the roofing materials. This was handled by calling farmers a day before and scheduling the survey with them early to enable completing the exercise early, using the dry hours, in the day. Apart from that, the data collection was conducted using mobile devises which were well stored in zip

locked bags. This helped to flatten the process and improve efficiency, ensuring shortest time possible per smallholder farmer.

Lastly, farmers had memory loss on previous season's information and had no record keeping documents. To ensure accurate data collection, information on the most recent planting season was captured, that is first planting season of 2024.

1.8 Assumptions of the Study

The below were key assumptions as basis of the study:

1. That the farmers started practicing trained the agroecological biodiversification practices as soon as they were introduced to it, that is in the year 2020, and that they consistently practiced.
2. That farmers provided true responses to the interview questions.
3. That the modified FAO TAPE Tool was appropriate and relevant for assessing agroecological biodiversity performance in the Kenyan smallholder context.
4. That within the parameter of this study, reliable identification, measurement, and analysis of agroecological indicators was possible.

1.9 Operational Definition of Terms

Agroecological Diversity/ Agroecological Biodiversity: These are interchangeably being used, meaning the same: The variety and variability of above-ground components, that is trees, crops, animals and activities, within a farming system.

FAO TAPE Tool: A standardized framework developed by the Food and Agriculture Organization for evaluating the performance of agroecology using identified indicators.

Smallholder Farming: Agricultural production managed by individuals or households with limited land size (typically less than 2 hectares).

Soil Productivity: The capacity of soil to support plant growth and sustain agricultural output over time, influenced by chemical, biological and physical aspects of soil health.

Localization (of a tool): The process of modifying and/or improving a global assessment tool to fit the conditions of a specific local context.

CHAPTER TWO

LITERATURE REVIEW

2.1 Agroecology

The establishment of Agroecology can be traced back to the early twentieth century, when Benzin in 1928 first used it as a descriptor of ecological methods in research concerned with crops or plants (Naicker et al., 2023). From then, advancements have been on the definition of agroecology where it has transformed to consider ecological and social aspects in managing food systems (E. Barrios et al., 2020). Agroecology has developed now into a transdisciplinary endeavor encompassing ecological principles into agricultural systems to sustain that system, biodiversity, and equity (Wezel et al., 2020). It is now a combination of knowledge with traditional and farmer/local knowledge of farming systems to attract novice practice adoption and increase productivity while conserving the environment. As per Gliessman (Gliessman, 2015) , agroecology "is the application of ecological concepts and principles to the design and management of sustainable agroecosystems." To elaborate further, this means that agroecology is a package entailing forms and techniques of production not leaving behind cultural, social, economic, and political aspects of the complex agriculture dynamic; hence the empowerment of farmers and food sovereignty (Wezel et al., 2009).

According to Rivera-Nunez (Rivera-Núñez et al., 2020), agroecology arose at the threshold at which agronomy and ecology are apparently diverging into two opposing-but-strengthening disciplines. The first appropriation of the agroecology term took

place, according to (Tittonell, 2023), in the 1930s, when the Russian agronomist Bensin asserted that agricultural crops should be considered ecosystems. The term found legitimacy in scientific circles in the late 1970s, when a group of Latin American scholars disturbed by the environmental and social consequences that industrial agriculture provoked in Latin America applied the term to their critiques (Gallardo-López & Fellipe, 2019).

In the 1980s and 1990s, agroecology globally topped as a movement championing for an alternative to the Green Revolution model, one that promoted high use of external input at the expense of smallholder farmers and the environment. Agroecology was defined as an academic discipline and a movement back toward peasant agriculture and indigenous knowledge systems by Miguel Altieri, one of agroecology's early and top protagonists, (C. L. Anderson et al., 2021; Moseley, 2024). In the past recent years, organizations such as the Food and Agriculture Organization (FAO) have taken on agroecology as a core framework for sustainable food systems, supporting it through instruments like TAPE (FAO, 2021c). Currently, agroecology is defined as a science, a set of management and farming practices, and a social movement whose thrusts are social equity and ecological sustainability.

2.2 Elements of Agroecology

Agroecology is based on an assortment of interrelated principles and elements aimed at achieving greater sustainability, resilience, equity, and adaptability of agricultural systems to local ecological and socio-economic contexts. The FAO established an exhaustive framework in 2018 with ten elements of agroecology, aiming to assist

countries and stakeholders in transforming their food and agricultural systems (E. Barrios et al., 2020).

These elements are: diversity, co-creation and sharing of knowledge, synergies, efficiency, recycling, resilience, human and social values, culture and food traditions, responsible governance, and circular and solidarity economy.

2.2.1 Diversity

An increase of area under variety and variability is inclusive of improvement in ecosystem services pertaining to pollination, pest control, soil fertility, and climate resilience (de la Riva et al., 2023) (Puech & Stark, 2023). Farm level diversity also opens the doors for dietary diversity and its nutritional benefits. Therefore, it can be concluded that diversity is an umbrella term covering biodiversity (M. A. Altieri, 1999; Wang et al., 2021). There is more contribution to stability and variety of ecological functions making basis for food production and soil health through diverse agricultural systems (Renard & Tilman, 2019). Farm activity diversity is a buffer to the uncontrollable and unpredictable market risks as well as climate change. This is so due to the fact that plants and livestock require different environmental conditions for their optimal performance. The FAO states that diversity is a precondition to agroecological transitions especially in the context of global change.

2.2.2 Co-creation and Sharing of Knowledge

Leave no one behind and participatory knowledge systems are of utmost essence to agroecology becoming, fundamental of collaborative processes through which farmers, researchers, extension agents, and countless other stakeholders generate and exchange agricultural knowledge. (Gliessman, 2015).

In the agroecology continuum, co-creation and knowledge-sharing of practices and scientific innovations assume a great role in farmers' decision-making (E. Barrios et al., 2020). Transdisciplinary cohesion can be fostered through agroecology through the integration of knowledge from diverse sources and perspectives, including traditional and indigenous knowledge of agricultural biodiverse management practices, and practical knowledge from both male and female farmers and traders about local markets (Bendito & Barrios, 2016). This ensures knowledge decentralization supports farmer-led innovations; whereby farmers are active partners in the design, testing, and fine-tuning, enhancing their participation, of agricultural techniques and technologies and promoting their adoption and scaling rate. (Wezel et al., 2009).

It is more of a horizontal transfer than vertical when it comes to knowledge sharing in agroecology. Initiatives for experience-sharing and innovation, such as farmer field schools, peer-to-peer learning groups, community workshops, etc., empower the communities to own their agricultural processes and promote joint problem-solving (FAO, 2019b). In addition, it includes indigenous knowledge-such as traditional soil fertility techniques, pest control methods, or crop selection strategies-preserving

cultural heritage and bolstering ecological comprehension in their localisms (M. A. Altieri & Toledo, 2011). More importantly, co-creating knowledge also builds trust and partnerships between researchers and communities. Farmers who own the process create a feedback loop in which practical field knowledge informs research, and research in turn is enriched by local insights.

2.2.3 Synergies

All the activities involved in different components of a farming system such as crops, animals, soil organisms, and natural vegetation are put together and organized by complementarity in an agroecological environment to produce an output larger than the total of its parts. Additional such synergy signs promote increased productivity, efficiency in resource use, and ecological sustainability. Agroecology encompasses intercropping among other practices for fostering such positive interactions (M. A. Altieri, 2019). For instance, when intercropping, several crop species are grown together for soil fertility enhancement, pest control, and stability of yield. For example, intercropping a legume species with a cereal for the fixation of atmospheric nitrogen enriches the soil for nitrogen and cuts down the use of artificial fertilizers (Jensen et al., 2020).

The same way, crop livestock integration induces nutrient cycling where manure from animals augments soil fertility while crop residues are fed to animals, thus forming a closed-loop system (Domínguez-Hernández et al., 2025).The Agroecological approach maximizes these mutualistic ecological interactions where beneficial organisms, including pollinators and mycorrhizal fungi, promote plant growth, and

regulate natural enemies (predators and parasitoids) against herbivorous pest species (M. A. Altieri et al., 2024). Such systems thus rely on maximizing ecological functions these processes provide to offset expensive external inputs like chemical fertilizers and pesticides while enhancing the efficiency and resilience of farming systems (Gliessman, 2015). Thus, synergisms enhance short-term productivity and play a major role in ensuring the ecological sustainability and long-term health of agricultural landscapes.

Furthermore, agroecology therefore acknowledges the need to capitalise on greater-than-additive-or-synergistic interactions between components in the agroecosystem (Naicker et al., 2023). Such potential scenarios could play out at field level, looking at the benefits of intercropping species of legumes and cereals; at farm level, recognising the positive impacts of organic matter management on soil health; or at ecosystem level, looking at the impact of biodiversity on biological pest and disease control (Naicker et al., 2023). For agroecological systems design, fostering diversity and synergies must be prioritized to tap into the multitude of benefits available in component interactions (E. Barrios et al., 2020).

2.2.4 Efficiency

The efficient utilization of resources is the main precept of agroecology, which ultimately aims at attaining optimization in agricultural inputs such that it becomes maximally productive with minimal deleterious effects on the environment. Thus, agroecological systems use all inputs from nature: sunlight, water, soil nutrients, and

so on, while minimizing the applications of non-renewable or external inputs (Hawes *et al.*,2021) (FAO, 2019).

An assortment of context-specific practices is applied, for instance precision agriculture to achieve full farm potential. Secondly, mulching, where by use of organic or polyvinyl chloride materials are used to conserve soil moisture, suppress weeds and regulate soil temperature reducing use of herbicides (El-Beltagi et al., 2022). Apart from recycling nutrients through farmyard or compost manure the manures also support to improve soil structure and biological activity, reducing soil erosion and improving water movement within the soil profile (Gliessman, 2015). These increase input-use efficiency, that is soil moisture and nutrients, while also minimizing production costs, ultimately enhancing soil productivity (Bommarco et al., 2018), meaning increased output per unit input over time (Hodapp et al., 2019), increasing income flows, thus leading to increases in returns to production factors for farmers (van der Ploeg *et al.,* 2019) (Mottet *et al.,* 2020).

2.2.5 Recycling

This is one of the key component that works towards closing nutrient loops and cut down on synthetic and externally sourced inputs (Hawes et al., 2021), enhancing soil health and sustainability of the farming practices (Sharma et al., 2019). Organic matter can be very useful for namely animal manure, crop residues, compost, or some other kind of biomass, which, in turn, means putting it back into the soil for nutrient enrichment and an increased organic matter content (Tittonell, 2014).

This provides the soil with fertility and structure, porosity for microbial functioning, retention of water, and sequestration of carbon. The cost-effectiveness of nutrient cycling is augmented by these ecological processes. Agroecology fosters the use of locally available resources-generally farm-generated-composite or mulches-while discouraging imports of synthetic fertilizers or chemical amendments, thus promoting self-sufficiency and reducing the impact on the environment (M. Altieri & Nicholls, 2018). This enormous recycling through the optimization of internal resource use can, as Tittonell (2014) says, considerably reduce the ecological footprint of farming while fostering system resilience and productivity through time.

Recycling in agroecological production strives to close nutrient cycles through composting, which brings back biological resources from agricultural wastes to soil health, moving up the value chain through regional recycling systems among many actors of the food system. For example, food wastes and processing by-products are recycled-back into soils, fed to animals, and used for biogas production. Recycling thus reduces the economic and environmental costs involved in production while improving the independence of farmers from external inputs through closing energy and nutrient cycles and reducing wastes (Shurson, 2020). This increase in autonomy translates to reduced vulnerability of farmers to unexpected shocks.

2.2.6 Resilience

In agroecosystems, resilience is understood as an ability to absorb disturbances and shocks stemming from disturbances such as climate change, pest outbreaks, changes in the price of commodities, market adjustments, and other socio-economic or

environmental stressors. Thus, agroecological resilience entails not just survival amidst these adversities but also survival in a productive and functioning way. According to Altieri, Nicholls, Henao, and Lana (M. A. Altieri et al., 2015), resilience is closely linked to diversity and integration within the farming system: Diversified systems through polycultures, agroforestry, and crop-livestock integration, as well as including local varieties, tend to be more stable and adapt better to changes by spreading risk and reducing vulnerability to specific threats.

Composting and cover cropping are soil enhancers; they set up interfaces for water retention and infiltration, while beneficial biotic interactions reduce pest populations and offer pollination services (Vikas & Ranjan, 2024). Biodiversity is a key factor for resilience and is, in the language of political economists, referred to as "ecological redundancy," or paraphrased with (Vasiliev, 2022) as a situation where many species carry out almost the same tasks, thereby allowing for ecosystem functioning to continue uninterrupted even upon the loss or stress of some elements. Agroecological systems, thus, are much stronger and better in withstanding acute shocks and long-term stressors by promoting these ecological processes.

It upholds a diversified community of organisms, which through the occurrence of pest and disease outbreaks will be allowed to self-regulate within the ecosystem. These diversified agroecological systems are usually more resilient to extreme weather events (Wood, 2023). Inappropriate food and animal species hence create pathways toward economic and social resilience through diversification by agroecological transitions (Tittonell et al., 2020). This is because farmers depend less on a solitary

crop that could be affected by external market and climatic conditions. Agroecology on the other hand reduces dependency on external inputs by encouraging recycling and efficiency by enhancing biological processes.

2.2.7 Human and Social Values

Agroecology is, by definition, not confined to an ecological or technical approach; it is as much a social movement that advocates human dignity, equity, inclusion, and social justice (Bezner Kerr et al., 2022). In its essence, agroecology positions people at the center of defining sustainable food systems for agroecology, especially the voices of those who have been systematically marginalized in the past (Wezel *et al.*, 2022). The above definition entails that smallholder farmers, rural women, youth, and Indigenous groups contribute to agriculture, much less appreciated and oftentimes excluded from decision-making processes (Zulu et al., 2021). Empowerment of these groups is the goal of agroecology so that the groups may enjoy equal entitlements to land, seeds, water, credit, and equal participation in the governance of food systems. One of the hallmarks of the agroecological transformation is that it is centered on human development. Policies and practices are supposed to be developed for people, not for the market (Tornaghi & Dehaene, 2020). In this, the agroecological transformation takes into consideration the need for dignified livelihoods, the promotion of cultural identity, and respect for traditional knowledge systems (FAO, 2019). Agroecology promotes social harmony and collaboration among individuals for better collective action towards strengthening the rural social fabric while contributing to more democratic and resilient food systems. A study done by Wezel and others (2009) stated that incorporating social values into agroecological practices

makes certain that sustainability encompasses social dimensions as well as environmental goals. Thus, see that agroecology is a path for realizing not only ecologically-oriented farming practices, but also transformative changes within rural societies.

Human and social values such as dignity, equity, and inclusion feature prominently in agroecology. They relate to the dimension of Improved livelihoods under the Sustainable Development Goals (Wezel *et al.,* 2014). Values in human and society shall add flavor to social capital and collective action by bringing the needs of food producers, distributors, and consumers to the center of food systems (Nosratabadi et al., 2020). This approach to development would provide an alternative lens of social sustainability for rural development, endowing people as initiators of change.

2.2.8 Culture and Food Traditions

Important driving factors to good agriculture practice in an area are food culture and food traditions (Zhang et al., 2017) (Dumont et al., 2016). Food culture and traditions are viewed as a must in establishing a food system that sustain food security and nutrition and nurtures the well-being of ecosystems and agrobiodiversity (Kennedy *et al.*, 2022). Food systems are tied much deeper with local knowledge, food practices, and cultural heritage (Morgan & Trubek, 2020). Food is a reference point and not just a source of livelihood and additionally a cultural identity, as is concerned with agroecology (FAO, 2019). This again is crucial with preserving agriculture biodiversity through crop and local diets (Kennedy et al., 2022). Community seed

banks , local open markets and farmers' field schools strongly contribute to revitalization of traditional food systems (Marchetti et al., 2020).

2.2.9 Responsible Governance

The shift toward sustainable agriculture and food systems through agroecological methodology necessitates the establishment of effective and pioneering policies, institutions, and market structures that actively support and stimulate this fundamental transformation (Caron et al., 2018; Naicker,2023). These governing mechanisms operate across multiple levels, culminating in the legitimization of agroecological products within niche markets and providing tangible incentives to participating farmers.

A critical dimension of responsible governance in agroecology involves environmental protection policies that prioritize biodiversity enhancement, the reduction of synthetic chemical inputs, and effective water resource conservation (Migliorini & Wezel, 2017). Furthermore, strengthening farmer collectives, cooperatives, and analogous local grassroots entities is crucial. This is accomplished by facilitating the transfer of technical knowledge for minimizing synthetic input dependency and by ensuring governance transparency (Wezel et al., 2009). Such institutional support strategically builds both the rural community's economy and its social capital (Wezel et al., 2009).

2.2.10 Circular and Solidarity Economy

The convergence of the circular economy (CE) and the solidarity economy (SE) presents a robust conceptual and practical framework for realizing the Sustainable Development Goals (SDGs), specifically by rebuilding direct, reciprocal relationships between producers and consumers (Shroeder et al., 2022). Crucially, driving agroecological transitions is fundamental to cultivating genuine rural community resilience. Such transitions ensure the economic viability of primary food producers while simultaneously establishing equitable pricing structures for end-consumers (Feliciano et al., 2019). The solidarity model finds practical expression through mechanisms like local markets, cooperative organizations, and Community-Supported Agriculture (CSA) initiatives (Rommel et al., 2022). These structural alternatives intentionally bypass conventional supply chains, fostering direct engagement that cultivates trust, transparency, and a foundation for just pricing. This essential shift significantly reduces food miles, thereby mitigating associated negative environmental impacts and reinforcing the durability of local economic ecosystems. Furthermore, the embedded principles of fair trade within agroecological practice are non-negotiable, requiring farmers to receive just compensation, operate under acceptable labor conditions, and adhere strictly to sustainable farming methodologies (Wezel et al., 2020). Beyond economic and environmental imperatives, the solidarity economy actively facilitates social inclusion and empowerment, deliberately creating avenues for marginalized populations to engage and ensuring their democratic participation in the critical processes of food system decision-making. In its essence, agroecology acts as the catalyst that unites the dual objectives of circularity; the

systemic reuse of resources to minimize waste, and solidarity, a commitment to social justice and cooperation. This integrated approach positions itself as a systemic counter-narrative to extractive economic models, securing food sovereignty and long-term ecological balance. (Pimbert, 2018).

2.3 The transition from agroecological elements to agroecological principles

Initially, agroecology was firmly rooted in the ecological dimensions of agricultural systems like crop diversification, nutrient cycling, and natural enemy regulation of pest populations (M. A. Altieri, 1995, 2019). In fact, this diversity for agroecology was often applied purely as a technical measure for improving sustainability of farming practices-due to the evident tendency of environmental degradation attributed to conventional agriculture. Realization was that biophysical alone would not be enough to overcome this harmful state of food and farming systems over time as the area of inquiry matured in the hands of scholarly and practitioner communities. In this regard, agroecological principles were born, which were wider, normative guidelines that included the ecological, social, economic, and political dimensions (Wezel *et al.*, 2009). It thus marked a conceptual shift from agroecology seen as tool hours to agroecology as a transformative paradigm for realizing food sovereignty, social justice, and environmental resilience (Gliessman, 2016).

FAO identifies ten components of agroecology such as diversity, synergies, recycling, and co-creation of knowledge that collectively bring forth a set of agroecological principles. It has also succeeded in institutionalizing this transition within some membership states through (D. Barrios et al., 2019). "These principles are not just

technocratic prescriptions but value-based participatory and concerned with farmer agency, equity, and cultural identity-from research scholars such as Nicholls and Altieri (2018), who argue that for agroecological principles to be realized, power relations in food systems must be reconfigured." This implies not just substitution of inputs but redesigning agricultural systems with local communities. For example, the principle of co-creation and sharing of knowledge challenges topdown extension approaches by valuing indigenous knowledge systems and farmers' innovations.

The transition is further supported by peasants' movements like La Vía Campesina, which endorse agroecology as a political instrument defending peasant rights and resisting corporate control towards agriculture (Rosset & Altieri, 2017). Such grassroots mobilizations need to entrench agroecology in government structures taken up with independent policy-making and decentralized food systems. Despite the growing consensus on the importance of agroecological principles, there is a rift between such words and deeds. Anderson et al. (2021) cite such things as incoherence of policy, inadequate funding for research, and institutional resistance as part of the barriers to realize fully the transformation from agroecology. However, the transition from individual isolated components of a technology to comprehensive principles is, in its own right, a significant step toward a holistic reimagination of agriculture as an ecologically sound, socially just, and culturally appropriate practice.

2.4 Principles of Agroecology

Agroecology is defined by principles" Tittonell *et al.* (2020) -in other words, it is "an applied discipline based on principles" (Patton, 2018). There is an agreement among agroecologists that the discipline of agroecology developed throughout the years around a set of principles, based on key fundamental values, resulting from the cumulative experience of knowledgeable Indigenous farmers, activists, and scholars concerned with advancing ecologically sustainable farming and just food systems (Wezel et al., 2020; Barrios et al., 2020; Gliessman, 2018) (Rosset & Altieri, 2017). In the 1970s, there was an evident "gradual shifting toward an ecosystem approach to agriculture, with an enormous expansion of agroeconomic literature with an agroecological perspective" (Rosset & Altieri, 2017).

Particular agroecological principles apply directly to farmers (Barrios et al., 2020; Wezel et al., 2020) requiring some form of support from other actors in the food system (Bendito & Barrios, 2016).

Principles have "general relevance but not global outcomes," thus the use of principles in agroecology requires modification to fit specific area for "generalization without universalization" (Bell & Bellon, 2018). As Patton (Patton, 2018) emphasized "principles guide adaptation." Thereupon, the value of using the principles of agroecology is to move forward a global countermovement based on sustainable and just agroecological transformations in different scenarios including complex urban ones. Using agroecological principles for "agroecological urbanism," Tornaghi and Dehaena (2021):

It facilitates the awareness of the other principles and signals actors to engage with them. For example, social values and diets can be promoted through multistakeholder discourse, including indigenous communities, consumers, academic institutions, and food producers (Wezel et al., 2014). When consumers become aware of the ecological and social benefits associated with agroecology, it signals producers to cater to those needs by adopting the on-farm principles (van der Ploeg et al., 2019). The same can be implied with connectivity, they require consumer participation or an enabling environment. Land and resource governance directly refers to policy that supports institutional arrangements to improve, including the recognition and support of family farmers, smallholders, and peasant food producers (Wezel et al., 2020). Participation also refers to social organisation and multistakeholder discourse.

Table 1: The 13 Principles of Agroecology

Criteria	**Principle**
On-farm	1) Recycling
	2) Input Reduction
	3) Soil Health
	4) Animal Health
	5) Biodiversity

	6) Synergy 7) Economic Diversification 10) Fairness
Off-farm	8) Co-creation of Knowledge 9) Social values and Diets 11) Connectivity 12) Land and Natural Resource Governance 13) Participation

Source: Naicker (2023)

The High Level Panel of Experts on Food Security and Nutrition (HLPE) identified thirteen key agroecological principles related to ecological, economic, and social dimensions: recycling, reducing inputs, soil health, animal health, biodiversity, synergy, economic diversification, co-creation of knowledge, social values and diets, fairness, connectivity, land and natural resource governance, and participation. Concepts like economic diversification and using arm's reach resources contribute to farm resilience and reducing external input dependency (Wezel et al., 2020).

The principles also respond to social equity and governance issues through application of co-creation of knowledge, fairness and (Wezel et al., 2020). In Kenya, there is a study that investigated how the components of agroecology would be included into legal and policy frameworks and other pointed out sectors (Awiti & Ndiwa, 2024). This was also reflected in South Africa (Greenberg et al., 2023).

The 13 consolidated principles in agroecology are: (1) recycling, (2) input reduction, (3) soil health, (4) animal health, (5) biodiversity, (6) synergy, (7) economic diversification, (8) co-creation of knowledge, (9) social values and diets, (10) fairness, (11) connectivity, (12) governance of land and natural resources, and (13) participation (FAO, 2020; Sinclair et al., 2019). These principles are combined together and interactively engage the ecological, the political, the economic, and the social dimensions of food systems - in line with the holistic rationale of agroecology (FAO, 2020).

Agroecological biodiversity is its fundamental, championing the preserved and varied genetic, species and ecosystem diversity at various scales. This spills over with synergy, whose mandate is to provide ecosystem services such as pest regulation and nutrient cycling (Sinclair et al., 2019). Co-creation of knowledge emphasizes the value of blending scientific research with indigenous and local knowledge, and co-innovation through participatory processes (FAO, 2020).

The principles were designed to be broad, offering local context relevance (FAO, 2020; Wezel et al., 2020). These context-specific principles mirror the FAO's 10 Elements of Agroecology providing a level of specificity in relation to soil and animal

health, likewise to differentiating biodiversity and economic diversification (Wezel et al., 2020).

There is tension on implementing and maintain agroecologically aligned practices on large scale farms. Despite all that, the 13 principles provide a chance to manoeuvre these conditions, enabling many parties to co-develop sustainable, resilient and just agrifood systems (FAO, 2020; Wezel et al., 2020).

2.5 Critique of Agroecology

The ambiguous definition of agroecology is the major concern resulting into a variety of interpretations resulting in incoherent application (E. Barrios et al., 2020). The broadness of agroecology makes it difficult to establish common metrics for measurement and distinguish between a true agroecological change process and just a superficial masking of market-based actors under a green label ("greenwashing") (Greenpeace, 2023). A couple of researchers argue that the lack of an agreed definition may hinder the incorporation into mainstream agriculture policy and practice (Snapp & Doss, 2019).

(Rivera-Ferre & Ortega-Cerdà, 2011) The authors argue that the different alaborations of the terminology of agroecology has led to more disputing narratives. The issue has been faced by agroecologists with continuous resistance against things which would pervert or simplify the unique pluralistic trajectory of the discipline with a fusion of heterogeneous modes of knowing and a transdisciplinary lens (Juncos, 2021). By building alternatives thought processes of agroecology, this has brought about

pluralistic trajectory of the heterogeinity and transdisciplinary lens (Anderson et al., 2021).

Moreover, in the past several decades since agroecology has picked up steam, an increasing number of voices that have been engaged with the issue of hunger have asked the question of whether sustainable agriculture can rise to the challenge of feeding the world (Adidja et al., 2019; Arroyo et al., 2018). Recent research reported there were about 500 million food insecure and food deprived households worldwide in 2010 and developing countries were still struggling to implement new food security strategies and policies to address these challenges (Vanloqueren, 2011). On the other side of the ledger, meanwhile, the world population is expected to reach 8 billion people by 2025, while the amount of cultivable land will not be increasing, which is declining in fertility and healthy nutrients of which it has depleted the soil with pesticides and herbicides and non-sustainable agricultural practices (Juncos, 2021).

Criticism also arises with respect to the scalability and practicability of broad-based agroecological practices. There are common challenges about whether agroecological approaches that are generally trialed at a local scale can reliably feed a growing global population (Blesh et al., 2019). Opponents of agroecology often cite the time demands of many agroecological practices like diverse cropping systems and on-farm nutrient cycling may dissuade the use of agroecological practices by large-scale conventional farms or farms locally with little labor available (Reganold & Wachter, 2020). If the start point for functioning agroecological systems can require lower yields and greater

management, it is a significant risk for farmers, and many will not be willing to face that risk of failure without guarantees of support (IPES-FOOD, 2020).

Among the critiques is the claim that agroecology would never offer producers an alternative as attractive as what the Green Revolution offered (i.e., hybrid seed, chemical fertilizers, price supports for large farms, etc.) because it cannot be a means of agricultural intensification (Juncos, 2021). Also, allegations of social justice and equity, women empowerment, and so on are not sufficiently backed up by research done in agroecology in various contexts. However, the strongest criticism is that agroecology is simply a modern label for 'traditional farming, 'wherein it resurrects the traditional methods and gives importance to the cooperation of researchers and peasants (Mugwanya, 2019).

Policy frameworks, especially at national levels, often fall behind international and regional support for agroecology. In Tanzania, while international and regional policies endorse agroecological approaches, national policies usually fail to address localized indicators, have poor institutional coordination, and provide minimal integration of sustainability principles. In addition, the bad institutional capacity of agricultural extension services to promote sustainable agroecological principles also represents a barrier, as many farmers reported limited access to such support when isolated from extensions services (Magesa et al., 2025). There are also questions over the resilience of agroecological systems, particularly under extreme climatic events, such as prolonged drought. Although agroecological practices such as crop diversification and soil management can increase resiliency, agroecological systems

have limits. Prolonged and severe stressors may outcompete their systems adaptive capacity particularly if they are undermined by environments requiring broader collective action aimed at watershed restoration and supporting policies that incumber farms alone (M. A. Altieri et al., 2025).

Moore (Moore, 2016)puts salinization of irrigated lands, water wastage, pest resistance, and climate change in the pot for creating disasters. And just the other news, public investment in agriculture is down, political will is down, and the gap between public and private sectors has widened the problem even more (Arroyo et al., 2018). Therefore, in the midst of all this, there remains good reason to say that agroecology can solve world hunger. Corbeels (Corbeels et al., 2020), a harsh and outspoken critic of agroecology, claims that agroecology in many African regions may be trapping farmers in poverty and food insecurity. Hence, agroecology at best brings no benefit for most poor farmers but instead lures them to put more into the soil for less in return, thus deepening their poverty than before. Hence, agroecology may not fit smallholder farmers' need to overcome low crop productivity and food insecurity (Corbeels et al., 2020).

D'Annolfo et al. (D'Annolfo et al., 2017) reported in their review study of 17 papers on the economic performance of agroecology that there was evidence of agroecology contributing to the financial capital of smallholders. The explanation for the improved financial capital is found in the study by Pretty et al. (Pretty et al., 2003) on the yields of small farms practicing sustainable practices and technologies. Pretty et al. considered 208 projects from 52 countries. Pretty et al. (Pretty et al., 2003)found that

yield increases of 50-100 percent tended to be bigger for lower yields, providing greater income for poorer farmers. Therefore, regarding the question about feeding the world, agroecology provides a more holistic answer. Farmers, peasant, and other smallholders of the world can begin the brave journey to feed their communities with organic, nourishing, healthy foods.

Put differently, each community should feed themselves, not the world, as sustainable farming practices vary "across the diversity of our territories... and each sector is adding their colors of their local reality and culture" (Nyéléni, 2015). Once we have achieved this goal, the issue of hunger worldwide should be eradicated. Moreover, the root causes for world hunger are not the same in every country (Adidja et al., 2019), so each situation requires a specific solution. Agroecology does not endorse a one-size-fits-all, it requires approaches that are integrative, participatory, and action-oriented for each different socioecological system (Gliessman, 2018).

The authors Adidja et al. (Adidja et al., 2019) provided an exhaustive study for the answer to such criticism. The authors selected a handful of major global assessments that reviewed hundreds of agroecological projects throughout the world, reporting on their yields, food production output, and food security. They concluded that evidence from different studies strongly supported that agroecology really does play a predominant role in addressing world hunger(Juncos, 2021). Besides, agroecology also attacks the hunger issues in the world at their roots through a holistic view of inequality and increased poverty and malnutrition while providing efficient remedies

to the farming system in terms of conserving biodiversity and natural resources and maximization of resilience against climate change (Adidja et al., 2019).

There is widespread agreement amongst many activists and scholars that a primary challenge for agroecology is the attempt to co-opt the discipline through oppositional discourses and definitions (C. L. Anderson et al., 2021). Over the course of its history, it has travelled through an interesting reposition. Agroecology has transitioned from the Cinderella of agriculture, a movement which was dismissed, ignored, and rejected by dominant institutions in formal agriculture, to a radically unexpected position. More recently, some key power actors have started to recognize agroecology as an alternative framework to develop solutions to the food crises created by the Green Revolution and to restore fear of the industrial agriculture (Rosset & Altieri, 2017). Agroecology therefore is now situated at a crossroads when it must choose whether to smoothly assimilate into the industrial agriculture process or take the difficult road of pressuring institutions, governments, research institutions, and multiple others to accept what agroecology stands for (M. Altieri & Holt-Gimenez, 2016).

The corporate food industry attempted to restrict the definition of agroecology to be a way of making sustainable food and farming practices easier to integrate as a technological fix, allowing for easy co-optation of agroecology into the mainstream industrial agriculture and food systems, without contesting the existing power structures maintained and used by agri-food industrial conglomerates (C. L. Anderson et al., 2021)This subversive approach would also "fine-tune the industrial food system, while simultaneously recognizing the environmental discourse…under 'climate-smart

agriculture' or 'sustainable' agriculture or 'ecological-intensification' or ‘organic’ food produced through industrial monoculture" and a variety of other ideas (Juncos, 2021).

This appropriation of agroecology has been identified as incorrect, inaccurate and hazardous (O. F. Giraldo & Rosset, 2018) Governments, the private sector and other large ac tors such as the Food and Agricultural Organization (FAO) consider agroecology as a way to address the food crisis and manipulate the industrial agriculture agenda. However, social movements and bottom-up initiatives perceive agroecology as a substitute to industrial agriculture, that will change the approach to agriculture (O. F. Giraldo & Rosset, 2018; Rosset & Altieri, 2017). The second danger derives from the use of narratives of multiple 'agroecologies', in other words, as other agricultural paradigms as agroecological model (Wezel et al., 2018). Utilising cognitive theory, Sanford (Sanford, 2011) identifies that the language has constructed the dichotomy of industrial agriculture and agroecology. Industrial agriculture is dependent on a discourse of "mechanistic relationships" between the human agents and the passive land, agroecology offers up a narrative of "interdependence and reciprocity" that refuses the industrial formula.

Another important aspect of concern refers to socio-political complexities and power dynamics that exist within food systems. Critics argue that promoting agroecological practices at the farm level means nothing if the underlying structural issues that maintain unsustainable food systems are not addressed. That includes factors such as market failures, unequal access to land, corporate monopolization of various aspects of the food value chain, and entrenched political interests that favour industrial forms

of agriculture (Clapp, 2022; IPES-FOOD, 2020). Critics also argue that the way agroecology is conceived does lead toward substantial technical solutions, while also deemphasizing fundamental political and economic change (Wittman & James, 2022). In addition, issues related to gender inequality, accessibility to key resources, and decision-making power within communities can also influence agroecological transitions and the distribution of benefits (FAO, 2023).

2.6 Soil Productivity Interventions

Soil productivity is the capacity of soil to support crop growth and development to yield over time and land size. This encompasses the soil health aspects, that is soil chemistry, soil biology and soil physics. Soil productivity has been on a declining trend as evidently seen with attained national production when compared to expanding crop land (FAOSTAT), fertilizer application campaigns, subsidized fertilizer campaigns amongst others. Improved soil productivity through diversified cultivation primarily improves the soil biodiversity, organic matter content and nutrient cycling process. Increasing crop diversities enhances diverse soil microbiome to process carbon, nutrients and breakdown organic matter (Erktan et al., 2024). Evidence exists (Wu et al., 2020) that identified diversified cropping systems increases biodiversity and abundance of microorganisms that improves soil multifunctionality, such as nutrient cycling, biological pest control, which vastly enhances sustainable agriculture. A meta-analysis of agroecological practices in Africa conducted by Kaudain et al. (2025), presented crop diversification, organic matter management, reduced tillage, and agroforestry, as indispensable practices to enhance soil fertility

and productivity. The favorable aspects of these practices is reduced reliance on synthetic inputs, increased soil organic carbon stock, reduced erosion, and ultimately sustainable long-term productivity.

Diverse cropping systems (intercropping and crop rotations) are important contributors to soil fertility. The 'doubled-up legume' technology; Intercropping pigeon pea with either groundnut (peanut) or soybean types of legumes has improved nitrogen and organic matter in soils, improving soil fertility and reducing the use of synthetic fertilizers promoting sustainable agriculture in Malawi and Zambia (Chikowo et al., 2020; Smith et al., 2016). Likewise, in Kenya rotating maize with a green manure legume-type bypassing velvet bean and crotalaria increased maize yields due to soil nitrogen and structure (Ojiem et al., 2014). It is evident from past studies that crop diversification can promote soil productivity naturally by increasing available nutrients. Long-term work has illustrated the total value of agricultural diversification on soil health. A meta-analysis spanning 50 years have shown practices such as intercropping and organic farming and soil inculcations improve soil quality characteristics (e.g., carbon stock and microbial diversity). These improved soil characteristics increase financial profitability and environmental services over time, indicating the sustainability of diversified agroecological management systems (Raveloaritiana & Wanger, 2024).

Christel et al. (Christel et al., 2021)conducted a meta-analysis demonstrating that diversified farming practices, such as reduced tillage and more different cover crops, led to more stable and resilient microbial communities that can adapt to environmental

stressors. These resilient microbial communities can also better decompose organic materials, cycle nutrients, and reduce the impacts of soil-borne pathogens, leading to a more sustainable agricultural practice and long-term soil productivity. Li et al. (Li et al., 2024) found evidence that different plant species release different chemical compounds that stimulate the growth of specific beneficial microorganisms, including plant growth-promoting rhizobacteria (PGPR) and mycorrhizal fungi. These microorganisms engage in a symbiotic relationship with the plant, providing greater soil support for nutrient uptake and stress resistance. The end result is improved soil productivity and increased crop yields.

One recent on-farm study explored conventional, no-till, and organic wheat-based systems and found that organic management that involved crop rotation with crop diversity and organic amendments maximized soil health enhancement (+47%) but had crop yield reduction of -34% compared to conventional systems. There were intermediate soil health benefits from no till system. The researchers showed that soil health parameters were positively correlated with crop yield in their study, specifically in conventional farming systems. They reported diversification could improve both soil health and yield with a follow on an effective crop protection mechanism (Walder et al., 2023).

Improved agroforestry systems for instance maize intercropped with Faidherbia albida trees increased maize yields significantly in Malawi due to soil fertility improvement (Ekyaligonzaa et al., 2022).

Oelbermann and Echarte (Oelbermann & Echarte, 2011) found that intercropping legumes with non-leguminous crops reduces leaching and volatilization losses, making the system environmentally sustainable as well as increasing the soil productivity. Cao et al. (Cao et al., 2024) looked at how diversified pastures, containing a mixture of grasses and forbs, can enhance phosphorus availability. It was observed that plants can exude organic acids that release organic phosphorus making it available to plants, reducing the amount of externally applied phosphorus. Further, livestock further reduces by contributing to recycled nutrients through farmyard manure (Asghar et al., 2024). This not only improves soil nutrient levels and availability but also improves soil structure and water retention capacity (GIZ, 2025; Üllenberg, 2025) (Francaviglia, 2022). Agroecological practices that increase soil biological health will contribute to improved productivity. Beneficial soil organisms such as mycorrhizae fungi and earthworms are increased through practices like reduced tillage, applying organic amendments, and applying crop residues. These organisms make valuable contributions to nutrient cycling, soil structure stability, and soil-borne pathogen suppression. Overall, these soil health improvements lead to more productive and healthier soils (Mattoo & Gowda, 2022).

McClelland et al. (2022) (McClelland et al., 2022)showed that diversified cropping systems including cover crops and legumes can produce much higher soil organic matter (SOM) levels than conventional monoculture cropping. The degree of SOM in a soil is the most important factor determining soil fertility because SOM enhances water holding capacity, aggregate stability and nutrient holding capacity. Huang et al. (2024) (Huang et al., 2024)documented that agroforestry systems (tree-crop or tree-

livestock) improve soil structure and reduce soil degradation and erosion rates because of the greater root systems of the trees and their continuous deposition of organic residues. Yang et al. (2023) documented those complex rotations with multiple crop species encourage a more active and more diverse soil microbial and soil community overall. Microbial diversity plays an important role in a number of ecosystem services such as nutrient mineralization and disease suppression. Yang et al. (2023) suggested that overall, the increased number of beneficial fungi and bacteria in the diversified plots of their study led to greater nutrient availability for future crops (Yang et al., 2023)

Policy frameworks are increasingly recognizing an important role for agroecological diversification as a way to increase soil health and food security. For example, the Vihiga County Agroecology Policy (2025) recognizes 'land management that minimizes or eliminates the harmful use of agrochemicals and exploitation of food systems, which supports the production of sustainable food based on agroecology, thereby increasing/improving soil health' (Vihiga County, 2025). Similarly, initiatives in Ethiopia offer financial support and technical assistance to encourage adoption of crop diversity, while emphasizing the critical role of integrated soil fertility management, erosion control, and sustainable productivity (CIAT, 2024). Though the benefits of agroecological diversification are clear, there are still barriers to farmers adopting diversification strategies from economic limitations, to knowledge and context-processes for managing diversified systems. Research is needed on understanding the temporal functioning of soil biodiversity and above and belowground functioning, and development of common metrics for assessing soil

biodiversity/multi-functionality in diversified systems (Erktan et al., 2024). Economic analyses are also needed to inform useful policy strategies to overcome barriers to adoption, and find ways to promote the usage of sustainable agroecosystems (Francaviglia et al., 2022).

2.7 FAO's Tool for Agroecological Performance Evaluation (TAPE)

The Tool for Agroecology Performance Evaluation (TAPE) from the Food and Agriculture Organization marks a major step in measuring and evaluating agroecological systems. It was developed to harmonize scorings across the globe and bring a universal understanding of state of agroecology (FAO, 2023, 2024) (CIRAD, 2024; Kansanga et al., 2019). This holistic approach is necessary as agroecological transitions need to mirror the complexities involved and at the same time capture key insights about growth for research, practice, and policy.

TAPE tool's greatest potential is its ability to have the 10 Elements of Agroecology by FAO (FAO, 2019b; HLPE, 2019), keeping a record of actions and offers an opportunity to improve particular elements during agroecological transformations. It also supports data collection, generating evidence. This enables the development of knowledge based on agroecology by documenting the costs, benefits, and tradeoffs of agroecological practices (CIRAD, 2024).

Evidence is vital for policymakers for informed decision making, sharing the benefits of agroecological measures with the wider population (FAO, 2020). TAPE's data can contribute to working at the intersection of qualitative findings (i.e. interviews) and a

more systematic scientific assessment of agroecology that would offer more scientific credibility to agroecological claims. The FAO's global consultations, from 2014 to 2018, identified the urgent need for a standardized tool to produce comparable data from varying contexts (FAO, 2023, 2024). To answer this need, the FAO, with many partners and stakeholders, created TAPE through a consultative process with experts and civil society from over 25 countries (Mottet et al., 2020).

TAPE has been designed as an integrated but easy-to-use tool to follow a stepwise approach, mainly at the household or farm level with aggregation at a community or territorial level. It stands on and is built around the sum of various assessment frameworks. It is intended to require minimal training and data collection so that it can be widely adopted, even in resource-limited settings (FAO, 2024; Mottet et al., 2020). The tool walks users through a diagnostic process aimed at assessing agroecological performance across several dimensions environmental, social, economic, etc. using a set of prioritized indicators (FAO, 2023, 2024).

TAPE has been piloted in more than 58 countries, and it has shown that it can be applied in a wide variety of agroecological zones, production systems, and local contexts (FAO, 2024). TAPE provides strong, multidimensional performance data for evidence-based policymaking, and designing interventions to support sustainable agriculture. It provides opportunities for participatory data collection, leading to knowledge and ownership development among producers, so that they can observe their strengths and weaknesses in their systems, and see progress over time. It helps to diagnose the enabling and disabling environments for agroecological transitions,

and provides better targeting for support, as well as scaling the best practices (FAO, 2023, 2024).

After the successful implementation of the original tool, the TAPE+ project, which is financed by the European Commission, is currently refining existing metrics, which include enhanced digital components, and a greater user experience and analytical potential. TAPE+ is being implemented in multiple countries in Africa, in order to bolster national level agroecological assessments, and support the wider adoption of agroecological practices (FAO, 2024). While TAPE has been praised for its simplicity and flexibility, major adjustments are still needed to refine indicator selection based on context, connect to other monitoring frameworks, and ensure accountability for data quality given existing or new contextual changes (Mottet et al., 2020). Nevertheless, TAPE is considered a significant step in systematizing agroecological evidence and making sustainable agriculture a reality at a global scale.

Notwithstanding these above-mentioned challenges, the current view in the emergent literature is that TAPE represents a major step forward for evaluating agroecological performance. It is a standardized and flexible tool that can help yield more rigorous progress to understand agroecological transitions, promote evidence-based policy making and provide continuous improvement to sustainable food systems around the world (FAO, 2020; HLPE, 2019). Ongoing development and application of TAPE, while addressing challenges to implementation, will be of great importance in advancing its utility within a shifting global environment for agroecology.

2.8 Knowledge Gap

The literature on agroecology has revealed a number of significant knowledge gaps that challenge the scaling of, and policy uptake of, the agroecological paradigm shift. The most significant is the neglect of participatory action research (PAR) to substantiate knowledge about the socio-cultural drivers and barriers to agroecological transformation. In many of the agroecological literature, the focus is on the (often technical) practices, rather than engaging with farmers and other communities to co-generate knowledge which engages the user, thus restricting the category of knowledge obtained with respect to longer-term adoption and related social processes (F. O. Giraldo & Rosset, 2023). Likewise, while much of the literature focuses on smallholder farmers, there is clearly a gap in literature to explore how agroecology can be integrated in larger farming systems, which dominate much agricultural land area globally but are also constrained (by way of example) by institutional scale, complexity, governance processes (Tittonell et al., 2020).

Policy gaps also remain highly visible, especially in many African nations, where to reflect localized indicators and institutional coordination to achieve agroecological transitions has eluded national frameworks. Research on the resilient limits of agroecological systems while facing extreme climatic stress, such as severe droughts, is limited and often only refers to how to extend the adaptation thresholds at either the farm or landscape scale (M. A. Altieri et al., 2025).

Another area that is underexplored is social-ecological governance, especially power relations and bottom-up community-led organisations, which are highly relevant for

bringing about sustainable agroecological transformations, but have been little studied (F. O. Giraldo & Rosset, 2023). Finally, there are methodological issues regarding the development of multidimensional, participatory, and scalable assessment tools that capture the complexity of agroecological systems in different contexts (Kaudain et al., 2025). Filling these gaps will be needed for developing agroecology' s involvement in facilitating a transformation of the sinful food system.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The project was carried out on smallholder farmers in Busia County, one of the forty-seven (47) counties with a medium high potential area for agriculture, located in Western region of Kenya, It is adjacent to other three counties that is Bungoma to the north, Kakamega to the East and Siaya to the south west. Part of the Lake Victoria is in Busia County on the South East and borders the lake with the Republic of Uganda to the west. Busia County lies between latitude 0^0 and 0^0 45 north and longitude 34^0 25 east, receives an annual rainfall between 760mm and 2000mm, experiences temperatures range of 14^0C to 30^0C and has altitude range of 1130m to 1500m asl. It has two (2) rain seasons that is long rain season between mid-March and Late May and short rain season between August and October. Its major soil type is Acrisols. The agriculture in Busia County is primarily rain-fed with maize, sugarcane, beans, sorghum, cotton as the major crops grown; chicken, pigs, goats, cows as the major livestock reared and Cypress and eucalyptus tree varieties as the popular tree varieties planted.

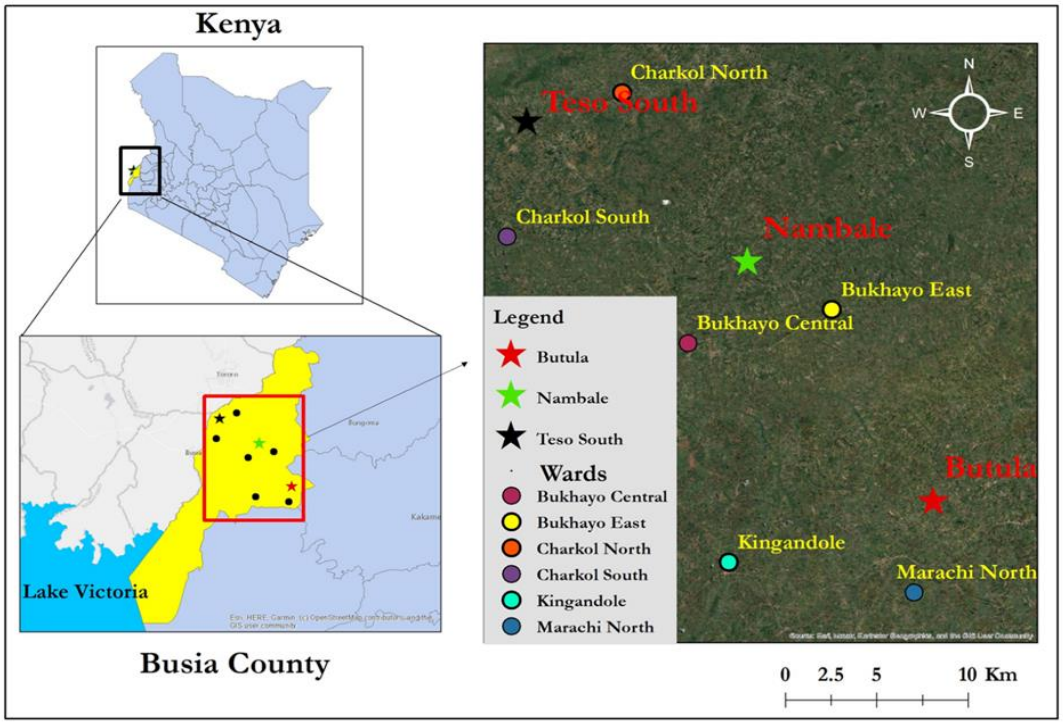

Figure 3. Map of Busia County and the selected administrative wards, indicating the study area

3.2 Methodology

A descriptive survey was employed to respondents, by trained enumerators using KoboCollect tool, a mobile data collection tool, to generate qualitative and quantitative data, observations combined with farmers' response. Data was collected from smallholder farmers specifically in Charkol North and Charkol South of Teso South subcounty; Kingadole and Marachi North of Butula subcounty and Bukhayo Central and Bukhayo East of Nambale subcounty. The data set was acquired from the Ministry of Agriculture, Livestock and Fisheries, and the locations were purposively selected, those are the administrative locations where entities delivered training on agroecological biodiversity. The households in the locations were previously exposed

to practices that are aligned to agroecological biodiversity principles since the year 2020. They got exposed to the practices through trainings, workshops and farmer school centres, offered by private sector and the county projects. Since the exposure, they have practiced them so as to be food secure and to increase incomes from their farms.

To determine the sample size, the Fischer formula was applied and a value of 210 was obtained. The obtained value, n=210, then divided by 6, the total number of administrative wards resulting to 35 per administrative ward. In each ward, those with more than 35 smallholder farmer household, random sampling using Microsoft Excel was done and the top 35 were selected. The administrative wards which had less than 35 smallholder farmer households, snowballing was conducted to achieve the n=35 number. The smallholder farmer households that did not consent to the survey or were unavailable, snowballing was conducted to reach the required number of households (n-35).

3.2.2 Target Population

The target population was smallholder farmers engaged in agricultural activities that align with agroecological biodiversity principle, who learnt the practices from either the county government projects, private stakeholders or national government projects.

3.2.3 Target Crop

Maize was the target crop, for it is staple food and majorly grown in Kenya and it is key food security indicator globally, regionally and in Kenya.

3.2.4 Sample Size

The desired sample size was determined using the formula of (Fischer et al., 1998). Which population of more than 10,000 was used to calculate the constant.

$$n = \frac{z^2 pq}{d^2}$$

Where;

n= the desired sample size in case the population targeted is more than 10,000

Z= A standard normal deviation at the required confidence level (given as 1.96 for 95%

Confidence level)

p= proportion of the target population estimated to have characteristics being measured (0.5)

q= statistical notation for (1-p) = (1-0.5)

= 0.5

d= degree of accuracy (acceptable error margin) = 0.05

q= 0.5

d= 0.05

z =1.96

Thus n= $\frac{(1.96)^2 \times (0.5)(0.5)}{}$

$$(0.05)^2$$

= 384.16

Since the population was less than 10000 to be studied, fisher's method of 1998 was used to determine the sample size.

$$n_{adjusted} = \frac{n}{1 + \frac{n-1}{N}}$$

$$n = \frac{384}{1+{}^{384-1}/_{460}}$$

= 209.60

n = 210 respondents

3.3 Data Collection Methods

3.3.1 Quantitative Data Collection

Structured surveys, using digital data collecting application tool; Kobo Toolbox, were administered to smallholder farmers to gather data on the types and extent of diversification practices. The Kobo Toolbox is an open-source tool with both online and offline functionalities enabling data collection using any device or browser.

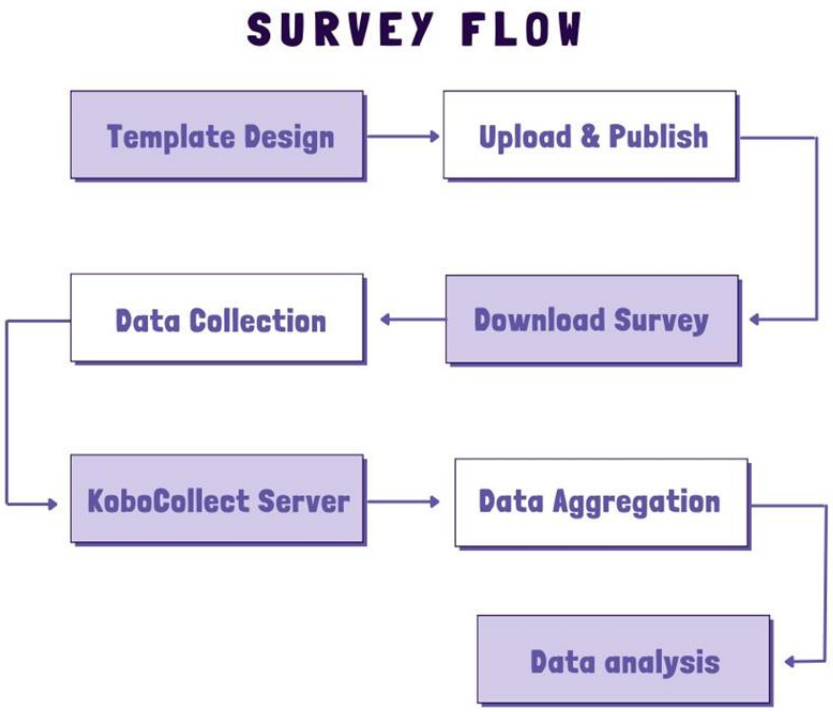

Figure 4 Survey flow, demonstrating development of the survey on the KoboCollect tool

The scoring framework, the FAO TAPE tool, was developed to quantitatively evaluate the application of the agroecology. The diversity section of the tool was modified to fit local context and used to evaluate the agroecological diversity principle based on predefined indicators, that is, as crops, activities, trees and livestock diversity.

Table 2. Characterization of Agroecological Transitions

CROPS	
Scores	Diversity
0	Monoculture (or no crops cultivated)
1	One covering more than 80 percent of cultivated area.
2	Two or three types of crops with significant cultivated area
3	More than 3 crops with significant cultivated area adapted to local and changing climatic conditions.
4	More than 3 crops of different varieties adapted to local conditions and spatially diversified farm with multi-, poly- or inter-cropping.
ANIMALS (INCLUDING FISH AND INSECTS)	
0	No animal raised.
1	One animal only
2	Two or three animals, with few animals.
3	More than 3 animals with significant number of animals.

4	More than three animals with different breeds well adapted to local and changing climatic conditions.
TREES (AND OTHER PERENNIALS)	
0	No trees (nor other perennials)
1	Few trees (and/or other perennials) of one species only
2	Some trees (and/or other perennials) of more than one species.
3	Significant number of different species of trees (and/or other perennials).
4	High number of trees (and/or other perennials) of different species integrated within the farm land.
DIVERSITY OF ACTIVITIES, PRODUCTS AND SERVICES	
0	One productive activity only (e.g. selling one crop only)
1	Two or three productive activities (e.g. selling 2 crops or one crop and one type of animals)
2	More than 3 productive activities
3	More than 3 productive activities and one service (e.g. processing products on

	the farm, ecotourism, transport of agricultural goods, training etc.)
4	More than 3 productive activities, and several services

Source: (FAO, 2019b)

Following the process as outlined by TAPE tool FAO (2019) and further recommended by Namirembe *et al.* (2022) the TAPE tool was modified to fit the local context as shown below.

Table 3. Modified TAPE Tool as per the researcher (2025)

CROPS	
Scores	Diversity
0	Monoculture of one variety/or no crops cultivated/at least 2 types of crops with insignificant cultivated area
1	One crop type /monoculture of two varieties covering more than 80 percent of cultivated area.
2	crops types with significant (>20% of the farm)
3	More than 3 crop types with significant cultivated area adapted to local and changing climatic conditions.

4	More than 3 crop types of different varieties adapted to local conditions and spatially diversified farm with multi-, poly- or inter-cropping.
ANIMALS (INCLUDING FISH AND INSECTS)	
0	No livestock raised/ 1 breed with few number livestock type
1	One breed only with significant number of livestock type
2	At least 2 breeds, with few livestock types
3	At least three breeds with significant number of livestock types.
4	More than three livestock types with different breeds well adapted to local and changing climatic conditions.
TREES (AND OTHER PERENNIALS)	
0	No trees (nor other perennials) >>>> / one species
1	Few trees (1-50) of one or different species.
2	Some trees (51-100) of more than one species
3	Significant number of trees (101-150) of different species.
4	A high number of trees (>151) of different species are integrated within the farmland.
DIVERSITY OF ACTIVITIES, PRODUCTS AND SERVICES	
0	One productive activity only (selling one crop only).

1	Two or three productive activities (selling 2 crops or one crop and one type of animals)
2	More than 3 productive activities
3	More than 3 productive activities and one service (e.g. processing products on the farm, ecotourism, transport of agricultural goods, training etc.)
4	More than 3 productive activities, and several services

3.4 Data Analysis

3.4.1 Quantitative Data Analysis

Descriptive statistics data from surveys were analyzed using descriptive statistics (means, percentages, and frequencies) and inferential statistics (Pearsons correlation analysis). Data was analyzed using R to score the diversity principle. The values were then averaged by first summing scores from each indicator score and then averaged by dividing with 4, the maximum score, to get overall score of the indicator. The indicator scores were then totaled up and divided by 16 (4 indicators each with a max of 4, hence total max score of 16) to get the average score of agroecological biodiversification. This was then converted to percentages and interpreted using the simple traffic light approach.

Scores of less than 50% are coded red, meaning unsustainable.

Scores of more than or equal to 50% and less than 70% are coded yellow, meaning acceptable.

Scores of more than or equal to 70% are coded green, meaning desirable. (Mugenda & Mugenda, 2003)

Soil productivity value was assessed using the soil productivity index (SPI) formula;

$$SPI = \frac{\text{actual yield}}{\text{potential yield (sourced from Kenya Seed packages of maize 5 series variety)}} \times 100$$

Below is the table interpretation of the different values of SPI

Table 4. Interpretation of SPI class values and Interpretations

SPI Value (%)	Interpretation	Class
80-100	very high productivity	I
60-79	high productivity	II
40-59	moderate productivity	III
20-39	low productivity	IV
0-19	very low/none producitve	V

Source (W. Anderson et al., 2016) (FAO, 2015)

A correlation analysis, using Microsoft Excel, was then done on the two variables, the agroecological biodiversity principle and soil productivity to determine their type and strength of relationship. Below is a table with the Pearson correlation coefficient values of correlation analysis and their interpretations, at 5% level ($p > 0.05$). (Papageorgiou, 2022)

Table 5. Interpretation of r values

Value of r	Interpretation
+1.0	Perfect positive correlation
+0.7 to 0.9	Strong positive correlation
+0.4 to 0.6	Moderate positive correlation
+0.1 to 0.3	Weak positive correlation
0	No correlation
-0.1 to -0.3	Weak negative correlation
-0.4 to -0.6	Moderate negative correlation
-0.7 to -0.9	Strong negative correlation

-0.1	Perfect negative correlation

3.5 Ethical Considerations

All participants were informed of the study's purpose, their rights, and the voluntary nature of participation; participant data was anonymized to protect privacy, and ethical approvals were obtained from the National Commission for Science, Technology and Innovation (NACOSTI).

CHAPTER FOUR

RESULTS

4.1 Response Rate

Out of the intended sample size of 210 respondents, only 206 of them completed the questionnaires and this yielded a return of 98.1%. The very high response rate was achieved due to working very well with local authorities, rigorous training of the enumerators, having timely follow-ups and check-ins with the trained enumerators. The data collection activity was done face to face, thereby curbing nonresponses. According to (Mugenda & Mugenda, 2003), a response rate of 50% is considered adequate, 60% good, and 70% and above very good. The response rate of this study was, therefore, excellent at 98.1%, and these can go a long way in making the study to be credible, reliable, and truly representative.

4.2 Demographic characteristics of the respondents

Understanding the demographic profile of the respondents was important in contextualizing this study. Demographic characteristics give insight into the social, economic, and educational background of the study population and hence might affect their farming methods, adoption rate of farming innovations, biodiversity integration, and land productivity. Key demographic variables investigated in this study were gender, age, level of education, average annual household income from farming, and main source of income of the household heads. The demographic data were collected from 206 respondents, which are summarized and discussed in Table 4.1.

Table 6: Demographic characteristics of the respondents

Demographic character	Attribute	Frequency	Percent
Gender of the household head	Female	83	40.3
	Male	123	59.7
	Total	206	100.0
Household head's age	18-35	138	67.0
	36-60	56	27.2
	Above 60	12	5.8
	Total	206	100.0
Level of education of the household head	Primary	38	18.4
	Secondary	80	38.8
	Tertiary	88	42.7
	Total	206	100.0
Average annual household income from the farm	Above Ksh. 100,000 (per year)	38	18.4
	Ksh. 20,000-40,000 (per year)	86	41.7
	Ksh. 40,500-60,000 (per year)	37	18.0
	Ksh. 60,500-80,000 (per year)	21	10.2
	Ksh. 80,500-100,000 (per year)	24	11.7
	Total	206	100.0
Main source of income	Business in farming (this involves sell or transportation of	17	8.3

farm produce that was not produced by the farmer)		
Business of other commodities	3	1.5
Employment	5	2.4
Farming	181	87.9
Total	206	100.0

According to Table 4.1, households were male headed to a majority of 59.7%. A substantial number of the household heads were considered to be young adults, ages between 18 and 35 (67.0%), suggesting an increasingly youthful farmer population. Regarding formal education, most respondents attended tertiary education (42.7%) followed by those with secondary education (38.8%). For a majority (87.9%), it was their income from farming that was the major income considered; thus, showing the agrarian nature of the study area.

The results showed that most of the households in the study were male-headed, but there were also a good number that were female-headed. This trend reflects the stereotypes associated with gender roles observed in rural Kenya, where men are often acknowledged as heads of households because of culture and land ownership structure. This aligns with past work by Kabubo and Irene (Kabubo-Mariara et al., 2009) (Irene et al., 2022) who found that land tenure systems, and their associated ownership and control of agricultural decisions, favor men over women, which is reflected in the delineation of heads of households

It is interesting to observe that most head of households are relatively young adults. This was an unanticipated yet positive observation for the regional profiles, given that a similarly young population in many other parts of sub-Saharan Africa appear to view agriculture as an 'old generation ' endeavor. The outcome of the findings suggests that young people's engagement with farming in the study area is positive by improving perceptions of the agricultural sector, specifically at the production level, for a future generation of farmers. These outcomes align with (FAO, 2021b) observations regarding incentive programs, and access to education, that are beginning to influence a positive perception of youth engaging with farming. This is promising for the future of agroecological aligned practices, as younger generation farmers are likely to be more prone to experimenting and engaging in innovative sustainable practices.

The education levels of the household heads were relatively high; many respondents had completed tertiary education. This education level potentially has an impact on the ways that farmers receive and engage with agroecological biodiversity aligned knowledge and adopt the practices. Earlier research such as that by (Mango et al., 2018) supports the argument that educated farmers are more likely to comprehend environmental risks and apply adaptive strategies that will potentially improve resilience and productivity. The implication is that a knowledge capacity among farmers could play a significant role in how households adopt sustainable land use, and biodiversity conservation practices.

Furthermore, farming was seen as the main economic activity by most respondents. This again reinforces the important role that agriculture plays for rural livelihoods,

especially in places like Busia County. The Kenya National Bureau of Statistics (KNBS, 2022) also reported that farming is still the backbone of the household economies of many rural counties in Kenya. The significance of being involved in farming is important, but can also add vulnerability when soil productivity is low or climatic variability is a challenge, and showcases the importance of integrated strategies that conserve agroecological biodiversity (above ground) and enhance productivity, improving income stability of smallholder households.

Objective 1: Agroecological biodiversity principle of the smallholder farmers using the FAO tape tool

The diversity scores were then converted to percentages, following the FAO TAPE tool guidelines, for interpretation purposes. This was done by dividing the obtained score by four (4) and then multiplying it by a hundred (100). The overall agroecological biodiversity was attained by totaling each indicator score and dividing by 16 (maximum score of each indicator is 4 and the indicators were 4, hence 16) then the obtained value converted to percentage by multiplying by 100.

4.3.1 Animal Diversity

The findings regarding livestock diversity showed the average total livestock diversity score was 1.25 out of a total score of 4, which is equivalent to 31.25%, interpreting unsustainable extent of practice.

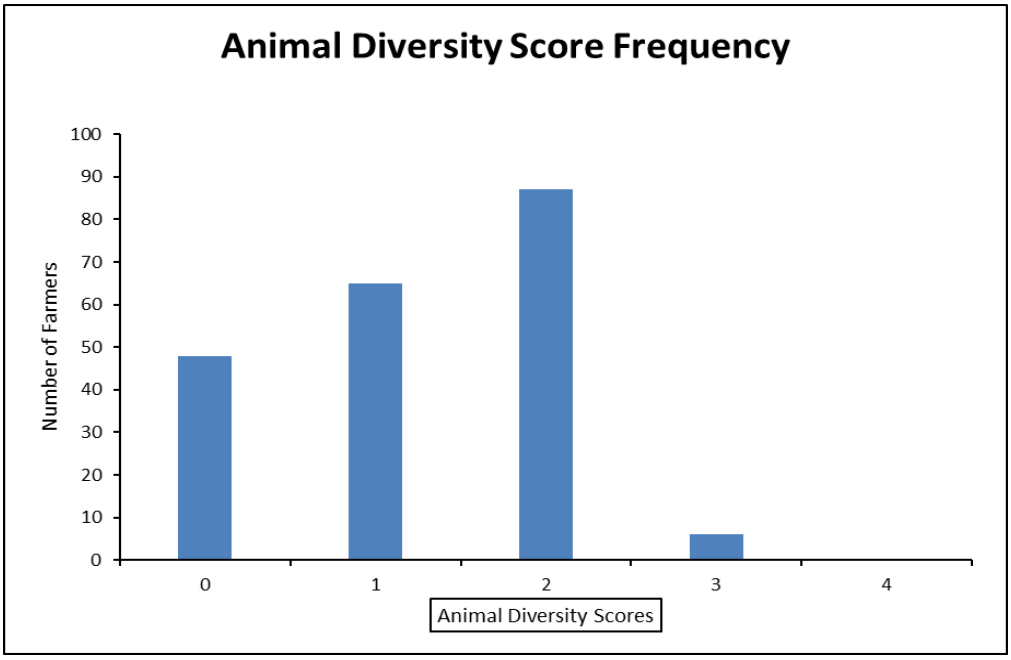

Figure 5: Frequencies of the animal diversity scores among smallholder farmers in Busia County, Kenya. Score 0-4 indicates low to high diversity

Out of two hundred and six (206) farmers, no farmer managed to score 4, forty-eight (48) farmers scored zero (0), sixty-five farmers scored one (1) and eighty-seven farmers scored two (2).

This indicates a fairly low level of diversity in the number of livestock owned by smallholder farmers in the study area. Local/indigenous poultry were the most commonly kept livestock, averaging 36 birds owned per household, followed by exotic broilers/layers with an average of 20 birds per farmer. Cows and goats averaged 4 per household, while 3 pigs averaged per household. The data highlights possible reliance on poultry due to the community culture, lower input costs and a short time period of return compared to larger livestock. Notably, over half (42.23%) of farmers had only one livestock type kept in significant quantities, indicating a lack of livestock

diversity in the study area. Unsustainable agroecological biodiversity across species indicates local economic hardship or a lack of extension support to promote diversification of various breeds of livestock, or constrained market conditions which disincentivized the diversification of livestock.

4.3.2 Tree Diversity

The average number of tree diversity score was 1.82 translating to 45.5%, the highest diversity score

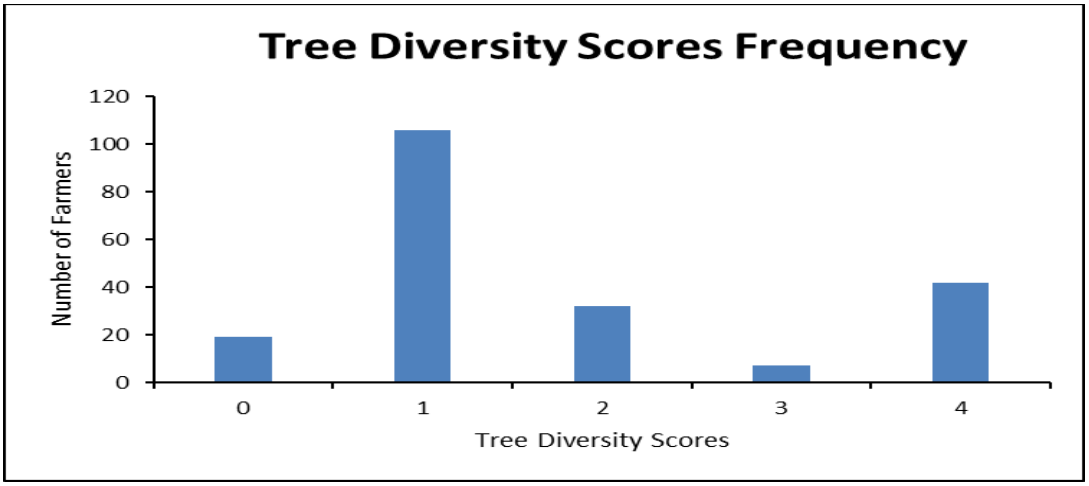

Figure 6: Frequencies of the tree diversity scores among smallholder farmers in Busia County, Kenya. Score 0-4 indicates low to high diversity

Out of two hundred and six (206) farmers, nineteen (19) farmers scored zero (0), one hundred and six (106) farmers scored one (1), thirty two (32) farmers scored two (2), seven (7) farmers scored three (3) and forty two (42) farmers scored four (4), This interprets to unsustainable extent of practice.

Only 22.33% of farmers developed diverse tree systems, including timber, ornamental, fodder, firewood and shade trees, indicating that they may have some knowledge and understanding of the ecological and economic benefits of planting

multifunctional tree systems. Most farmers, however, 51.46% had planted only one tree species, timber variety. This suggests that the farmers are aware of the high investment returns from sale of the tree harvest; high quality timber.

4.3.3 Crop Diversity

The average crop diversity score was 1.62, translating to 40.5% and interpreting unsustainable.

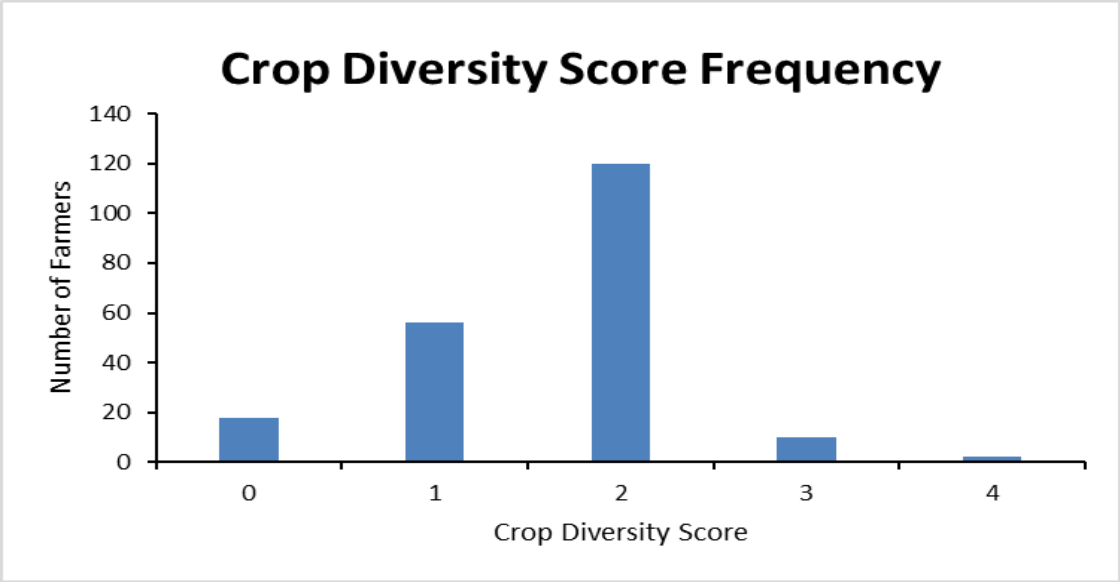

Figure 7: Frequencies of the crop diversity scores among smallholder farmers in Busia County, Kenya. Score 0-4 indicates low to high diversity

Out of two hundred and six (206) farmers, eighteen (18) farmers scored zero (0), fifty-six farmers (56) scored one (1), one hundred and twenty (120) farmers scored three (3) and two (2) farmers scored four (4).

A large number of farmers, that is one hundred and seventy-six (176) of them, scored their cropping system diversity between 1 and 2, indicating that their cropping system

contained one or two main crops. Still, a number of farmers (23.43%) scored higher, indicating they grew two or more crops including maize, beans, cassava, and soybeans.

4.3.4 Activity Diversity

The average activity diversity score was recorded at 1.67, translating to 41.75% and interpreting unsustainable practice.

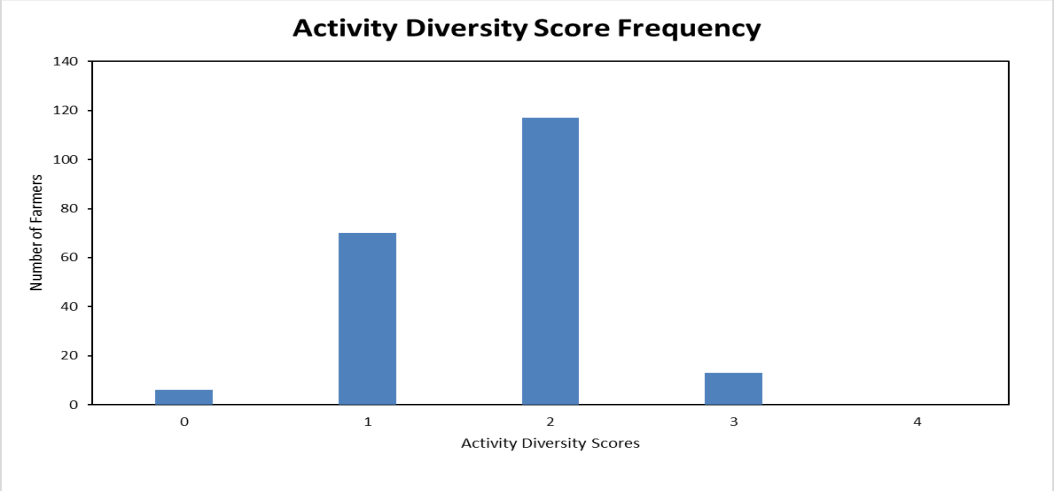

Figure 8: Frequencies of the activity diversity scores among smallholder farmers in Busia County, Kenya. Score 0-4 indicates low to high diversity

Out of two hundred and six (206) farmers, six (6) farmers scored zero (0), seventy (70) farmers scored one (1), one hundred and seventeen (117) farmers scored two (2), thirteen (13) farmers scored three (3) and no farmer managed to score four (4). Indicating that farmers are active in multiple activities, but not truly diversified. The largest percentage of respondents (56.80%) were engaged in two main activities, and only 6.31% achieved a score of 3 indicating they were engaged in three or more large

on-farm enterprises. It is likely that this low intensity of practice represents either specialization or resource limitations restricting expansion into other productive activities. Specialization can be effective when resource productive, however, over-specialization may expose farmers to additional climate and market variability risk by relying primarily on one or two activities.

The obtained scores show an unsustainable extent of agroecological biodiversity practice. This supports the need of strategic urgency intervention to stimulate a holistic farming system with greater and diverse productive opportunities.

4.3.5 Overall Agroecological Biodiversity Score

The overall agroecological biodiversity score gives a summary measure of the extent of practice across important components of the farming system, that is crops, animals, trees, and on-farm activities. This composite score represents the degree to which smallholder farmers embrace biodiversity as an important aspect of their farming systems.

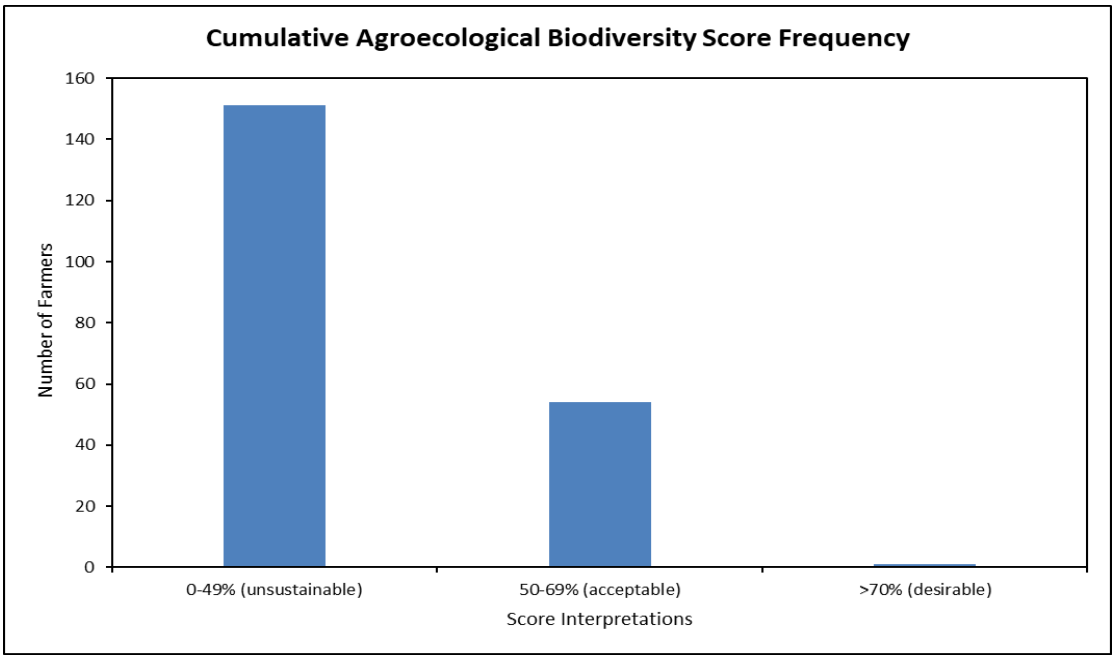

Figure 9: Frequencies of the Cumulative agroecological biodiversity status in percentages among smallholder farmers in Busia County, Kenya. Score of 0-49% is unsustainable, 50-69% is acceptable and more than 70% is desirable.

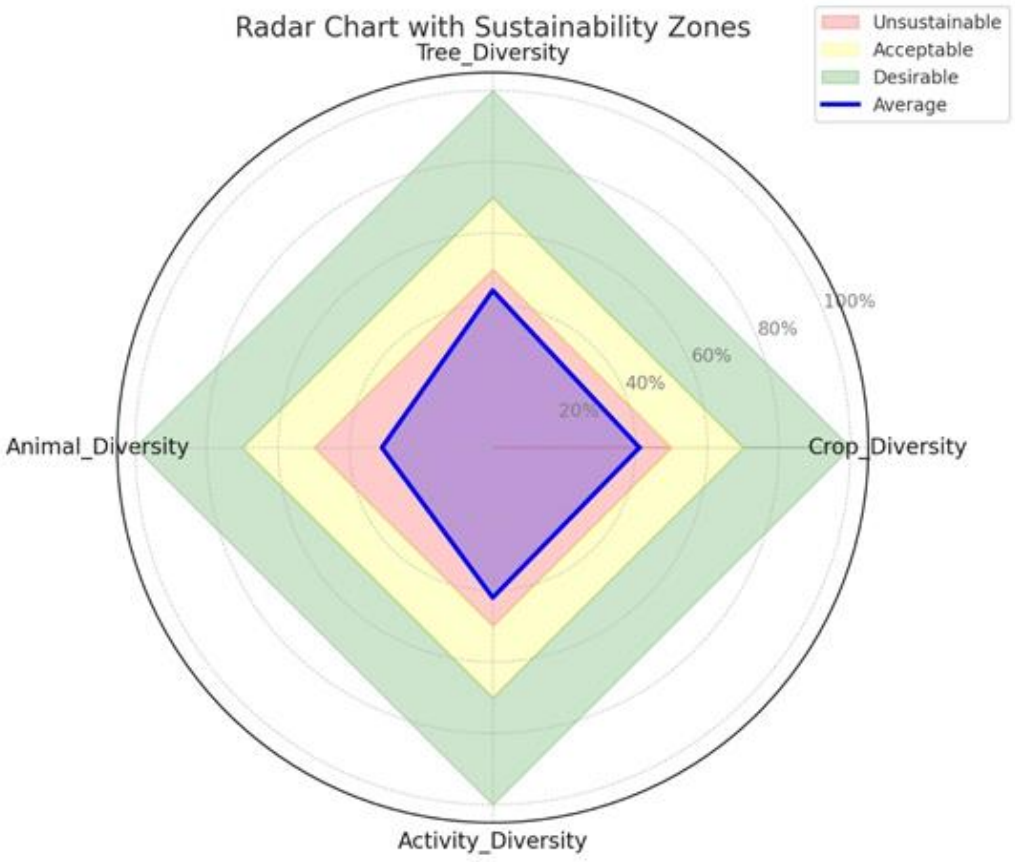

Figure. 10 A radar chart showing the cumulative agroecological biodiversity status in Busia County, Kenya.

The overall agroecological biodiversity score for the study area was 1.59, which is 31.8%, interpreting unsustainable, in the TAPE (Tool for Agroecology Performance Evaluation) scoring system. It is a composite score based on the average of the animal, tree, crop, and activity scores. Only one (1) farmer attained the desirable extent of practice, one hundred and fifty one (151) of them are unsustainably practicing agroecological biodiversity and fifty four (54) of them are acceptably practicing agroecological biodiversity practices. A score of 1.59 indicates that while some farmers are practicing agroecological biodiversity aligned practices, most farmers (151) still have unsustainable biodiversity within their farming systems. This overall

score aligns with the prior analysis showing that the scores of livestock, crops, tree diversification, and agricultural activity were unsustainable to acceptable levels of diversity.

A score this low could reflect many aspects: lack of awareness practices that are agroecological diversity principle aligned, insufficient access to extension services, low showcase of practicability of the aligned practices, economic pressures forcing farmers into a monoculture cycle, or limited access to varied inputs, such as seed for various crop varieties, variability of tree species seedlings, or breeds of livestock. Certainly, these results did provide a compelling case for capacity building, policy support, and other incentives for diverse, hands-reach to access and practicability.

The assessment of livestock diversity across the sampled farms revealed that indigenous poultry species were overwhelmingly the most prevalent. This preference can be attributed to several key factors: their superior adaptation to diverse local environmental conditions and the significantly lower input requirements, making them particularly suitable for resource-constrained smallholder farmers. This observation aligns with existing literature, such as the work by Bett et al. (Bett et al., 2012) which established that local poultry are frequently chosen by rural households for their enhanced economic resilience and cultural significance.

However, the current concentration on only one or two livestock species presents a suboptimal scenario regarding the ecological benefits that genuine diversity offers, specifically in terms of soil nutrition and nutritional safety. A broader spectrum of livestock species is known to substantially enhance nutrient availability within the

farming system. For instance, while poultry manure is rich in nitrogen, it is produced in smaller quantities compared to cattle waste. This difference, as noted by Thornton and Herrero (Thornton & Herrero, 2015) permits a broader, more even distribution across a larger land area, optimizing soil enrichment.

A comparable pattern of unsustainable lack of diversity was evident in the assessment of tree species diversity, despite this indicator achieving the highest score overall. The data shows a significant dichotomy: only a minority of farmers (45) cultivated a varied array of trees for purposes such as timber, fodder, firewood, or shade. In stark contrast, the majority of smallholder farmers (106) displayed an overwhelming reliance on a single species, primarily timber trees. Studies, including that by Garrity (Garrity, 2004) have demonstrated that integrating arable trees into farming systems positively affects soil health.

The limited variability in tree species and the over-dependence on timber can be interpreted as a symptom of insufficient technical extension services. This highlights systemic weaknesses where information dissemination channels or techniques may not be adequately simplified or effective, or, critically, where misinformation is being communicated to smallholder farmers. Majority of farmers (118 farmers) highly dependent on one or two crop types with maize majorly farmed for it is the staple crop. Only a small number of smallholder farmers (5) practiced diversified crop farming having legumes and root crops. It was reported by Altieri (M. A. Altieri et al., 2015) that monoculture continues to be entrenched in the agroecological diversity of smallholder farmers in Africa, despite well- known risks like soil degradation and

putting farmers at risk of pests and climate stresses. The high overreliance on maize crop by smallholder farmers point out the role of structure and policies privileging cereal production and overlooking nutritional and ecological diversity.

On farm activity diversity also scored unsustainable extent of practice. The farmers (117 farmers) remained anchored to one or two main activities. A variety of on-farm activities can offer protection against market protection unpredictability and environmental uncertainty (Pretty, 2011).

The results communicate that agroecological biodiversity in the study area is unsustainable level of practice. These results resonate recently discovered results by FAO in the Soil Protection and Rehabilitation for Food Security (ProSoil) global project that reported diversity score of 51%, incipient stage. (FAO, 2025). This means that the advancement of agroecological biodiversity in this landscape is dependent upon the implementation of targeted interventions aimed at supporting integrated, knowledge-based and place-based agroecological biodiversity practices. This resonated with FAO (FAO, 2025) for they identified apart from underlying issues of high levels of degradation and limited access to ecological inputs and markets, conflicting technical information by various organizations leading to confusion among farmers and farmer cooperatives hindering adoption of most appropriate farming practices.

The average score for agroecology biodiversity in the case study area had an unsustainable score. The unsustainable score indicates that agroecological biodiversity is poorly practiced among the smallholder farms. The score describes a

farming environment with diversity in crops, livestock, trees, and on-farm activities but not sufficiently developed in order to achieve the benefits associated with agroecological biodiversity farming and farming systems. As the FAO (FAO, 2019b) describes, greater agroecological biodiversity implies improved system resilience, increased nutrient cycling, and improved soil productivity. Elaboration here however reveals that in this instance, so much agroecological biodiversity was lost in transition to agroecological farming, with the score recording the loss of already lost potential ecological services.

Earlier studies showed that farming communities that are characterized by the widespread practice of agroecological biodiversity practices such as intercropping, agroforestry, rotational livestock systems, and diversified income actions consistently have higher biodiversity scores (M. Altieri & Nicholls, 2017). Modifications were lower than expected in the present study, likely due to constraints in access to agricultural extension services, limited knowledge of sustainable practices, and capitalism forcing farmers to prefer monocultures to highly specific enterprises.

These findings correspond with the observations of (Méndez et al., 2013), who argue that structural and institutional limitations often restrict agroecological biodiversity in smallholder contexts, despite widespread awareness of its ecological and economic value. This suggests that supportive policy environments and interventions to promote and scale agroecological biodiversity principle through changing practices, will be necessary. Given that the score produced here incorporates not only the outcomes of agroecological biodiversity but the unrealized agroecological biodiversity potential of

these farming systems. In order to support resilience and sustainable productivity in the region, next generation agricultural systems must prioritize these agroecological biodiversity-enhancing practices, including improving agroforestry, livestock systems, cropping system practices, farm waste management and training farmers.

4.4 Objective 2: Soil Productivity Index

Soil productivity is a key factor influencing agricultural performance and food security as a whole for smallholder farmers. The Soil Productivity Index (SPI) is a method for evaluating soil's ability to support crop over land area and time period influenced by fertility, structure and biological activity. In this investigation, the farmers' land was classified into five SPI classes, based on productivity which were classified as high to very low or non-productive.

Table 4. Interpretation of SPI class values and Interpretations

SPI Value (%)	Interpretation	Class
80-100	very high productivity	I
60-79	high productivity	II
40-59	moderate productivity	III
20-39	low productivity	IV
0-19	very low/none producitve	V

To evaluate the agricultural soils' fertility and productivity in the study area Soil Productivity Index (SPI) was used. The SPI estimates productivity based actual attained yield versus potential yield, into five categories from Class I (highly productive) to Class V (very low/ non-productive).

Table 7. Frequency table of soil productivity index status

SPI Value	SPI Class	Frequency
80-100%	I	7
60-79%	II	10
40-59%	III	15
20-39%	IV	63
0-19%	V	111

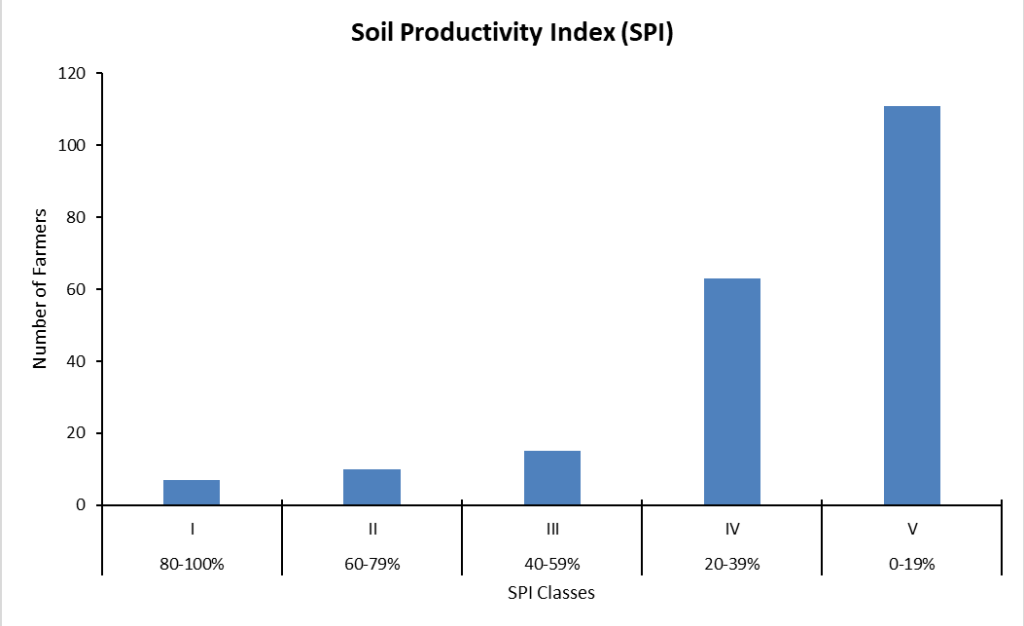

Figure 11: Frequencies of the Soil productivity index of smallholder farmers who practices agroecological biodiversity in Busia County, Kenya

The results showed that the majority (111 out of 206) of farmers were in Class V, indicating their soils were very low or non-productive (Table 2 and Figure 7). This finding is significant because it reveals serious soil health and productivity issues. The reason Class V soils are so common could be attributed to many factors of soil health degradation, especially, biological soil health breakdown (continuous mono-cropping), low or poor quality compost manure or farmyard manure additions to fields, erosion, soil degradation, poor quality of green leaf manures from the timber tree species or crop residues due to insufficient nutrient supply during crop growth time period or poor soil land management practices. The high number of farmers falling under Class V soils indicates a critical need for stimulating soil productivity improvements in agricultural soils with agroecological biodiversity aligned practices like composting, cover crops, green leaf manuring, agroforestry with leguminous trees resulting to improved soil characteristics, eventually leading to improved soil productivity.

The result that most farmers in the study area are classified in Soil Productivity Index (SPI) Class V - described as very low or nonproductive - is troubling. This result indicates that soils, on many farms, are in very poor condition (degraded) or at very low potential for supporting sustainable agricultural production. From the researcher's observations, many farmers are experiencing declining soil fertility, after farming the during same plots year after year with insufficient to no soil enrichment practices. This practice may reflect limited access and knowledge to soil amendments, limiting agronomic practices, and limited access for good soil management advisory and practices through extension support.

According to (Lal, 2015), low SPI in smallholder systems is often associated with continuous cropping, little crop rotations, erosion, and not adding sufficient and quality organic matter. (Tittonell & Giller, 2013) maintain that declining soil productivity in sub-Saharan Africa is primarily due to long-term nutrient mining. A fundamental challenge in modern agriculture lies in the systematic extraction of essential soil nutrients during harvest, with insufficient corresponding restoration. This deficit serves to explain the continued deterioration of soil health across many farming enterprises, despite individual efforts toward diversification. Crucially, agroecological theory asserts that biologically active, nutrient-rich soils are the necessary foundation for truly sustainable agricultural systems (FAO, 2019b). Thus, increasing productivity must be built upon the restoration of this biological integrity. Analysis under the current SPI classification suggests that persistent yield gaps and food insecurity will remain unless widespread, active soil restoration initiatives are undertaken. These critical measures include the implementation of proper farm waste decomposition, agroforestry, cover crops, and green-leaf manure. Supporting this transitional necessity, the FAO (FAO, 2025) has separately documented significantly lower perceived levels of food insecurity among households that have fully integrated agroecologically aligned practices. Additionally, the evaluation was done more than 5 years after farmers were introduced to the practices. This study was conducted 3 years after farmers were introduced to the practices. Therefore, there is an evident need to recognize and develop soil restoration measures, with consistent practice throughout the period, as part of wider agroecological efforts to support soil productivity and resilient farming systems.

4.5 Objective 2: Correlation analysis between agroecological biodiversity with soil productivity

This section explores the relationship between the two quantitative analysis; agroecological biodiversity and soil productivity at smallholder farms using Pearson correlation analysis.

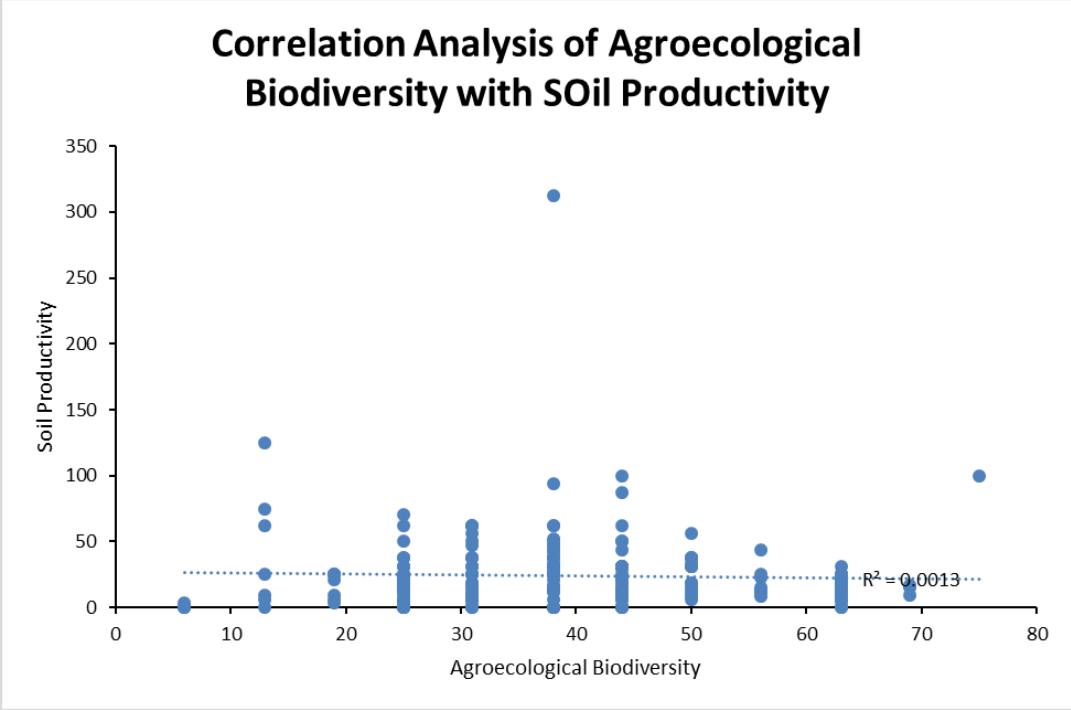

Figure 12: Regression Correlation analysis of Agroecology Biodiversity with soil productivity of smallholder farmers in Busia County, Kenya

The Pearson correlation analysis revealed a correlation coefficient (R value) of -0.038, a value very close to the zero value. The outcome suggests that there was no meaningful, statistically significant correlation between the two variables. There are several ways to view the lack of association. First, the benefits of agroecological biodiversity on soil productivity are often time dependent. It is possible that many or

even all of the permutations of practices, despite that the projects were initiated in 2021, that farmers have adopted, at different times, are not sufficiently imbedded to see any measurable improvement in soil productivity, especially if soils were already degraded. Second, soil productivity is affected by a variety of factors that, biodiversity, is one of them. Historical land use, the effects of erosion, soil nutrient depletion, rainfall variation, insufficient nutrient replenishment, the type of underlying soil characteristics, etc. will continue to be significant factors that may prevent the effects of biodiversity-related practices from being seen. Third, while some of the farmers may have indicated that they are engaging in pro-biodiversity activities, they may not apply these practices consistently enough or on a scale that has a consequence for soil productivity.

The correlation analysis is done to determine the relationship on two variables using the interpretation of R value that is within a range of -1 to +1. The two variables; agroecological biodiversity and soil productivity produced an R value of -0.038. The computed coefficient was exceedingly minute, approximating zero. This result indicates a complete absence of a linear correlation between the two variables under investigation, thereby rendering the relationship statistically non-significant and practically negligible.

Within the scope of this research, substantial heterogeneity was observed in agroecological biodiversity levels across the sampled farms. Critically, this pronounced variation in biodiversity among the farms did not correspond to a discernible pattern in soil productivity. In practical terms, a farm exhibiting superior

biodiversity metrics was not inherently assured of achieving enhanced soil productivity. Conversely, a farm characterized by lower agroecological biodiversity did not consistently demonstrate diminished soil productivity relative to the wider sample.

Contrastingly, a report issued by the Food and Agriculture Organization (FAO, 2025) presented evidence suggesting a significantly lower self-reported incidence of food insecurity among households utilizing agroecologically aligned farming practices. The FAO report posits that as the adoption of advanced agroecological methods increases, a corresponding decrease in food insecurity levels is to be anticipated. This finding, however, introduces a significant point of contention because the report did not sufficiently document the underlying productivity levels. Given that productivity is often considered a more precise and objective metric for assessing the foundational capacity that underpins food security, this omission weakens the strength of their ultimate conclusion regarding the direct impact on household food security. Additionally, the evaluation was done 5+ years after farmers were introduced to the practices. This study was conducted 3 years after farmers were introduced to the practices.

This study contributes to the knowledge challenge that agroecological biodiversity research has in the assumption that just greater agroecological biodiversity leads to better soil productivity. Although agroecological theory says that biodiversity will provide better ecosystem services, such as soil regeneration and nutrient cycling (M. Altieri & Nicholls, 2017), this finding from the study might indicate that, while there

is a relationship between agroecological biodiversity and soil productivity, that relationship may not occur consistently or take longer to emerge, particularly in farming systems that may not be of full & inconsistent diverse and are under serious resource constraints.

The weak correlation could also reflect the fact that agroecological biodiversity in the region is not yet functionally integrated into the farming systems in a manner that alters soil processes. (Méndez et al., 2013) point out that having a diverse many of crops, trees or animals does not necessarily translate into ecological benefits unless crops and animals are managed in some interactive way (e.g., through rotational grazing, arable agroforestry practices, cropping systems and management of farm organic wastes). While the fact that farmers reported some agroecological diversity (plant density, rotational grazing), it may be too fragmented or managed poorly to affect soil productivity in way that can be measured. In addition, factors such as geographic history of land degradation, climate-induced stressors, wrong choice of tree species or the lack of inputs like soil amendments, may be concealing the real benefits of that agroecological biodiversity.

In summary, the absence of any correlation in this study is in line with (Tittonell et al., 2005), who concluded that soil fertility gradients do not invariably relate to biodiversity measures, especially in smallholder systems characterized by heterogeneity. So while agroecological diversification is indeed a highly valued strategy for farms to employ, its impact on soil productivity may be indirect, non-linear or depend on other enabling factors.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study aimed to measure and assess agroecological biodiversity among smallholder farmers and how it relates to soil productivity in Busia County. Although smallholder farms have an element of diversity in crops, animals, trees, and farming activities, it was found that levels of agroecological biodiversity were overall unsustainable. The average agroecological biodiversity score of 1.59 shows that most of the farming systems are not diverse enough to trigger and support ecosystem services and sustainable productivity. Soil productivity was found to be very low among the farms, with the majority falling into the lowest soil productivity index category provided by that score.

The correlation analysis demonstrated there was no relationship established between agroecological biodiversity and soil productivity ($R = -0.038$), which means that the current levels and types of agroecological biodiversity on-farm have not affected soil health and productivity in a measurable way. This disconnect indicates critical shortcomings at many levels of the implementation of agroecological biodiversity principle and their functional integration in the study area.

5.2 Recommendations

Conduct as assessment of the training module and training style of agroecological biodiversity on farmers to understand the root-cause of the gaps in practice and consistency of practice by farmers

Farmers should be put in a position to replenish nutrients from cover crops such as leguminous cover crops with high N fixing capability and are suitable to the region in the form of compost manure, green-leaf manure and farmyard manure, to regenerate soil nutrients and soil structure, especially on the compromised plots.

Over-dependence on a single production crop (e.g., maize) needs be actively discouraged with the provision of seed access and markets for under-utilized crops to enable both income and ecological functions.

Individual and community monitoring and assessment of soil productivity indicators must be made a part of extension packages, so that together with farmers they can make early, best practice, evidence-based decisions while tracking their improvements over time.

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APPENDICES

Appendix A: Agroecological performance for each interviewed farmer (individual scores and overall score)

Farmer Code	Crop Diversity	Tree Diversity	Animal Diversity	Activity Diversity	Overall	Score in Percentage
TCS4	2	4	1	2	9	56%
TCS5	3	4	2	2	11	69%
TCS6	2	4	2	2	10	63%
NK33	2	1	2	2	7	44%
NK31	2	2	2	2	8	50%
NK32	1	1	0	1	3	19%
NK4	2	1	2	1	6	38%
Nk2	2	2	2	1	7	44%
Nk3	1	1	0	1	3	19%
TCN4	2	4	0	1	7	44%
TCN5	2	3	0	2	7	44%
BBC7	1	0	0	1	2	13%
NK34	1	1	0	1	3	19%
NK35	1	1	0	0	2	13%
BBC8	1	1	1	2	5	31%
BBC9	1	1	1	1	4	25%
BBE6	1	1	2	1	5	31%
BBE7	1	1	2	2	6	38%
BBE8	2	1	0	1	4	25%
BBE9	2	1	1	1	5	31%
NK5	2	1	1	3	7	44%
NK6	2	1	2	3	8	50%
Nk7	1	3	1	2	7	44%
NK29	0	1	0	0	1	6%
NK28	0	1	2	1	4	25%
NMN8	2	2	2	2	8	50%
NMN9	1	1	2	1	5	31%

| Farmer Code | Crop Diversity | Tree Diversity | Animal Diversity | Activity Diversity | Overall | Score in Percentage |

TCN35	2	1	2	2	7	44%
BBC31	2	0	1	2	5	31%
BBC32	1	1	1	2	5	31%
BBC33	3	0	0	1	4	25%
BBC34	2	2	1	2	7	44%
BBE31	3	1	2	2	8	50%
BBC35	1	1	1	1	4	25%
BBE32	1	1	1	2	5	31%
BBE33	1	1	1	1	4	25%
Nk23	2	2	2	3	9	56%
Nk24	4	2	2	3	11	69%
Nk25	2	1	1	2	6	38%
Nk26	3	2	0	1	6	38%
Nk27	2	2	2	1	7	44%
NMN32	2	2	2	2	8	50%
NMN33	3	1	2	2	8	50%
NMN34	2	1	0	1	4	25%
NMN35	2	2	2	2	8	50%

BBC27	2	1	0	1	4	25%
BBE25	2	1	2	2	7	44%
BBE 26	1	1	1	1	4	25%
Tcs28	2	4	2	2	10	63%
Tcs29	2	4	3	2	11	69%
Tcs30	3	4	1	2	10	63%
Tcs31	2	4	1	2	9	56%
TCN32	1	0	2	2	5	31%
TCN31	1	0	2	2	5	31%
TCN29	1	1	2	2	6	38%
TCN30	0	3	2	2	7	44%
TCN28	2	2	1	2	7	44%
BBC28	2	1	2	1	6	38%
BBC29	2	2	1	1	6	38%
BBC30	2	0	1	1	4	25%
NMN29	1	2	0	1	4	25%
NMN31	2	2	1	2	7	44%
BBE27	2	1	1	2	6	38%
BBE28	2	1	1	2	6	38%
BBE 29	2	1	0	1	4	25%
BBE30	2	1	2	2	7	44%
Tcs32	1	4	3	2	10	63%
Tcs33	2	4	2	2	10	63%
Tcs34	2	4	2	2	10	63%
Tcs35	1	4	1	2	8	50%
TCN33	2	0	0	1	3	19%
TCN34	2	2	0	0	4	25%

NMN21	2	2	0	0	4	25%
BBE20	2	1	1	1	5	31%
BBC23	0	0	1	2	3	19%
Tcs22	2	4	2	2	10	63%
Tcs23	2	4	1	2	9	56%
Tcs24	2	4	2	2	10	63%
Tcs25	1	4	2	2	9	56%
TCN23	1	4	2	2	9	56%
BBE21	1	1	2	1	5	31%
BBE22	0	1	2	2	5	31%
BBC24	3	0	2	1	6	38%
NMN22	2	2	2	1	7	44%
NMN23	3	1	0	1	5	31%
BBE23	0	1	2	2	5	31%
Tcs26	2	4	2	2	10	63%
Tcs27	0	4	2	2	8	50%
Nk20	2	2	2	2	8	50%
Nk21	2	1	0	1	4	25%
Nk22	1	2	2	2	7	44%
BBC25	1	1	1	2	5	31%
BBC26	2	1	2	2	7	44%
TCN26	1	4	2	2	9	56%
TCN27	2	2	1	2	7	44%
TCN25	2	1	0	1	4	25%
NMN24	0	1	1	2	4	25%
NMN26	2	1	0	1	4	25%
BBE24	1	1	1	2	5	31%

BBE16	2	1	2	2	7	44%
BBC18	1	0	0	0	1	6%
BBC19	4	1	0	1	6	38%
BBC20	1	1	0	2	4	25%
NMN18	2	1	1	2	6	38%
NMN20	2	1	2	2	7	44%
Tcs18	2	4	2	2	10	63%
Tcs17	2	4	1	3	10	63%
Nk17	2	2	0	1	5	31%
Tcs19	2	4	1	2	9	56%
Tcs20	2	4	2	2	10	63%
Tcs21	2	4	2	2	10	63%
Nk14	1	1	2	2	6	38%
Nk18	2	0	2	3	7	44%
Nk19	1	1	2	2	6	38%
NMN25	2	1	2	2	7	44%
TCN19	2	4	2	2	10	63%
TCN20	2	0	2	2	6	38%
TCN21	2	2	2	1	7	44%
TCN22	2	2	2	2	8	50%
BBE17	2	1	2	2	7	44%
BBC21	2	1	2	1	6	38%
BBE18	2	1	1	2	6	38%
BBE 19	1	1	2	2	6	38%
BBC22	1	1	2	2	6	38%
TCN24	2	4	2	2	10	63%
NMN19	2	1	1	2	6	38%

TCN12	2	0	2	2	6	38%
TCN11	2	4	2	2	10	63%
TCS13	2	4	3	3	12	75%
BBE13	1	1	1	1	4	25%
TCS14	1	4	1	2	8	50%
Tcs15	2	4	2	2	10	63%
BBC15	2	1	1	1	5	31%
BBC13	2	1	1	2	6	38%
BBE14	2	1	1	1	5	31%
BBC14	1	1	1	2	5	31%
TCN13	1	0	2	1	4	25%
TCN14	3	0	2	2	7	44%
TCN15	0	0	2	2	4	25%
Nk11	1	1	2	1	5	31%
NK12	2	1	1	3	7	44%
Nk13	2	2	1	2	7	44%
BBE15	2	1	2	1	6	38%
BBC16	2	2	0	1	5	31%
NMN16	2	1	0	1	4	25%
NMN17	2	2	2	2	8	50%
BBC17	2	1	1	2	6	38%
TCN16	2	1	1	2	6	38%
TCN 17	2	3	0	1	6	38%
Nk15	1	2	1	2	6	38%
Nk16	0	1	0	1	2	13%
TCS16	2	4	2	2	10	63%
TCN18	2	1	0	1	4	25%

5	NMN10	2	1	1	2	6	38%
6	TSC7	2	4	1	2	9	56%
7	TCS8	1	4	1	2	8	50%
8	TCS9	1	4	2	3	10	63%
9	NMN11	2	1	0	1	4	25%
0	NMN12	2	1	1	2	6	38%
1	TCN6	1	1	0	1	3	19%
2	TCN 7	2	0	0	0	2	13%
3	TCN8	1	2	2	2	7	44%
4	TCN9	0	0	0	1	1	6%
5	TCS10	1	3	3	3	10	63%
6	TCS11	1	4	3	2	10	63%
7	NMN13	1	1	2	3	7	44%
8	NMN14	2	1	1	2	6	38%
9	BBE10	1	1	2	1	5	31%
0	TCS3	2	2	2	2	8	50%
1	BBE11	2	1	1	1	5	31%
2	Nk9	0	0	0	1	1	6%
3	Nk8	2	2	0	1	5	31%
4	Nk10	1	1	0	2	4	25%
5	Tcs12	0	2	1	2	5	31%
6	BBE12	2	1	0	1	4	25%
7	BBC10	1	2	1	2	6	38%
8	BBC11	2	1	0	1	4	25%
9	BBC12	2	1	1	2	6	38%
0	NMN15	2	1	0	1	4	25%
1	TCN10	2	3	2	2	9	56%

Appendix B: Modification of the FAO TAPE tool

Modification of the FAO TAPE tool was based on the collected data, nature of farming of Busia County.

i). Tree Diversity

The average number of trees owned by a farmer was 98. From this, a value of 100 was made to interpret significant number of trees. From that, the below value interpretations were made

Number of Trees (Range)	Value Interpretation
1-50	Few
51-100	Some
101-150	Significant
➢ 150	High

Further interpretations

Statement	**Interpretations**

Few trees of one species	Farmer has less than the significant value and are of one species only.
Species	Types of tree, derived from its main use. This was translated to this for easy understanding with the enumerators and farmers.
Some trees (and/or other perennials) of more than one species.	Farmer has a count of trees that is nearing the significant value but is less than the value, the trees comprise of more than one species.
High number of trees (and/or other perennials) of different species integrated within the farm land	The farmer has tree count that is higher than the significant value and are of variety of species.
Significant number of trees (and/or other perennials) of different species.	Farmer has a count of trees that is nearing the average value but is more the average value and are of variety of species.

Score Modification

Score Value	Score Interpretation
0	No trees (nor other perennials) or available trees but of one species only
1	Few trees of one or different species
2	Some trees of more than one species
3	Significant number of trees of different species
4	High number of trees of different species integrated within the farm land

ii). Activity Diversity

Score Value	**Score Interpretation**
0	Sale of one product only e.g. selling one crop produce only

1	Sale of two or three products e.g. selling two crop produce or one crop produce and one animal produce or animal
2	Sale of more than 3 products
3	Sale of more than 3 products and one service e.g offering land for farming demonstration purpose
4	Sale of more than 3 products and several services

iii). Animal Diversity

The average value of animals owned per farmer per type was obtained and these values were used to define the words few and significant.

Animal Type	**Average Value**
Local chicken	29

Broiler chicken	1
Cows	2
Bulls	1
Sheep	0
Rabbit	0
Goats	1
Pigs	1

Further interpretations

Terms	**Definition**
Species	Types of animals reared on the farm

Few	The count value of animals is less than the average count value
Significant number	The count value of animals is more or equal to the average count value.
Breeds	Animals belonging to the same species but of different characteristics arising from crossbreeding to enhance its adaptation/characteristics.

Score interpretations

Score value	**Score Interpretation**
0	No animals/ only 1 species of a few count
1	One species only with significant count
2	Atleast two species with a few count

3	Atleast three species with significant count
4	More than three species with different breeds well adapted to the local area and changing climate

iv). Crop Diversity

This was identified by calculating the sum farm land size of each crops and crops of the top 4 largest values were picked.

Terminologies/phrases	**Interpretation**
Significant cultivated area	Average farm size is 2.261 acres. Smallscale farm is 0.5-30 acres. Significant cultivated area will be defined as 0.5 acres and above (0.2 ha).
Varieties	These are defined as Hybrid (any hybrid) and local sourced (from fellow farmer or from open market or a recycled seed).

Time	This is defined as planting seasons in a year, the region has two planting seasons in a year.
Local condition	This are the agroecological zones and the crops suitable for that region as per climate and soil
Major 4 crops	Most grown crops by the farmers; Maize, common brans, cassava and soy beans.

Score value	**Score interpretations**
0	Monoculture/no cultivated crop in one season
1	One/two species in subsequent seasons/ if the total cultivated area is not significant

2	Two or three crops, same season, with significant cultivated area.
3	Two or Three crops, subsequent seasons, with significant cultivated area adapted to local and changing climatic conditions
4	More than 3 crops, subsequent or same seasons, of different varieties adapted to local conditions and spatially diversified

Appendix C: Questionnaire:

STATUS OF AGROECOLOGICAL BIODIVERSITY AND ITS EFFECT ON SOIL PRODUCTIVITY IN SMALLHOLDER FARMS IN BUSIA COUNTY, KENYA.

CONSENT REQUEST

We're conducting this exploratory survey in Busia County to explore on farmers' farming practices. The study aims to identify the farming practices aligned with the agroecological diversity principle that farmers are adopting so as to improve on soil productivity, with focus on the past four planting seasons.

Yes

No

A. HOUSEHOLD INFORMATION

***Farmer's name**

***Farmer's contact**

***Household head**

***Household head's age**

18-35

36-60

Above 60

***What is the level of education of the household head?**

Primary

Secondary

Tertiary

***Could you kindly provide the average household monthly income for our records?**

Ksh. 5,000-15,000

Ksh. 15,500-25,000

Ksh. 25,500-35,000

Ksh. 35,500-40,000

Above 40,001

***What is your main source of income?**

Farming

Employment

Business in farming

Business of other commodities

***Who makes the farm decisions?**

Farmer (respondent)

Household head

***For how long have you been the farm decision maker?**

5-10

11-20

21-30

Beyond 31

Do you solely make the decisions or who else supports in the decision making? (Multiselect***)**

Solely

With spouse

With spouse and parents

With parents

With spouse and children

With children

B. FARM INFORMATION

***What is the ownership of your farming land?**

Community/ customary

Freehold

Partial partnership

Public

Leased

Ancestral

***What is your total land area? (In acres)**

0-2.5

2.5-5

5-7.5

7.5-10

Above 10

***What is your land size for farming? (Acres)**

0-0.5

0.5-1.0

1.0-1.5

1.5-2.0

2.0-2.5

2.5-3.0

3.0-3.5

3.5-4.0

4.0-4.5

4.5-5.0

Above 5.0

What type of farming do you practice? (Multiselect***)**

Mixed farming

Arable farming

Silviculture

Aquaculture

Agroforestry

Organic farming

Intensive farming

Hydroponics farming

Vertical farming

Horticulture

Dairy farming

Poultry farming

Apiculture

Sericulture

Permaculture

What is the reason behind your choice of farming system? (Open ended question***)**

***What is your source of water for farming?**

Rainfed

Irrigation

Combination

What type of irrigation do you practice? (Multiselect***)**

Traditional irrigation system

Modern irrigation system

Which traditional irrigation method do you practice? (Multiselect***)**

Basin

Furrow

Trenches/Terraced irrigation

Surface irrigation

Flood irrigation

Manual irrigation

Which modern irrigation method do you practice? (Multiselect***)**

Drip irrigation

Overhead sprinkler irrigation

Centre pivot irrigation

Subsurface irrigation

Lateral move irrigation

***What size is under irrigation (Acres)**

0-0.5

0.5-1.0

1.0-1.5

1.5-2.0

2.0-2.5

2.5-3.0

3.0-3.5

3.5-4.0

4.0-4.5

4.5-5.0

Above 5.0

***What size is under rainfed (Acres) place the options.**

0-0.5

0.5-1.0

1.0-1.5

1.5-2.0

2.0-2.5

2.5-3.0

3.0-3.5

3.5-4.0

4.0-4.5

4.5-5.0

Above 5.0

What crops are on irrigation? (Open ended question***)**

Why the choice of crop selection for irrigation (Open ended question' probe and get value***)**

What crops are on rainfed? (Open ended question)*

C. FARMING PRODUCTIVITY

i). CROP FARMING

***Name crops in your farming**

Crop	**Variety**	**Acreage**	**Season & year**

***Why are the crops of preference?**

Subsistence use

Commercial

Both commercial and subsistence

Tolerant to diseases

Tolerant to pests

Short maturity period

Tolerant to drought

Fetches better market price

Hybrid seed availability

Health

High yielding

Market high demand

***What is the yield for your preferred crops?**

Crop	**Yield**	**Unit time**

ii). ANIMAL FARMING

***What farm size is allocated for animal farming?**

***Name animals in your rearing.**

Animal	**Breed**	**Number**	**Acre coverage**	**Distance of source of breed**

***Why are the animals of preference?**

Subsistence use

Commercial

Both commercial and subsistence

Tolerant to diseases

Tolerant to pests

Short maturity period

Tolerant to drought

Fetches better market price

Breed availability

Health benefits

Market high demand

High produce amount

High produce quality

***What is your produce amount for your preferred animals?**

Animal	**Yield type**	**Amount**	**Unit Time**

***What cropping systems do you carry out?**

Mono-cropping

Inter-cropping

Mbili-mbili system

Agroforestry

Crop rotation

Alley cropping

Shamba system

Relay system

Fallow system

Mixed cropping

Strip cropping

Cover cropping

How often do you change your cropping system? Number per unit time (Open ended question***)**

How do you change? (Pattern of the change) From what cropping system to what cropping system (Open ended question***)**

Why do you change your cropping systems? (Open ended question***)**

On which crops do you do on the above selected cropping system? (Open ended question; Write consequently***)**

iii). TREES/SHRUBS FARMING

What type of trees/shrubs do you have on your farm? (Multiselect***)**

Fruit/nut trees

Shade trees

Medicinal trees

Fodder trees

Timber trees

Firewood trees

Ornamental trees

Live fence trees

None

***How many trees/shrubs do you have of each above? (Ask and observe)**

Fruit/nut trees

Shade trees

Medicinal trees

Fodder trees

Timber trees

Firewood trees

Ornamental trees

Live fence trees

None

How do you integrate the trees/shrubs with crops and animals? (Choose one***)**

Fencing/boundary

Within the crop and animal land area

Segmented area for trees only (afforestation)

Within the crop land area (agroforestry)

Fencing/boundary and segmented area

Within the crop and animal area and segmented area too

Boundary + within crop land area

Boundary/fence + within crop and animal land area + segmented area

Why do you plant integrate the trees/shrubs with crops and animals? (Open question***)**

What tree species do you grow? (Multiselect***)**

Grevillea Robusta

Eucalyptus

Citrus

Mango

Avocado

Maesopsis eminii

Markhamia lutea

Cordia Africana

Macademia

Croton megalocarpus

Jacaranda mimosifolia

Sesbania sp

Leucanae sp

Baobab

Blue gum

Other

***Are the trees indigenous or exotic?** (*Appropriately tick*)

Indigenous

Exotic

Both

How much land is covered by each tree/shrub type on your farm? (Acres***)**

Why do you plant trees/shrubs? (Multiselect***)**

Shade for humans

Shade for animals

Increased soil fertility

Barrier to soil erosion

Medicine

Timber sale

Land restoration

Wind breaker

Green leaf manure

Food (Nutrition)

Fruit sale

Fodder

Construction

Fodder sale

Firewood

Security

Land boundary

Soil moisture retention

Ornamental

Manure composting

Ornamental

Biopesticides substances

Raw products e.g. gum

None

Others

D. END OF SURVEY

We have come to the end of the survey. Thank you very much for your valuable time. Do you have any question or comment for us? *Thank you!

Appendix D: Similarity Report

DrillBit

The Report is Generated by DrillBit AI Content Detection Software

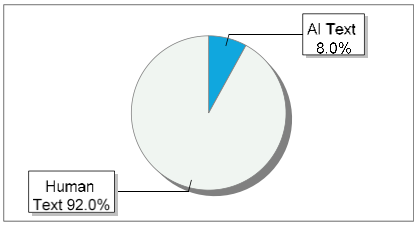
Submission Information

Author Name	NYAGUTI SUZZETTE KERUBO SAGR/SOS/M/003/22
Title	EVALUATION OF AGROECOLOGICAL DIVERSITY AND SOIL..
Paper/Submission ID	4616069
Submitted By	similarity@uoeld.ac.ke
Submission Date	2025-11-03 16:01:46
Total Pages	149
Document type	Thesis

Result Information

AI Text: 8 %

Content Matched



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