CLASSIFICATION OF AGROFORESTRY SYSTEMS, THEIR SOCIO-ECONOMIC BENEFITS AND CONSTRAINTS IN SOIN WARD, KERICHO COUNTY, KENYA

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A Thesis Submitted to the Board of Graduate Studies in Partial Fulfillment of the Requirements for the Conferment of the Degree of Master of Science in Agroforestry of the University of Kabianga

UNIVERSITY OF KABIANGA

AUGUST 2023

DECLARATION AND APPROVAL

Declaration

This thesis is my original work and not been presented before for the conferment of diploma or degree in this or any other Institution.

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Approval

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DEDICATION

This thesis is dedicated to my parents, Mr. Simon Langat and Mrs. Esther Langat for all the sacrifices you made for me to get to this point in my life, even when it meant that you go out of your way and be uncomfortable for your children to succeed. May the Lord keep you and guide you in all your endevours.

ACKNOWLEDGEMENT

I wish to convey my heartfelt gratitude to my supervisors; Prof. Peter Kipkogei Sirmah, Dr. Thomas Kibiwot Matonyei and Prof. James Simiren Ole Nampushi who supported, guided, advised and encouraged me. They also took their time to make necessary corrections on my work right from initial stages of research proposal development, data collection up to the final stages of writing up the thesis. I greatly and sincerely acknowledge their efforts.

I am also very grateful to National Commission for Science, Technology and Innovation and University of Kabianga for making it possible to undertake research and production of thesis.

Lastly, I wish to thank the entire School of Agricultural Sciences and Natural Resources staff and any other person who helped me directly or indirectly during the study.

ABSTRACT

Agroforestry Systems (AFS) are integrated land use systems involving trees/shrubs and agricultural and/or animal crops, simultaneously or sequentially, with the objective of sustainably increasing the total productivity of plants and animals per unit area. However, despite strong evidence describing the benefits of agroforestry to livelihoods, there is little information as such in Kericho/Nyanza sugar belt border where sugarcane is a major cash crop. This study aimed at classifying agroforestry systems, evaluating their socio-economic benefits and constraints in Soin Ward, Kericho County, Kenya. The study adopted qualitative research design through administration of pre- tested questionnaires on types of agroforestry systems, scale of production, land utilization, preference of trees and sugar cane varieties and their interactions to 384 respondents in lower, upper and midland parts of Soin Ward. Collected data were analyzed using SPSS version 28.0. Four (4) classes of agroforestry systems were identified in Soin Ward that comprised; (48.2% agrosilvopastoral and 31.6% agrosilvicultural and 20.2% silvopastoral); (16.2% protective and 83.8% productive); (45.7% subsistence and 54.3% commercial) and Integrated farm-based agroforestry 47.4%, homestead (6.8%), animal farm (31.4%), dairy farm (1.4%) and forest land (13%) respectively. Majority of the respondents (42.7%) preferred *Grevillea* tree species for blending with sugarcane in a tree-sugarcane agroforestry system in comparison with *cypress* (29.4%), e*ucalyptus* (15.1%), *casuarina* (12.6%) and c*alliandra* (0.2%) respectively. Sixty (61.7%) plant trees along the boundary, as woodlot (24.0%), hedge row (8.9%), intercropping/mixed (3.1%) and as alley cropping (2.3%). The preferred sugarcane species in the tree-sugarcane agroforestry system was CO 617 (46.9%), CO 412 (25.4%), CO 945 (12.4%), CV 38-22 (10.9%) and KEN 83-737 (4.4%) for low land (altitude of 1200-1400m) ecosystems. For midland ecosystems (altitude 1400-1600m) CO 617 (20.9%) and CO 412 (20.9%) were preferred. For lower highland ecosystems (altitude of 1600-1800m) CO 617 (39.4%), CO 412 (22.4%), CO 945 (15.9%), CV 38-22 (11.4%) and KEN 83-737 (10.9%). Direct benefits from the identified agroforestry systems include; income (67.6%), food (8.3%) and employment (24.1%). Indirect benefits include provision of biofuel (21.9%), enhanced soil fertility (21.1%), bio drainage (20.4%), biodiversity conservation (19.4%) and carbon absorption (17.2%), improvement of social amenities such as roads (27.2%), markets (25.8%), hospitals (19.3%), schools (18.5% and electricity (9.2%).Constraints faced by the agroforestry systems include; long waiting payback (39.2%), limited possibilities to sell product (28.3%), labour intensive (27.8%) and knowledge and technology gap (4.7%). Such results are useful for policy making decisions towards afforestation and improved livelihoods in Kenya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zones
AFS	Agroforestry Systems
CIFOR	Centre for International Forestry Research
COP22	Conference of the Parties
GDP	Gross Domestic Product
FAO	Food and Agriculture Organization of United Nations
FRAs	Forest Replacement Associations
ICRAF	International Council for Research in Agroforestry
LH	Lower Highland
LM	Lower Midland
NGOs	Non-Governmental Organizations
NGP	National Greening Program
RFD	Royal Forest Department
SDGs	Sustainable Development Goals
SPSS	Statistical Package for Social Sciences
SSGs	Small-Scale Sugarcane Growers
UH	Upper Highland
UM	Upper Midland
WFP	World Food Program of United Nations

DEFINITION OF TERMS

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence.

Agroforestry system is an interconnecting network of woody vegetation with crops and/or animals that work together.

Benefits is an advantage or profit gained from something.

Biodiversity is the biological variety and variability of life on Earth

Biofuel is any fuel that derived from biomass. It’s a class of renewable energy derived from living materials.

Characteristics is a distinguishing trait, quality or property.

Classification is the grouping of agroforestry systems according to characteristics.

Conservation is careful preservation and protection of something for example planned management of natural resources.

Constraints are condition of optimization problems that the solution must satisfy.

Crop is a plant or animal product that can grow and harvested extensively for profit or subsistence.

Farmer is a person engaged in agriculture, raising living organisms for food or raw materials.

Household is a house and its occupants regarded as a unit.

Livelihoods is a means of securing the necessities of life or making a living.

Monoculture is the cultivation of a single crop in a given area.

Partner is pair of people engaged together in the same activity.

Polyculture is the simultaneous cultivation or exploitation of several crops.

Semi-arid region or climate is dry but have slightly more rain than an arid region or climate.

Socio- economic show how economic activity affects and is shaped by social processes.

Sugar cane is the common name of a species of herb belonging to the grass family. The botanical classification of sugar cane is *Saccharum offi cinarum*, and it belongs to the family Gramineae. A perennial plant can grow up to 4.25 m.

Sustainability is the ability to maintain process at a certain rate or level.

System is a set of things working together as a mechanism or interconnecting

Technology is the application of scientific knowledge for practical purposes.

Tree is a woody perennial plant

Tree-sugarcane the term used to mean combine planting of trees and sugarcane in piece of land.

CHAPTER ONE

INTRODUCTION

1.1 Overview

This chapter contains the background of the study, statement of the problem, study objectives, research questions, justification and significance of the study, scope, limitations and assumptions.

1.2 Background of the Study

Agroforestry Systems (AFS) are integrated land use systems involving trees or shrubs and agricultural and animal crops, simultaneously or sequentially, with the objective of sustainably increasing the total productivity of plants and animals per unit area, (Catacutan *et al.,* 2017). Similarly, agroforestry comprises land-use systems and technologies in which woody perennial plants (trees, shrubs, palms or bamboos) and agricultural or animal crops are cultivated on the same plot organized in planned spatial and temporal arrangements, (FAO and ICRAF, 2022). Such biodiverse and interactive production agroforestry systems provide social and ecological benefits to the communities and land users, (Catacutan *et al.*, 2017).

Agroforestry systems (AFS) are further classified as silvoarable systems (combination of trees or shrubs with crops), silvopastoral (combination of trees with livestock), and agro-silvopastoral (combination of trees or shrubs with both crops and livestock), riparian buffer strips, and home gardens, (Mosquera-Losada, 2022). Besides provisioning services, such as food, fodder, fibre and fuelwood production, agroforestry systems (AFS) provide several other ecosystem services, including regulation of nutrient cycling, carbon sequestration, habitat for biodiversity, erosion control, fire and flood control, and recreational and cultural services, (Mosquera-Losada, 2022). Similarly, agroforestry systems improve resilience of smallholder farmers through more efficient water utilization, improved microclimate, enhanced soil productivity and nutrient cycling, control of pests and diseases, improved farm productivity, diversified and increased farm income while at the same time sequestering carbon, (Fagerholm, 2022).

One of the key global agenda by vision 2030 is the achievement of the Sustainable Development Goals (SDGs), (Dennis, 2017). The goals promote the world’s effort to eliminate poverty and hunger, improve access to health services, basic education, support women empowerment and regenerate the global environment through conservation and agroforestry. If SDGs are fully attained and implemented, they will benefit everyone by contributing globally towards a greater economic abundance, peace and security. Similarly, the achievement of SDGs will give ways of overcoming hunger and poverty in a thorough and comprehensive manner through developments of rural communities in the developing world such as Kenya, (Dennis, 2017).

Efforts to increase forest cover worldwide have been gaining momentum over years as a climate change mitigation and adaptation measure. Kenya is among the countries putting up the effort through the development of different strategies such as agroforestry and land use management with the ultimate aim of achieving 10% forest cover by 2030 (Vision, 2030). This study aimed at classifying agroforestry systems, and evaluating their socio-economic benefits and constraints in Soin Ward, Kericho County, Kenya.

1.3 Statement of the Problem

Agroforestry systems (AFS) provides products and ecosystem services to communities. It further improves resilience of smallholder farmers through more efficient water utilization, improved microclimate, control of pests and diseases, improved farm productivity, diversified and increased farm income, (Fagerholm, 2022). There are several limiting factors in the diffusion of agroforestry in developing countries because of poor adoption strategies and high deforestation rates among rural communities leading to exposure to climate risks. Additionally, a lack of access to capital and insecure land tenure contribute to these problems, (Ullah *et al.,* 2021). Thus, the poor diffusion of agroforestry is partially explained by a lack of fit between the technical aspects required for adoption versus the economic and institutional context of the different farming communities in which they are applied.

Literature studies indicate that agroforestry systems contribute to poverty and hunger eradication, improved access to health services, basic education, support women empowerment and regenerate the global environment through conservation, (Dennis, 2017). However, despite strong evidence describing the benefits of agroforestry to livelihoods, there is little information on classification of agroforestry systems, their socio-economic benefits and constraints in Soin Ward, Kericho County, Kenya. Soin Ward borders the Nyanza sugar belt of Kisumu County where sugarcane is a major cash crop. Thousands of farmers in the area depend on sugarcane farming as their source of livelihood but of late they have diversified into forestry related activities. An increase in demand for sugarcane, timber and non-timber forest products will lead to a rapid decline of forests and other resources through deforestation and other human activities.

1.4 Purpose of the Study

The main purpose of this study was to classify agroforestry systems, evaluate their socio-economic benefits and constraints in Soin Ward, Kericho County.

1.5 Specific Objectives

The specific objectives of the study were to:

i. Classify agroforestry systems in Soin Ward, Kericho County.
ii. Determine socio-economic and ecological benefits of agroforestry systems in Soin Ward, Kericho County.
iii. Evaluate socio-economic constraints of agroforestry systems in Soin Ward, Kericho County.

1.6 Research Questions

The following research questions used.

i. What are the different classes of agroforestry systems in Soin Ward, Kericho County?
ii. What are the socio-economic benefits of agroforestry systems in Soin Ward, Kericho County?
iii. What are the socio-economic constraints of the agroforestry systems in Soin Ward, Kericho County?

1.7 Justification

Agriculture is the major contributor to the national Gross Domestic Product (GDP) in Kenya due to the high demand for agro-based products. Increasing demand for these products over years has led to an expansion of agricultural farms and mainly of the monoculture systems such as sugarcane and tea plantations. To get a large area for the monoculture in agriculture requires large forests and land be cleared to provide an area for agricultural purposes, (Oxfam Case Study, 2011).

Global deforestation for more agricultural land has led to the development of negative environmental impacts for example forest degradation, habitat fragmentation and climate change (Wong, 2001 and Walls, 2006). The conversion of forest area into agricultural land has threatened biodiversity mainly in tropical countries of Malaysia and Indonesia. The Forested area in both countries is home to several species of terrestrial habitat (Fitzherbert *et al*.,2009). Aratrakom, Thunhikorn and Donald (2006) and Sheil *et al*., (2009), claim that some wildlife both exotic and endangered species including orangutans (*Pongo spp*.), Sumatran tiger (*Panthera tigris sumatrae*), Sumatran elephant (*Elephas maximus sumatrensis*), tapirs (*Tapirus spp*.), clouded leopards (*Neofelis spp*.), forest-dependent birds and butterflies are extinct due to the forest conversion activities mainly in agriculture.

Over-dependence on monoculture systems by farmers has led to the consumption of huge quantities of chemical fertilizers and agrochemical products (pesticides, insecticides, herbicides and fungicides) because agrochemical products and chemical fertilizers are used in farms to ensure yield consistency, profitability and productivity, (Wong *et al*., 2011).

Chemical fertilizers and agrochemicals cause great negative impacts to the environment, making the agriculture sector to be among the key sectors that require be developed sustainably.

The agriculture sector is a fundamental supplier of food, fiber, and shelter for the human population and it is reported that food sufficiency, environmental stewardship, socio-economic viability and equity are major examples of sustainable agriculture development. Sustainable agriculture is therefore a practice of farming using principles of ecology and study of the relationship between organisms and their surroundings. As mentioned by Kassie and Zikhali (2009), sustainable agriculture is an alternative in agriculture systems that focus on addressing the problems faced by humans, especially the poor farmers to improve their quality of life and improvement of the environmental conditions. It can gather for high demand on food production with the creation of minimizing impacts to the environment and humans, unlike conventional agriculture.

Sugarcane is the third important cash crop grown in Kenya after tea and coffee. It is majorly grown in Soin Ward under approximately six Ha. Sugarcane is a very demanding crop as regards nutrients; it sequesters carbon in the soil. Sugarcane is an industrial crop that is mainly grown in semi-arid areas of Kenya for sugar production. Demand for sugar among households and industries as raw materials have led to a rapid expansion of sugarcane farms and sugar mills. Semi-arid areas characterized by low biodiversity and due to expansion of farms under sugarcane farming have led to some species endangered due to intense water consumption and intense use of agrochemicals during sugarcane production. An established tree-sugarcane agroforestry system promotes maximum productivity and sustainability among farmers. Despite what already exists, there is a need for more research on the classification of agroforestry systems such as tree-sugarcane interactions that have not been fully exploited for its potential benefits in Kenya.

1.8 Significance of the Study

The findings will further help in designing agroforestry strategies to support other sugarcane farmers in the establishment of a tree-sugarcane agroforestry system. The findings will provide a baseline data to national and county governments will develop rules and policies that will aid in sustainable management of agriculture and forestry activities. It will also help develop a tool for building knowledge and facilitating learning in schools and research institutions. The study findings will further be of importance to both forestry and agriculture stakeholders as more information related to tree-sugarcane information will be gathered, all of which will be important to extension work in the area.

1.9 Scope of the Study

The study focused on the classification, socio-economic benefits and constraints of the agroforestry systems in Soin Ward, Kericho County.

1.10 Limitation of the Study

Inadequate information on the agroforestry systems within the Soin Ward to backup new information has become a challenge for comparison over time. There was a need to avail adequate time and resources for this study research to deliver new information and techniques on the tree-sugarcane agroforestry system.

1.11 Assumptions

The following were the assumptions of the study:

i. The respondents understood the classes, socio-economic benefits and constraints of the agroforestry systems so that facts are obtained on the ground.

ii. The respondents were knowledgeable on the characteristics, socio-economic benefits and constraints of the agroforestry systems and therefore answered the questions correctly and honestly.

iii. All respondents had a sincere interest to participate in this research without any other motives, such as giving money.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This section entails literature from the academic work of other scholars that describe various issues on classes, characteristics, socio-economic benefits and constraints of the agroforestry systems. This chapter also provides a conceptual framework of the study.

2.2 General Information on Agroforestry Systems

The adoption of agroforestry in farmlands is an option to mitigate climate change while promoting productivity of crop yields and other outcomes from the environment, (Mbow *et al*., 2014). In agroforestry systems, woody perennials (trees, shrubs, palms, bamboos, etc.) are planted in the same land-management unit with crops and/or animals, in either a spatial arrangement or a temporal sequence. The diversification of plant species through agroforestry system can lead to an increase in yields production, improvement of soil fertility, control of erosion, conservation of biodiversity and diversified income among households, (Bishaw *et al*., 2013). Agroforestry can also be defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. Agroforestry is therefore important to smallholder farmers and other rural people in the promotion of food supply, income and health, (Smith *et al*., 2013).

Agroforestry is a land-use practice that directly conserves biodiversity, reduces land fragmentation and loss of habitat among various wildlife species. Some of the major concerns of these land-use practices are the overstated deforestation benefits, (Kaimowitz,

2004) even though the risks associated with it have not been adequately accepted. The agroforestry practices claim on the provision of products and services however the literature does not have evidence for many of these claims until recently. The last hundred years have seen an increase in scientific data that proves some of these claims through agroforestry is viewed as a multifunctional working landscape that provides ecosystem services, environmental benefits and economic products. The roles of the agro-ecosystems have been clearly stated by both the Millennium Ecosystem Assessment-2005 and the International Assessment of Agricultural Science and Technology for Development-2008. It is also a greater activity of interest that provides funds to the landowners and farmers for land-use practices that regulate valuable environmental services to the whole society, (FAO, 2007). Several trials have been carried out to quantify the environmental benefits of agroforestry although there has been inadequate information. The available information mostly focused on a single ecosystem service, (Sinclair, 2003) put together the first comprehensive information of the functions of agroforestry systems in the conservation of biodiversity in tropical landscapes with examples from many several countries, (Sinclair, 2003).

Montagnini, (2006), used different examples from the world to determine the carbon absorption potential of agroforestry systems. The goal of this special issue was to bring together all the research articles on several ecosystem services and environmental benefits from agroforestry practices to a central point over the world. In developing countries, about 2 billion people rely on wood fuel for cooking as a major source of energy for households, (FAO, 2005). In East Africa, the forest cover has been reduced by 9.3 % between 2001-2009, (Pfeifer, 2012).

2.2.1 Types of Agroforestry Systems

There are three main types of agroforestry systems: Agrisilvicultural systems are when crops and trees combined in the same land, such as alley cropping or home gardens, ((FAO, 2015). Silvopastoral systems are when forestry and grazing of domestic animals on pastures, rangelands, or on-farm are combined. Agrosilvopastoral is where trees, animals and crops combined and mostly illustrated in the home gardens when animals, as well as scattered trees on croplands, used for grazing after harvests, (FAO, 2015). Other types of agroforestry include mixed garden systems where trees, crops, and animals are combined on small plots to supply nutrients, materials, and marketable products to households. Multi-use and production systems provide services such as control of erosion and recharging of watersheds and production of forest products: In this system, various nectar-producing trees are frequently visited by honeybees and are mainly planted along the boundaries of the agricultural fields, (FAO, 2015). Aquaforestry is a system where various trees and shrubs preferred by fish are planted around the fish ponds. The leaves of the trees are used as feed fish. The main role of this system is fish production and bond stabilization around fish ponds, (Peace Corps, 2021).

There are other different systems of agroforestry as discussed below:

2.2.2 The functional classification

The functional classification production and protection are, theoretically, two fundamental attributes of all agroforestry systems. This implies that agroforestry systems have a productive function yielding one or more products that usually meet basic needs and a service role, such as protective function, (Kebebew, 2022). Based on various functions, the agroforestry systems are classified into the following: Productive Agroforestry system: This system refers to the production of essential commodities required to meet society's basic needs. It includes intercropping of trees, home gardens, plantation of trees in and around the crop field, production of animals and fishes associated with trees. Productive functions are as follows; Food, Fodder, Fuelwood and other products, (Kebebew and Urgessa, 2022). Protective Agroforestry system: This system refers to protect the land, improving climate, reduce wind and water erosion, improve soil fertility, provide shelter, and other benefits. Protective functions are as follows: Windbreak, Shelterbelt, Soil conservation, Moisture conservation, Soil improvement, Shade (for crops, animals, and man), (Kebebew and Urgessa, 2022).

2.2.3 Socioeconomic classification

In this group, the agroforestry system is classified as: Subsistence Agroforestry system which aims at the basic needs of a small family having less holding and very little capacity for investment. There may be marginal surplus production for sale like shifting cultivation, scattered trees in the farms and homestead Agroforestry, (Kebebew and Urgessa, 2022). Commercial Agroforestry system is a large-scale production on a commercial basis and the main consideration is to sell the products such as tea or coffee under a shade tree. Intermediate Agroforestry system is an intermediate between commercial and subsistence systems and it is practiced on small and medium-sized farms with the aim to produce items that are not only enough to meet the needs of the family but also earn money from the surplus that can be sold, (Ahmad and Goparaju, 2017).

The socioeconomic agroforestry system is further classified based on management and technology used. Based on management we have an intensively managed system where the agroforestry systems are intensively managed for more production per unit area as in home gardens, trees with agricultural crops and the extensively managed system which includes Shifting cultivation, Silvopasture, Pastoral silviculture, (Urgessa, 2022). Based on technology there are three systems namely; Low technology system where the technology used is primitive as in shifting cultivation, high technology system that depends on modern technology for forest and agricultural crop production. Tissue culture, Biotechnology, Genetic engineering, and an Intermediate technology system that is an intermediate between low and high technology systems. Most agroforestry systems belong to this category, (Kebebew and Urgessa, 2022).

2.2.4 Classification based on utilization of land

Based on the utilization of land, the agroforestry production systems are classified into five categories. Homestead agroforestry system focus on production of fruit trees, selected multipurpose trees having less canopy and decorative trees, (Urgessa, 2022). Shrubs and vegetables spices, many shade-loving crops and forest land agroforestry system focus on production of crops in the vacant spaces of the forest, crop farm forestry system focus on production of crops and trees in the cropland, fish farm forestry system focus on production of fish and trees in the fish farm and animal farm forestry, (Urgessa, 2022). Animal farm forestry is further classified as; poultry farm forestry: Farming of poultry birds and trees, Dairy farm forestry: Farming of milk cattle and trees, beef cattle farm forestry: Farming of beef cattle and trees, Goat farm forestry: Farming of goats and trees and Integrated farm forestry: Production of crops, animals, fishes along with trees and roadside agroforestry: Production of deep-rooted tall trees with narrow canopies and soil building grasses or crops along the sides of roads, highways, railways, and embankment, (Ahmad and Goparaju, 2017).

2.2.5 Ecological classification

Ecological Classification is related to various ecological factors. It can be classified based on important ecological parameters (Climate, edaphic and physiographic ones). Based on Ecological parameters, classified into five as; Tropical: Vegetation in an extreme climate, such as high temperature, low humidity and scarcity of water, (Urgessa, 2022). Tropical Silvopasture, Sub-tropical: Vegetation in suitable climatic conditions. Agroforestry practices in the subtropical regions, temperate: vegetation in low temperature such as silvopasture or pastoral silviculture in the temperate region, Subalpine: Vegetation in low and medium mountainous regions, (Urgessa, 2022). Natural or artificial forest vegetation in low or medium mountains and alpine: Vegetation in high mountainous regions for example natural forest vegetation in high altitude. Each of these groups can further be subdivided based on moisture conditions as either wet: Vegetation under high moisture content of the growing areas as in marshy land, Swamp, waterlogged area, Moist: Vegetation under adequate moisture status of the following place as the crop fields with Agrosilviculture, Silvoagriculture or dry: Vegetation under very low moisture as in the tropical dry forest, (Kebebew and Urgessa, 2022).

In the world, there are different systems which have been adopted and over time more will be developed as the interaction of trees and food crops are increasingly being understood. In this study, we focused on the meaning of the tree and sugarcane in a farm, (Kebebew and Urgessa, 2022). The tree-sugarcane agroforestry system is a combination of trees and sugarcane in one farm as a farming practice hence it is an agrisilvicultural system.

2.3 Importance of land to agroforestry systems

Land capital is finite which needs to be prudently tap for the benefit of humankind and agroforestry systems in a sustainable manner in the increased population scenario as per scientific land evaluation criteria. Agroforestry systems got adequate focus in the world due to the global effort in the research and development, (FAO 2021). They addressed the issues in an integrated approach of the most crucial land-management goals and highlighted that one billion of agricultural land retain more than 10% tree cover; still several categories of land use/land cover globally have the capacity and utilized under various agroforestry practices, (Ahmad and Goparaju, 2017). International organizations are continuously doing intensive research on agroforestry to achieve a livelihood blueprint for the poor people around the globe, as well as for the improvement in environmental services.

Agroforestry is a dynamic, ecologically based, natural resource management system, which involves the integration of trees on farms and in the agricultural landscape that seeks to diversify and sustain production for increased social, economic and environmental benefits for land users at all levels, (Jose, 2018). One of the critical factors that have given consideration in determining the potential acceptability and viability of agroforestry is land fragmentation, land tenure systems and tree ownership. Land fragmentation at generational transfers has become a more important tendency in nearly all types of holdings, (Goparaju, 2019).

Rules of inheritance of land by all sons in a family and a larger family size inevitably imply a rapid fragmentation of family land. In areas already heavily populated with average land holdings of less than two hectares such as parts of western Kenya, the land fragmentation continues much below the limits of capacity to reproduce a family. This fragmentation has continued in spite of the legal instructions against sub-divisions below a minimum for reproducing a family, (Zougmore, 2018). This has reduced land sizes among families leaving only small pieces of land for food production.

Agroforestry depends on people's rights to plant and use trees, rights which in turn depend on the prevailing systems of land tenure and tree tenure. Tree tenure is often distinct from land tenure, but they affect each other, (Alemu, 2022). Tree tenure consists of a buddle of rights over trees and their produce, which may be held by different people at different times. These rights include rights to own or inherit trees, the rights to plant trees, the right to use trees and their products, the rights to dispose of trees and the right to exclude others from the use of trees and tree products. The nature of the tree, the nature of the use and the nature of the person or group influences who and what rights. Landowners tend to be relatively advantaged in terms of their rights to trees, (Alemu, 2022). However, rights to plant trees have been restricted in Africa. It been reported that trees may be planted as visible evidence of a claim to land in Kenya

The role of land tenure insecurity as a barrier to wider agroforestry uptake and has long been hypothesized as a key underlying factor, though there are few studies that have been able to demonstrate a definitive link between improved tenure security and changing agroforestry practices, (Arnot *et al*., 2022). It is also unclear to what extent insecure tenure acts as an important barrier to climate-smart agricultural practices across different socio-economic, institutional, biophysical, and related contexts. To date, no clear consensus has emerged from empirical studies across varying sub-Saharan Africa contexts on whether and how stronger land tenure security may, incentivize farmer decision-making and pursuit of different land investment strategies on their farms, (Place, 2019) in general. However, opportunities to rigorously test this supposition have also been limited, given the substantial challenges associated with piloting tenure interventions on the continent.

2.4 Tree-sugarcane Agroforestry System

For the sustainability of an agroforestry system, it is important to understand factors and interactions between all species within it. Therefore, the choice of species that compose a system is a consideration of great importance. The growth and development of different types of plants (that is sugarcane and tree species) in the same area presupposes the existence of dynamic system interactions. The vegetative growth of woody plants in mixed systems is important when considering management practices; planting arrangements also, (Elli *et al*., 2016).

2.4.1 Tree species for agroforestry system

Selective retention of naturally regenerated trees is probably the oldest and still important way of getting trees into agroforestry that can be intervened as maintaining trees on croplands for their usefulness to provide multiple products, (Etefa *et al*., 2014). Domesticating agroforestry trees involves accelerated and human-induced evolution to bring tree species into wider cultivation through a farmer-determined or market-lead process. The selection, retention, or deliberately planting and management of trees by farmers can be considered as the beginning of the domestication process of the species, (Etefa *et al*., 2014). It is common for farmers to manage the natural regeneration of trees within agricultural fields by protecting seedlings and young trees, mostly indigenous tree species that have germinated from soil seed banks. Mostly the people of the country cultivate indigenous tree species in the form of agroforestry for provisions as a source of food, charcoal production, timber production, house construction, fuel-wood and farm implement, (Moon, 2018).

Modern tree planting using introduced tree species (mainly *Eucalyptus* species) was initiated to alleviate the shortage of firewood and construction wood in the capital city, (Alebachew, 2012). Despite such signs of the indigenous tree species, people are planting more economically useful exotic trees without considering their ecological implications; hence there seems less and less preference for indigenous tree species. However, no evidence proves or disproves this assumption. Exotic tree plantations are meanwhile widely considered to have serious adverse effects on the environment, which include harmful changes in the physical, chemical and biological conditions of the soil, (Alebachew, 2012). Competition with agronomic land use for monetary reasons;

displacement of the local flora, the native vegetation and, in part, the native fauna; and enhancing problems of susceptibility of the exotic species to epidemic diseases and pests, (Alebachew, 2012).

2.4.2 Sugarcane species for agroforestry system

Sugarcane, which has been cultivated in more than 100 countries, is the most important sugar crop accounting for more than 78% of the total world sugar production, (D'Hont, Paulet and Glaszmann 2002). The 'noble' species *Saccharum officinarum* and the wild *Saccharum spontaneum* are valuable resources that contribute respectively sugar, biotic and abiotic stress resistance, and growth vigor. These two species belong to the genus Saccharum, which contains six different species including S. *officinarum*, S. *spontaneum,* S. *sinense*, S. *Barberi*, S. *robustum* and S. *edule*. Among them, S. *officinarum* and S. spontaneum are thought to be the ancestors of modern cultivated sugarcane, (D'Hont, Paulet and Glaszmann 2002), of which 70–80% from S. *officinarum*, 10–20% from S. *spontaneum* and about 10% from interspecific recombination. Thus, the genomic structure of modern sugarcane hybrids is recognized to have homologous interspecific and intraspecific chromosomes, (D'Hont, 2005), while S. *sinense* and S. *Barberi* are regarded as interspecific hybrids between S. *officinarum* and S. *spontaneum*, resulting in an exceedingly complex interspecific polyploid sugarcane genome. Due to the complexity in ploidy, the complete genome of modern sugarcane is remaining to be deciphered though great progress has been made by drawing allele-defined genome of tetraploid S. *spontaneum* AP85-441, and by assembling a mosaic monoploid reference sequence for modern sugarcane cultivar R570 based on a bacterial artificial chromosome (BAC) clone, (Garsmeur *et al.*, 2018).

In the past 50 years, demand for food, fuel, timber, fiber and freshwater has increased in East Africa (Swallow *et al.*, 2009). In the same period, the population in Kenya has grown rapidly, by 2.7% a year, (Regeringskansliet, 2010) and (World Fact book, 2010). About 45% of the total area in Kenya is agricultural land and 8% is arable land (Nationmaster, 2010). This makes agriculture the main occupation, and the agricultural sector contributes about 21% to Gross Domestic Product (World Factbook, 2010). Smallholder farmers mainly produce crops for domestic use, such as maize, beans, fruits and vegetables (Nationmaster, 2010). One of the most common cash crops in Kenya is sugarcane, but the sugar industry is not functioning very effectively. There are six different sugar companies, of which only one, West Kenya Sugar, is entirely privately owned. Another, Mumias Sugar, is partly private but the government is the majority shareholder (Kenya Sugar Board, 2010) and (Mbendi, 2010). The other four factories are entirely owned by the government. In total, the factories produce between 400,000 and 500,000 tons of sugar every year from their plantations and from 'out growers' (more or less contracted farmers). However, the farmers are usually paid late and get little general information about managing their sugarcane crop. In the area where this study was conducted, deforestation carried out in some places to make way for the cultivation of cash crops, a practice that poses a threat to the ecological systems in the region, (Mbendi, 2010). One way to reconstruct the ecosystem after deforestation and to compensate for the loss of resources is to design farming systems that satisfy the increased demands of the population.

Although the Kenya sugar industry is slightly over a century old, varieties Co 421, Co 945, CO 617 and N14 still dominate the industry. In 2011, they occupied about 89% of the cane hectarage in the country and 78% of farmers cultivated these varieties. The old varieties are characterized by late maturity, low sucrose content and susceptibility to major diseases such as smut, mosaic and ratoon stunting. To improve and sustain sugarcane productivity in Kenya the efforts to develop better varieties must intensified, (Kenya Sugar Board, 2010).

Up to date 13 varieties have been developed and released for commercial production. Key attributes of these varieties include early maturity (harvest in 14 – 19 months), resistance to smut, high sugar and cane yields. The varieties include 11 KEN varieties, 1 EAK and 1 import as follows: KEN 82 – 216, KEN 82 – 219, KEN 82 – 247, KEN 82 – 401, KEN 82 – 808 and KEN 83 – 737 were released in 2002, of these; KEN 83 – 737 has been adopted successfully in all the sugar zones, (Sugar Research Institute, 2015).

In 2007, four (4) varieties – 3 Kenyan bred varieties namely: KEN 82 –62, KEN 82 – 472 and EAK 73 – 335 and one foreign D8484 were released in 2006. EAK 73-335 and D8484 have been widely adopted in the Mumias Zone. Three varieties KEN 82-121, KEN 82-493 and KEN 82-601 were released in June 2011 primarily for the Nyando zone, (Sugar Research Institute, 2015).

2.4.3 Plants arrangement associated with agroforestry system

Alley cropping can vary from simple systems such as an annual grain rotation between timber tree species to complex, multilayered systems that can produce a diverse range of agricultural products. Alley cropping systems are sometimes called intercropping, especially in tropical areas, (Quinkenstein, 2012). It is especially attractive to producers interested in growing multiple crops on the same acreage to improve whole-farm yield. Growing a variety of crops near each other can create significant benefits to producers, such as improved crop production and microclimate benefits and help them manage risk.

Alley cropping systems change over time. As trees and shrubs grow, they influence the light, water, and nutrient regimes in the field. These interactions are what sets alley cropping apart from more common mono-cropping systems, (Quinkenstein, 2012).

A woodlot is a tract of land of any shape or size that supports naturally occurring or planted trees. Most woodlots in Alberta are family-owned and are often operated as part of an agricultural operation. These properties occupy 3.6 million hectares of forested land in Alberta's agricultural zone or 4% of the province's forested land base. Individual woodlots vary in size from a few hectares to several hundred; the average lies between 20 and 40 hectares. The report "Profile of Private Forested Sector in Alberta" suggests 10 to 20% of Alberta's timber supply is from privately owned land, (Quinkenstein, 2012).

The value of woodlots is often measured by their ability to produce forest products or to stimulate local or regional economies by creating or diversifying business activity and employment, (Alberta, 2015). However, woodlots produce more than goods and services. Forests protect soil from wind and water erosion. They contribute to cleansing, filtering and stabilizing wetlands and water bodies, and provide habitat for a wide range of wildlife and plant species. Woodlots contribute to clean air and provide a place to commune with nature, (Alberta, 2015).

2.5 Benefits of Agrisilvicultural System

In many countries around the globe, agroforestry has been established as a long farming practice. Agroforestry is a dynamic, ecologically-based, natural resource management system that through the integration of trees on farms and in the agricultural landscape, seeks to diversify and sustain production for increased social, economic and environmental benefits for land users at all levels, (ICRAF, 2006).

Agroforestry has risen to prominence as a strategy to help address global climate change and provide other environmental, economic, and social benefits, (Agric Food Syst, 2012). Benefits from agroforestry such as carbon sequestration, soil erosion and runoff control and improvement of nutrients and water cycling, as well as for offering socio-economic benefits and greater agricultural productivity have led to the promotion of its adoption, (Sustainability, 2016). Researchers and policymakers have long studied and supported agroforestry practices in low and middle-income countries (L and MICs), particularly in tropical regions by recognition and promotion of agroforestry in the temperate climates of countries where it gained steam only more recently, (Springer, 2012).

2.5.1 Bio-fuel or energy production

Trees and shrubs are the major sources of fuelwood in rural areas where 70-80% of the rural population relies on. Through the adoption of agroforestry initiatives, large quantities of wood produced from farmlands unlike before where produced from the natural forests, (NRCAF, 2007). The fuelwood potential of indigenous (*Acacia nilotica, Azadirachta indica, Casuarina equisetifolia, Dalbergia sissoo, Prosopis cineraria* and *Ziziphus mauritiana*) and exotic (*Acacia auriculiformis, A. tortilis, Eucalyptus camaldulensis* and *E. tereticornis*) trees indicates that calorific values range from 18.7 to 20.8 MJ/ kg for indigenous tree species and 17.3 to19.3 MJ/kg for exotics. Biofuels are renewable liquid fuels obtained from raw living materials that have a good substitute for transport fuel and such biofuels are being accepted by most countries worldwide since it solves the problem of environmental degradation, acts as an alternative source of energy, minimizes imports, contributes to rural employment and increases agricultural economy, (NRCAF, 2007).

2.5.2 Carbon sequestration

The role of agroforestry trees includes the sink of atmospheric carbon (C) because of their rapid growth and high productivity. Trees therefore in an agricultural production system cause an increase in the amount of carbon stored in agricultural land and still allow the growing of food crops, (Kursten, 2000). Management of trees in an agroforestry system is carried out intensively by pruning to minimize competition and maximize complementarity. The branches and other non-timber products obtained and therefore such materials usually returned to soils hence the amount of biomass and carbon (C) harvested and exported from the system is relatively low in comparison to the productivity of the tree. Unlike in tree plantations and monoculture, systems agroforestry to have a positive role in terms of C sequestration, (Kursten, 2000).

A study on carbon sequestration potential of agri-silviculture where *Albizia procera* had been planted for 5 years and three pruning regimes (70% canopy pruning, 50 % canopy pruning and un-pruned) with 2 crop rotations (black-gram-mustard and green gram-wheat) at NRC for agroforestry, (Jhansi, 2002). After 3 years, the system sequestered 23.58 to 24.79 t C / under different crop rotations irrespective of pruning regimes and the amount of C sequestered under-pruning regimes was 27.97, 22.96 and 21.33 t C/ ha in an unpruned tree, 70 % canopy pruning and 50 % canopy pruning, respectively. The C absorption in a pure tree was 40% less and the pure crop was 84 % less than agri-silviculture, (Newaj *et al.*, 2008). It, therefore, indicates that the agroforestry system is more important to sequester C than either growing of pure tree or crop. Unpruned trees can sequester more C but it does not allow cropping over a short period mostly after 2-3 years from planting. Pruning of trees gives advantages of C sequestration and allows growing of crops for desired period, (Newaj *et al*., 2008).

2.5.3 Bio-drainage

The bio-drainage technique is eco-friendly since the plantations purify our environment through the absorption of greenhouse gases and releasing oxygen back to the environment. This technique does not require any disposal of drainage effluent because the bio-drainage plantations drain filtered freshwater out by use of bioenergy, (Heuperman *et al*., 2002). Most of the drainage effluent is being disposed of into rivers and this practice has become problematic over time as the effluent/discharge contains nutrients, salts and residues of agrochemicals that affect the health of reservoirs, rivers and inland seas. Most of the inland wetlands are becoming more saline over time due to continuing inflow of saline waters. The Aral Sea Basin, the Indus basin in Pakistan have several river systems in India and the Murray-Darling Basin Catchment in Australia is experiencing the consequences of pollution of water in rivers caused by the discharge of polluted effluent from farms under irrigation (Heuperman *et al*., 2002).

The rise in groundwater table followed by waterlogging and secondary Salinization of soils has led to a serious problem in canal-irrigated areas in arid and semi-arid regions of the world, (Heuperman *et al*., 2002). To solve this problem an agroforestry model of bio-drainage was tested in the waterlogged area of Haryana state (north-west India) where 10% (0.44 million ha) was waterlogged resulting in a reduction in crop yields and abandonment of agricultural land. In December 2002 four parallel strip-plantations of clonal *Eucalyptus tereticornis* (Mysore gum) were raised on four ridges constructed in a north-south direction in a 4.8 ha waterlogged area. The spacing was at 66 m and each strip-plantation had 2 rows of plants at a spacing of 1 m x 1 m resulting in a density of 300 plants/ha. Between April 2005 to April 2008 the levels of the groundwater table were measured in 22 observation wells installed in 2 transects across the strip plantations, (Heuperman *et al*., 2002).

The strip plantation had a groundwater table underneath lower than the groundwater in the adjacent fields and the drawdown in the groundwater table during this period of 3 years was 0.85 m, (Heuperman *et al*., 2002). The rate of transpiration in May 2008), measured with a sap-flow meter, was 50 liters/day/plant which was equal to 438 mm/annum against the mean annual rainfall of 212 mm. The benefit-cost ratio of the first rotation (5.4 years) of strip-plantations was 3:1 against 1.3:1 of crops in Haryana and it would be more than 100:1 for the next 3 to 4 rotations due to the low cost of maintenance of coppiced Eucalyptus. Wheat yield in April 2007 in the interspace of strip plantations was 3.34 times the yield in adjacent waterlogged areas without plantations. This agroforestry model of bio-drainage has proved to be of low-cost, socially-acceptable and environment-friendly technique for the reclamation of waterlogged areas during 2008-09, (Heuperman *et al*., 2002).

2.5.4 Biodiversity conservation

A major challenge towards sustainable production and livelihood security is the exploitation of natural resources while deforestation causes effects on the biodiversity of an ecosystem. Agroforestry system with various components like trees, crops, grasses, livestock, etc. provides all kinds of life support thus may not entirely reduce deforestation, (Angelsen and Kaimowitz, 2004) but acts as an effective buffer to deforestation. Trees in the agroforestry system act as a refuge to biodiversity after serious adverse events such as fire, (Griffith, 2000). In the traditional society of coastal belts and tropics of any country, practicing home gardens and sacred groves support biodiversity conservation.

2.5.5 Enhancing soil fertility

The primary objective of soil conservation is to improve and maintain soil fertility and to get to this it involves control of erosion, maintenance of organic matter and physical properties. This practice constitutes sustainable land use and helps to improve soils in several ways therefore maintenance and enhancement of soil fertility through agroforestry is vital for global food security and environmental sustainability, (Manna *et al*., 2003). Although at present India is self-sufficient in terms of food production, a population is expected to rise further and therefore the country will need to enhance both food production and increase tree biomass. Ecologically sound agroforestry systems like intercropping and mixed arable-livestock systems can increase the sustainability of agricultural production while reducing on-site and off-site consequences which leads to sustainable agriculture. Other land-use systems such as agroforestry, agro-horticultural, agro-pastoral and agro-silvopasture are alternatives that are more effective for soil organic matter restoration, (Manna *et al*., 2003).

2.6 Uses of Trees for Economic Livelihoods

Trees provide several important functions in an ecosystem to sustain terrestrial systems, (Abson *et al*., 2014). These functions are said to contribute important ecosystem functions towards the maintenance of human populations. In a well-established nutrient, cycle trees contribute towards soil formation, climate, and water regulation, (Power, 2010). Forests are also important habitats for flora and fauna and they directly provide vital services through the production of fuel and fiber. They also aid in regulating pest control and supporting pollinating services. In Africa, the links between tree cover, access to food and improved dietary diversity are becoming increasingly evident, (Ickowitz *et al*., 2014 and Johnson *et al*., 2013).

Some factors that contribute to low living standards and reduced wellbeing include; scarcity of available arable land, a general absence of local roads to urban areas, low public investment in health and education, scarce basic infrastructure and low levels of employment, (World Dev, 2014). In rural areas, there are several numbers of long-term poverty traps and increasingly strict conservation policies have contributed to fewer opportunities on natural forest and bring it into agricultural production hence the potential to reduce poverty through expansion of agricultural land is limited. It is therefore important to understand how to improve constrained agricultural resources, especially in forest estates, and improve global human well-being to alleviate poverty, (World Dev, 2014).

Successful plantation and management of trees may lead to an increase in low incomes and contribute to poverty alleviation. Plantation of various trees such as Eucalyptus spp., tropical Acacia spp, and oil palm leads to an increase in incomes from wood and biofuel production at the household level, (Paquette, 2010). Polyculture has the potential to fulfill a variety of objectives, such as increased income, reduced vulnerability to volatile global markets for forestry products, better regulating services and nature conservation where else monoculture has a single objective, (Zheng, 2019). Polycultures could be designed to accomplish diverse and context-specific goals like intercropping with vegetables or legumes, forest farming for mushrooms, medicinal herbs, floral greenery and livestock integrated into plantation systems. The shortage of land can affect long-term income generation for local rural households in tropical forest areas although appropriate forestry land reallocation even though full use of current land resources might be helpful to alleviate poverty, (Zhou, Guo, and Liu, 2019). Tree plantations can contribute to economic growth and rural livelihoods but the plantation of one plant species (monocultures) usually generates environmental problems like air and water pollution, soil erosion, siltation along the waterways, flooding and loss of biodiversity, (Obidzinski, 2012).

2.7 Uses of Crops for Economic Livelihoods

The livelihoods approach has been widely used in urban and rural areas to analyze livelihoods and their relationships systematically. The common question which is crucial is how different livelihood strategies generate different outcomes for individuals, households, or groups in terms of incomes, nutrition, caloric intake, or other well-being measures, (Frison *et al*., 2011and Martin *et al*., 2013).

In rural parts particularly the multi-faceted nature of agricultural livelihoods, the dynamism of contexts, temporality, and the element of human agency responding to and acting on accessible capital assets make it challenging to generalize which livelihood strategies generate the best outcomes for human well-being, (Pingali, 2012). The need-to-know livelihood strategies lead towards the best food security outcomes within a specific context remains strong, particularly mainly when certain government policies prioritize specific crops like cash crops whose expansion might reduce the presence of other crops in existing livelihood strategies. Food security outcomes associated with a better understanding of the importance of different livelihood strategies in semi-subsistence landscapes often become the focus of government interventions for a shift to commercially-oriented agricultural production, despite many households not having the necessary capital assets to make the changes required, (Pingali, 2012).

Diversification of crops is the practice of cultivating different crops either in the form of rotations or inter-cropping. This approach is seen as the most ecologically feasible, cost-effective and rational way towards reduction of uncertainties, especially in agriculture among smallholder farmers, (Joshi, 2005). Intercropping of crops during the planting cycle causes enemies in a natural area of insects and pests thus breaking the disease cycles by suppressing weeds and other crops. It thereby creates a dilution effect by reducing resource concentration and microenvironment modification within the crop canopy and or making difficult the penetration of pest and disease pathogens, (Joshi, 2005).

Crop diversification also contributes to the improvement of local biodiversity especially when farmers grow indigenous crop varieties. The improvement of soil fertility as one of the benefits under crop diversification is a foundation of sustainable and productive farming systems, (Lin, 2011). Well-managed soils help to lower pest pressure, optimize water use by plants, and improve overall crop yields however there is an opinion that crop diversification has a positive impact on climate change effects through the ability of local flora (as opposed to monoculture) to hold carbon thus generating less carbon dioxide.

Cash crops such as cocoa and coffee, vegetables and maize offer income and employment opportunities to the rural economy by generating capital for management improvements and innovation while cash crops accelerate the building-up of institutions that enable further commercialization, (Ogundari, 2014). Farming activity especially on cash-crop agriculture requires the management of several types of risk such as soil degradation and price variability for example when a farmer employs several adaptive and risk-reducing strategies. For instance by diversifying cropping patterns to cope with risks of harvest failures, price slums or loss of market access and by establishing cooperatives or using agricultural commodity exchanges (Ogundari, 2014)

In Africa, demand for food will be increased over the next decades and sustainable intensification activities aim to reconcile production and protection of the environment in a practical approach for African farmers to cope with food insecurity (Rogan, 2018). Examples are micro-dosing of fertilizers, intercropping, genetic crop improvements, extension and establishing farmers' marketing associations. Cash crops are an essential part of sustainable intensification as income generated with cash crops provides farm households with means to save and invest in a more productive farm, and cash crops may have a catalytic effect on agricultural innovations as they add value and productivity in rural areas, (Corral, 2018).

In recent decade's tree planting with crops for food and wood production has received considerable attention in both tropical, (Garrity *et al*., 2010) and temperate regions, (Palma *et al*., 2007). Through agroforestry, it has shown potential towards an increase and sustainable food production per unit area in systems like the parklands of the Sahel, (Bayala *et al*., 2012). Through the use of ‘fertilizer trees either intercropped or in fallow rotations with crops over sub-Saharan Africa, (Sileshi *et al*., 2008) and integrating trees with crops on sloppy areas, (Tiwari *et al*., 2009). It is seen by many as a promising approach towards the improvement of food security, (Glover *et al*., 2012) because trees usually enhance crop yields and sustain soil health, (Barrios *et al*., 2012).

Trees also give out fodder, fuelwood and construction materials which are highly demanded in many rural areas. If produced on-farm it will reduce the costs of obtaining them off-farm and produce high-value timber, generate substantial additional revenue to farmers in both temperate, (Dupraz *et al*., 1997) and tropical contexts, (Dupraz *et al*., 1997, Bertomeu, 2006, Santos-Martin and van Noordwijk, 2009) While fruits obtained from trees enhance income, (Mithöfer and Waibel, 2003, Luedeling and Buerkert, 2008) and nutrition for humans, (Goenster *et al.*, 2009, Kehlenbeck *et al*., 2013).

Agroforestry is often part of strategies to improve natural resource management, (Ong and Kho, 2015). They are usually more effective than other land uses in providing regulating, supporting and cultural ecosystem services, (Pagella and Sinclair, 2014), such as microclimatic buffering, amelioration of soil structure and water infiltration, reduction of overland flow, regulation of the water cycle and provision of habitat for wild species, (Bayala *et al*., 2014).

The potential of agroforestry practices to sequester carbon in wood and soil has been widely demonstrated (Luedeling *et al*., 2011and Kuyah *et al*., 2013). Agroforestry may also affect the emissions of other greenhouse gases either positively or negatively (Verchot *et al*., 2008, Rosenstock *et al*., 2014) and is therefore expected to help farmers adapt to climate change through the risk-mitigating effects of additional farm products obtained from trees, positive microclimatic effects of shading and enhanced farm productivity through tighter cycles of nutrients and water (Garrity *et al*., 2010).

Agroforestry practices are carried out in many places, including locations where they have never been tested and demonstrated in many substantial positive contributions of agroforestry to food security, natural resource management, and climate change mitigation and adaptation. It is also clear that not all these successes can be replicated everywhere. The extent to which all documented or assumed benefits of agroforestry depends on site-specific responses by trees, crops, or other components of the system, with strong variation between locations and farming contexts, (Coe *et al*., 2014). Benefits also vary over time, because many effects of trees on soils are slow to materialize, (Barrios *et al*., 2012). For instance, the beneficial effects of Faidherbia albida on crop yields have been reported to start only after the trees reach 20 to 40 years of age, (Ong and Kho, 2015).

2.8 Drawbacks Associated with Tree-sugarcane Agroforestry Systems

2.8.1 Labor intensive system

Agroforestry system requires adequate knowledge, planning and periodic tree maintenance to become successful because having trees or shrubs among the crops does not allow complete mechanization of the farm’s production thus becoming a nuisance for some farmers, (Wilson, 2016). The Spaces between trees have to maintain by each farmer to control the growth of weeds and to ensure that all trees develop as per their purpose by having an adequate space, (Wilson, 2016).

A good example is when trees grow for timber, they are usually grown closer together so that they develop a straight trunk and on the other hand, fruit or nut trees should have larger spacing to allow full crown formation, (Mbow, 2014). Regular monitoring and systematic work are therefore required during tree growth stages for example small trees may require fertilization and irrigation in their first years. When they grow bigger, regular pruning and thinning are needed to ensure their healthy development and good yield. Individual trees should also be checked for pests and diseases each season, (Syampungani, 2010).

2.8.2 Long waiting time for payback

There are very few disadvantages associated with agroforestry for those trying to grow trees and shrubs for profit. Time is one of the disadvantages because agroforestry is never a quick "fix"; trees take a longer period to mature, unlike crops, (Rogan, 2018). An example of a tree is the pecan tree which usually reaches its full production when its ten years old thus it is a long time for a single farmer to wait for the potential profit. If the farmers planted trees with a greater vision in consideration of future generations, agroforestry is therefore worth the effort and investment since one pecan tree can keep producing nuts for more than 100 years and has other services that will perform the soil and for nearby crops, (Rogan, 2018).

Sometimes long waiting time is a serious obstacle among small farmers from developing countries who rely on their annual harvest as a livelihood, (Tumushabe, 2018). Due to the lack of money, the farmers need to carefully plan their activities because they cannot afford to spend time caring for trees, which will not earn money for the season. They rather spend their time cultivating cash crops or performing other activities that will generate money for them like crafts which bring money instantly, (Tumushabe, 2018). Another limitation for subsistence farmers is the uncertainty of market prices for agroforestry products may be high at the moment since it takes a few years waiting and farmers cannot be sure that the price will not drop when selling their products hence would render their hard work disappointing.

2.8.3 Limited possibilities to sell products

Agroforestry mainly underestimated and overlooked from different perspectives but, unfortunately, farmers are reluctant to switch to agroforestry due to poorly structured markets for many tree products, (WFP, 2020). Many agroforestry products are also not commonly traded and therefore become rare and difficult for farmers to access information related to market development. This results in a lot of uncertainty. Farmers have to face price fluctuations, or a refusal of their products and an inability to promptly find a new buyer. For example, a buyer may refuse the products if they do not look according to expectations or if the harvest was lower that year and a farmer cannot supply the agreed amount, (WFP, 2020).

The other problems are due to different types of agroforestry products. A study of marketing limitations in agroforestry in India found out that farmers do not have a problem with crops, fruits, vegetables to access markets and information on prices is transparent in the case of these products but on wood products the situation is different, (Van Noordwijk, 2018). The sale of wood product sales is under the forest and environmental laws and the laws don’t fully recognize agroforestry as a branch. When farmers want to market their agroforestry wood products, they undergo a lengthy and difficult process to get special permits like in the Philippines. Tree farming gains more money in terms of profits in the long term as compared with crop production but uncertain marketing conditions discourage small farmers from tree planting as a source of income for their livelihoods, (Van Noordwijk, 2018).

2.8.4 Lack of legal support for agroforestry farmers

After the Second World War agricultural activities replaced other farming activities where Monocultures prevailed because of their most productive systems that allowed mechanization and efficiency of other farm operations, (FAO, 2012). When agricultural policies and incentives flavored farming methods it marked the time when many trees on farms were removed to create space for subsidized cash crops. Despite research on various importance of agroforestry for sustainable agricultural production and supportive policies the farming methods are still insufficient. Even though this form of land management integrates forestry and agriculture, it always fails to qualify for subsidies of either sector. Agroforestry doesn’t have characteristics of a typical forest or agricultural land since it’s a combination of both land-use systems making it complex, (FAO, 2012).

Due to its characteristics agroforestry requires policies that specifically target the functioning of these systems so that it defines and coordinates various elements in agroforestry development such as the need to simplify regulations to allow easier access to the market by farmers, (Ogundari, 2014). This therefore an easy exercise because the whole process may take time, hindering some farmers from adopting this agricultural method. It may also sound disappointing because some countries have made the first steps towards creating a conducive environment. The first country to adopt an agroforestry policy was India in 2014 where their policy addresses problems and risks farmers undertaking agroforestry and it aims to encourage the integration of trees in rural landscapes, (Ogundari, 2014).

2.8.5 Knowledge and technology-intensive method

For an agroforestry system to become successful proper knowledge and evaluation of the complexities like on different production sites, (UN, 2015). Farmers need to understand combining various plants in consideration of their compatibility and long-term effects on each other as per their main objective. The main purpose of combining trees in the farming systems (Integration) is due to products and or services such as control of erosion. When agroforestry is applied wrongly, it may fail miserably. Some of the disadvantages are that it recommends seeking expert advice or doing thorough research that will take into consideration local conditions, market situation and government regulations for land management. In some cases, it is rather difficult since the concept of agroforestry is new and some important information could be missing, (UN, 2015).

The long-time process to determine the right system for the desired purpose is another barrier that enables many farmers to harvest trees once in their lifetime due to a lack of experience and knowledge on best management practices hence many farmers usually work based on trial and error. Lack of information and poor understanding of how agroforestry could improve production on small farms among poorer subsistence farmers who could have benefited from this practice are often reluctant to try therefore more research and awareness-raising is required to have more trees planted, (Rosenstock, 2019).

2.8.6 Competition for resources

When trees are not selected it may compete with crops or livestock for other resources and if farmers plant them in narrow alleys their crowns will shade most of the land below when they grow bigger, (Reith, 2020). During this period farmers will be required to switch to shade-tolerant crops to avoid poor harvest that will lead to cutting down of trees without getting their full benefits. Competition of trees and crops for water in arid and semi-arid areas makes soils drier hence causes problems with the amount of water available in soils (Reith, 2020). It is a common result caused by too many trees in areas that cannot support rich vegetation or from planting tree species that will require larger amounts of water than the indigenous species.

The same problem experienced when trees grown on soils with a low amount of nutrients like where tree roots and crop roots overlap leading to competition for available nutrients, (Ellison, 2017). To minimize competition among trees and crops scientists recommends the addition of fertilizers to any crops grown closer to the trees and select deep-rooted trees be planted rather than shallow-rooted varieties with branched lateral root while on the other hand, nutrient content in soils increases away from tree roots due to the decomposition of tree litter. The suitable tree species do support better crop growth when maintained properly but they have to choose wisely, (Ellison, 2017).

2.8.7 Invasive species and alternate hosts of pests

The type of tree species selected determines the success of the whole system because trees influence their surrounding environment and their impact does not have to be only a positive one, (CIFOR, 2020). Sometimes trees host pests, of crops or provide nesting habitats to birds and rodents that can lead to damage of crops. For example, the Leucaena leucocephala tree that is the main source of firewood, animal fodder and even fit for human consumption but is the worst invasive species that usually spreads faster to form dense thickets that destroy other plants if not managed, (CIFOR, 2020).

2.8.8 Allelopathy

Allelopathy is when some trees produce chemicals that suppress the growth of other plants, (Luedeling, 2011). Its common in some tree's species like Eucalyptus *spp* which were once favored in agroforestry suppress vegetation and crops up to a distance of 11 meters away from the mother trees because they release highly toxic volatile terpenes that kill germination of other seeds, (Luedeling, 2011) and for this reason, these trees are not recommended further in agroforestry.

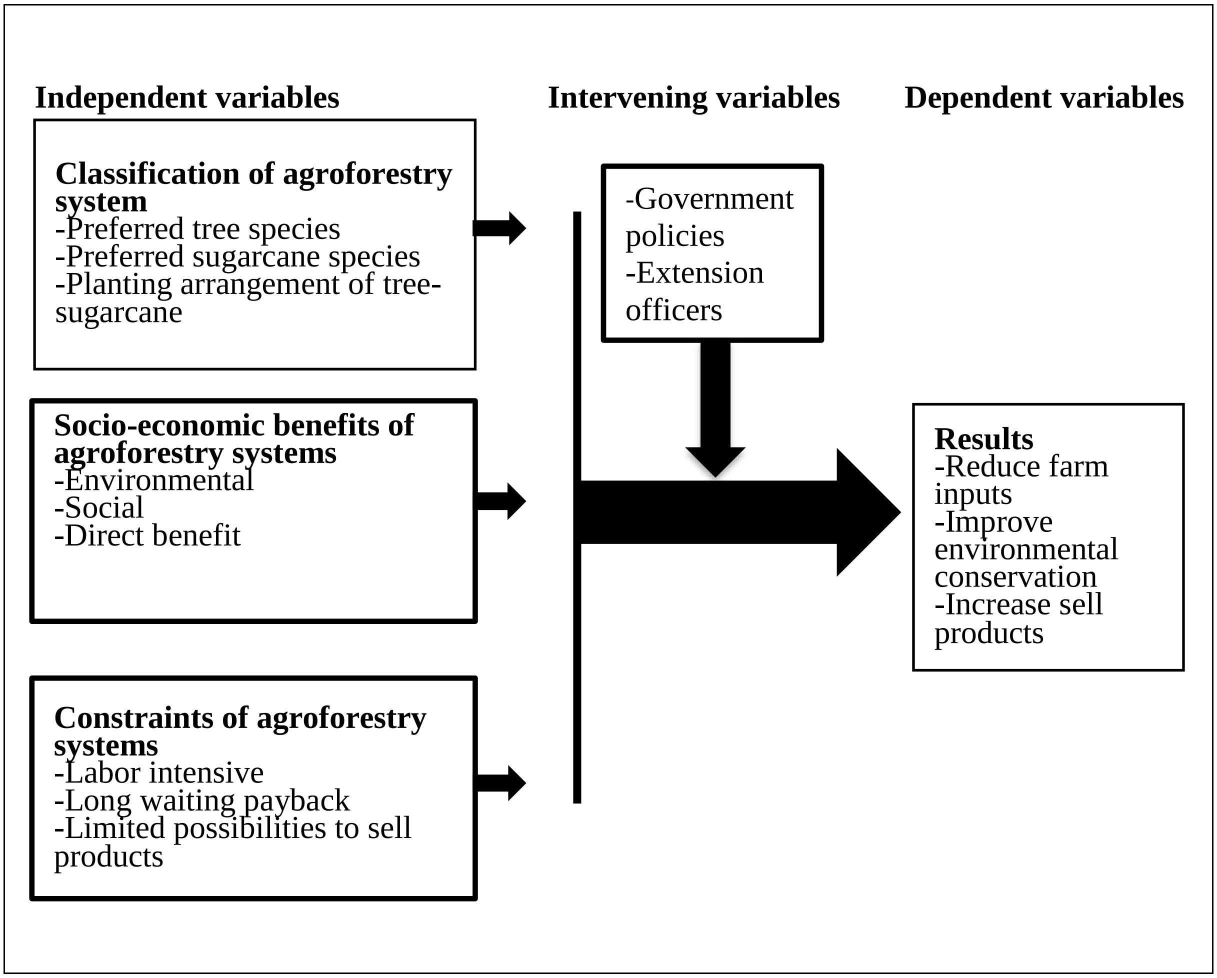
Neem tree is also another example because it used in cosmetics, medicine, or pest control, (Akinnifesi, 2008). It releases chemicals that affect the root growth of common crops such as oats, wheat, maize, or soybean and it is evident that one-quarter of oats harvest has been lost in the presence of neem trees on the field boundary and the interaction between trees and different crops are not yet fully understood it is tricky hence to eliminate negative influences and positive effects of trees on crop plans require more research to be done, (Akinnifesi, 2008).

2.9 Conceptual Framework

The table below summarizes the interaction between dependent and independent variables. When the independent variables acted upon it influences the dependent variables and the moderating variables will alter the association.

Table 2.1:

Conceptual framework



Source: Author, 2023

Preferred tree species is the most liked tree species by farmers in Soin ward

Preferred sugarcane species is the most liked sugarcane species among farmers in Soin area

Planting arrangement of tree-sugarcane is the way in which a farmer plant trees and sugarcane within an area to form a layout/pattern.

Environmental benefits are the advantages gained from the environment among communities.

Social benefits are the effects that a product or service of a specific product can have positively on a whole society

Direct benefit are any necessary requirements by an individual to perform in an activity

Labor intensive it is a large workforce is required in relation to the output.

Long waiting payback it is the period taken by an investment to recover its profits of saving is longer than the expected.

Limited possibilities to sell products is a restricted way where goods are sold under some guidelines/ regulation.

2.10 Identification of Knowledge Gaps

The communities living in rural parts of Kenya are dependent on forests for their livelihoods. An increase in demand for forestry products among households has led to the degradation of forestry ecosystems over time resulting in the adoption of different agroforestry systems among farmers. The Tree-sugarcane agroforestry system is one of the agroforestry systems established by sugarcane farmers in Soin ward. It enables them to maximize their productivity and improve livelihoods by obtaining different forestry products from the system. Despite the benefits of agroforestry, there is little documentation information on the tree-sugarcane agroforestry system. This study therefore, aimed to sought and explore the characteristics, socio-economic benefits and constraints of the tree-sugarcane agroforestry system in Soin Ward, Kericho County, Kenya.

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CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the selected research design for the study, location of the study, target and study population, sampling and sampling procedures, data collection procedures, data analysis and presentation and lastly on ethical issues and considerations.

3.2 Research Design

Descriptive research design was used in this study to allow for the evaluation of the classes, socio-economic benefits and constraints of the agroforestry systems among farmers.

3.3 Location of Study

This study was carried out in Soin Ward, Sigowet-Soin Sub- County, Kericho County, Kenya. Soin Ward lies between longitude 35º 02' and 35º 40' East and between the equator and latitude 0^0 23' South. The other five sub-counties that make up Kericho County include; Belgut, Ainamoi, Buret, Kipkelion-East, and Kipkelion-West. Kericho county has fertile soils and reliable rainfall with low annual evaporation rates thus suitable for agriculture. Despite the county being suitable for agriculture the government's target of ten percent forest cover has been enforced and most farmers have become innovative to meet the target of 10% forest cover by practicing agroforestry. The variation in altitude within the county has contributed to gradual changes in weather patterns over time. Temperatures in Celsius range between 10ºC and 29ºC with an average temperature of 17ºC (GoK, 2013b). The major challenges in Kericho county related to climate change include the long dry spells and emergence of erratic rainfall which cause negative impacts on the agriculture sector.

The rainfall pattern in the county is unique in that the central parts where tea is mainly grown receive the highest rainfall of about 2125 mm while the lower belts covering Soin and Kaplelartet wards receive lower amounts of rainfall of about 1400 mm. For a long time, the two rainy seasons in the county had no clear distinction as both seasons enjoyed a lot of rain. The long rains fall between April and June while the short rains occur between October and December. January and February are usually the driest months in the county. The county is divided into four agro-ecological zones (AEZ) which are sub-divided into minor agro-ecological and sub-zones:

1. Upper Highland (UH): The zone is characterized by very long cropping seasons. It is sub-divided into Upper Highland 0 (UH0), Upper Highland 1 (UH1) and Upper Highland 2 (UH2). UH0 is a forest zone, UH1 is suitable for sheep and dairy farming whereas UH2 is suitable for wheat and pyrethrum production.

2. Lower Highland (LH): This zone is further divided into sub-zones LH0, LH1, LH2 and LH3. LH0 is the forest zone, LH1 is the tea and dairy zone with permanent cropping possibilities divided into two variable cropping seasons with first rains starting February and second rains around the end of July. LH2 is a wheat, maize and pyrethrum zone with long cropping seasons. LH3 is the wheat, maize and barley zone.

3. Upper Midland (UM): This zone can further be divided into four sub-zones; UM1, UM2, UM3, UM4. 1-is for Coffee and Tea; 2-is for Coffee only; 3-is marginal Coffee zone; 4-is Maize-Sunflower zone.

4. Lower Midland (LM): The zone is suitable for marginal sugarcane growing with medium- to long-term cropping seasons. First rains occur towards the end of February with

second rains starting towards the end of August. This zone can be divided into two sub-zones. The zone is also suitable for cotton growing.

Land resources are mainly used for crop and livestock production. According to the climate risk profile for Kericho county, (MoALF. 2017), about 80% of the population (of which 78% were male-headed and 82% were female-headed households) drew their livelihoods from crop-related on-farm activities, while 58.5% (53% male-headed and 64% female-headed households) earned income from livestock activities. Agriculture within the county produces both cash and food crops. The main crops include tea, coffee, sugarcane, potatoes, maize, beans and horticulture (tomatoes, bananas, vegetables, pineapples) while the main livestock kept include dairy and beef cattle, sheep, goats and poultry, (GoK, 2014). The six sub-counties have different climatic conditions that led to the adoption of different agricultural practices by farmers and households. Sigowet-Soin Sub- County is characterized by commercial sugarcane farming that is proximal to the Nyanza sugar belt of Kisumu County. Soin Ward has a population of 126,500, (KNBS, 2019) and covers 517 Km^2.

Map of the Study 2022 Area

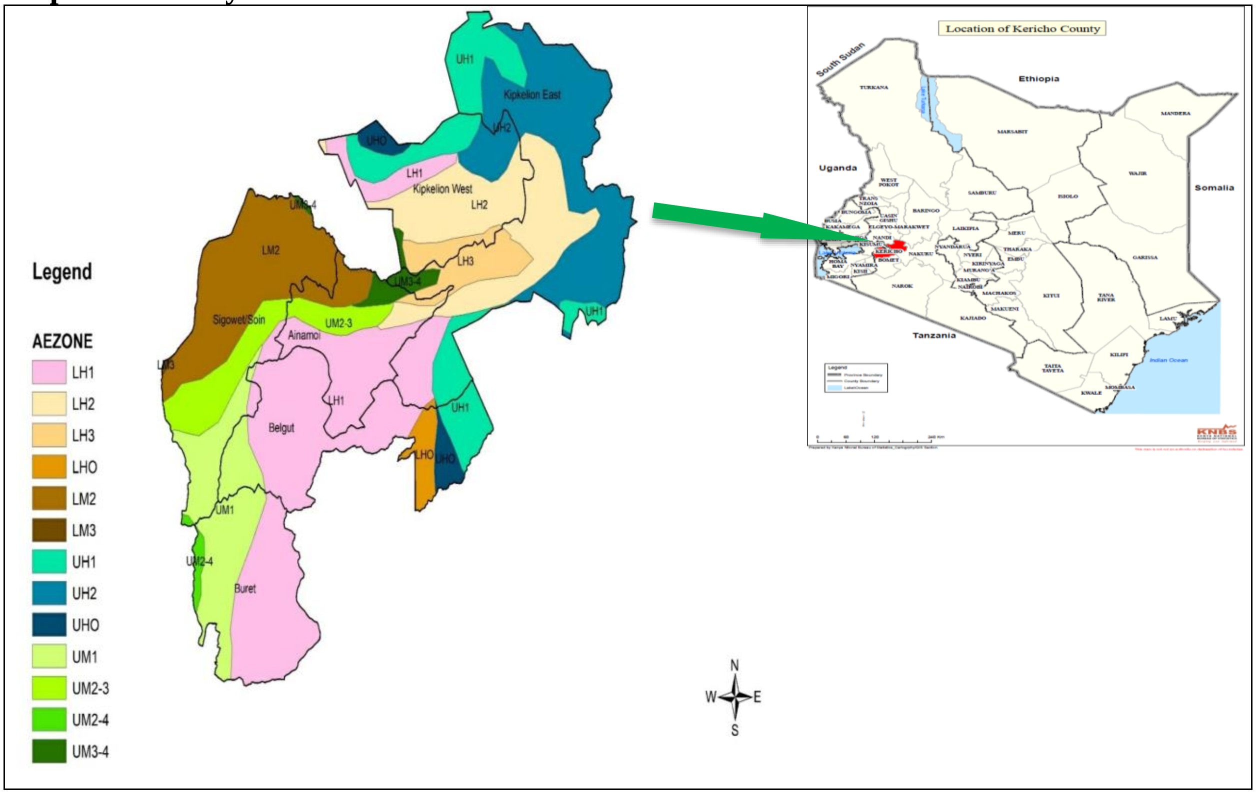


Figure 3.1: Soin ward with ecological zones

Source: Kenya Metrological Department – Kericho Office, 2020.

3.4 Target Population

A group of individuals, items/objects from which samples are taken for measurements is defined as the target population (Mugenda and Mugenda, 2009). This study targeted the 126,500 respondents within Soin Ward.

3.5 Sample Size and Sampling Procedures

Sampling is the process in which an appropriate number of subjects are selected from a defined population, (Kothari, 2014) and the representative of a target population is a sample. During this study, 384 respondents were targeted from a population of 126,500 in

Soin Ward. The Fischer Formula as given by Kothari (2014), was used to calculate the sample size as follows:

$n=Z^2*(p)*(1-p)/C^2$………………………………………………………equation1

Where;

n=sample size

Z = 1.96, the tabulated Z value for 95% confidence level

p = sample proportion expressed as a decimal (0.5 is the maximum that can yield at least the desired precision

c= degree of accuracy expressed as a decimal (0.05 because the estimate of the study should be within 5% of the true value.

Hence, $n=1.96^2 \text{ x}0.5 \text{ x } (1-0.5)/0.05^2$

n= 384 respondents

The sample size was then apportioned in a simple random manner to the four climatic zones in Soin ward as shown in table 3.1.

Table 3.1:

Apportioned Samples According to Ecological Zones in Soin Ward

Ecological Zone	Sampled Households (No)
Upper Highlands (UH)	96
Lower Highland (LH)	96
Upper Midlands (UM)	96
Lower Midlands (LM)	96
Total (Soin Ward)	384

3.6 Data Collection Instruments

Data on the classification, socio economic benefits and constraints of agroforestry systems were collected using a pretested questionnaire. Pre-testing of the questionnaire was carried out in the neighboring Ward of Kipkelion West three months prior to the commencement of the study.

3.6.1 Administration of the Questionnaires

The data related to classifying characteristics, socio-economic benefits and constraints of the agroforestry systems among farmers were collected through administration of structured questionnaires for respondents and interviews for experts from different fields. The questions were divided into sections to ensure that data for the specific objectives; classification and characteristics, the socio-economic benefits and constraints of agroforestry systems in Soin ward, Kericho County were collected. The questionnaire maintained the anonymity and honesty of respondents, (Bose, 2020). Data that was captured through observation were recorded in a checklist.

3.6.2 Secondary Data

Where necessary, secondary data related to characteristics, socio-economic benefits and constraints of the agroforestry system among farmers were obtained from various sources such as the internet and journals and entered into data extraction form.

3.6.3 Key Informant

Key informant interviews are qualitative in-depth interviews with people who know what is going on in the forestry, agriculture, agroforestry and community level. The purpose of key informant interviews was to collect information from a wide range of people including community leaders and professionals who have firsthand knowledge about the issue being explored by the researcher.

These experts, with their particular knowledge and understanding, can provide insight on the nature of problems and give recommendations for solutions, (Carter, 2014). In this research, expert view was acquired from the Director for Agriculture Kericho County, Manager for Sugar Research Institute, Kericho County Conservator and Manager for Mohoroni Sugar Company working in the area. In all cases simple random sampling ensured that each sample had an equal probability of being selected from the population and unbiased representation of the total population.

3.7 Validity

When results obtained from the research instruments actually represent the current condition under study, then it is said to be valid. Rolfe, (2022), validity therefore has to do with how the data obtained in the study represent the variables of the study. If reflection of a variable of such data is true, accurate and meaningful inferences based on such data will be made (Rolfe, 2022). To increase the validity, the student discussed the research instrument with the supervisor, whose expert opinion was used to improve the instrument.

3.8 Reliability

Reliability is a measure to which an instrument would produce consistent results on repeated trials. Consistent results are provided by a reliable measuring instrument. It means the consistency of the scores from one instrument to another and from one set of items to another and also refers to the internal consistency of the items being tested, (Morse, 2022). Reliability can be seen in the results which have been carried out and presented. The responses indicate whether there is consistency.

3.9 Data Collection Procedures

3.9.1 Classification of agroforestry systems

Data relating to the classification of agroforestry systems were collected through questionnaires, interviews and observation. These involved gathering data on types of: traditional agroforestry (agrisilviculture, silvopastoral, agrosilvopastoral); functional agroforestry (productive and protective); scale of practice (subsistence or commercial); Land utilization (homestead, forested land, dairy farm, animal farm, integrated farm); ecological classification (tree species preference, planting arrangement, sugarcane species).

3.9.2 Classification characteristics of the tree-sugarcane agroforestry

Data relating to the characteristics of the tree-sugarcane agroforestry system were collected through questionnaires, interviews and observation. These data include the types and preferences of trees, types and preference of sugarcane, planting arrangements of trees and sugarcane within the farm such as hedge raw, intercropping, boundary, woodlot and alley cropping. Social amenities within the study area were sampled.

3.9.3 Assessing socio-economic benefits of agroforestry systems

Data relating to the socio-economic benefits of the agroforestry system were collected through questionnaires, observation and interviews. Data on types of benefits and types {biodiversity conservation, bio drainage, soil fertility, carbon absorption, and biofuel, income, social amenities improvement and employment were captured}. Data on demographic information of respondents and households, sex, age, education level and marital status of household heads was also collected.

3.9.4 Examining socio-economic constraints of agroforestry systems

The data relating to the socio-economic constraints of the agroforestry systems were collected through the administration of questionnaires and interviews. Constraints in terms of labor intensity, payback periods, market accessibility, technology and knowledge were also captured. The questionnaire and observation checklist (Appendix II) maintained the anonymity and honesty of respondents, (Kasomo, 2007). Additional data relating to the tree-sugarcane agroforestry system were obtained from various secondary sources such as the internet and journals.

3.10 Data Analysis and Presentation

Classification, Socio-economics and constraints of agroforestry system in Soin Ward data obtained were analyzed using SPSS 28.0 statistical package. Qualitative methods of data analysis employing descriptive statistics were used to explain the results. All results were accepted as significant at $\alpha = 0.05$. The data were presented in a synthesized form using graphical techniques such as tables, bar graphs and pie charts.

3.11 Ethical Considerations

The privacy and rights of respondents were respected at all times. The purpose of the study was clearly explained before the administration of questionnaires. Respondents were not coerced to give information. Confidentiality was observed by ensuring that all the questionnaires had numerical codes instead of respondents indicating their names. Respondents' anonymity and all the information given were used specifically for academic purposes. All the findings of the study were presented without any manipulation or alteration of data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the study and explanations on how they fit the existing literature on agroforestry systems. Results on the demographic information of the respondents are presented first then followed by the classification characteristics, socio-economic benefits and constraints of agroforestry systems in Soin Ward, Kericho County, Kenya.

4.2 General Information of the Study Area

This section reports the demographic information of the sampled households namely; gender, age, marital status, level of education and land sizes.

4.2.1 Demographic information of the households

Table 4.1 Sixty-eight (68.1%) of the respondents were males, while females were minority (31.9%). In Kenya's population census of 2019, the total population of Soin Ward was 21,072 heads, with the ratio for male to female standing at 49.05% and 50.05% respectively.

Table 4.1:

Mean Demographic information of respondents in Soin Ward

Item	Description	% Response	Item	Description	% Response
Gender	Male	68.1	Marital status	Single	12.1
	Female	31.9		Married	55.5
				Widowed	26.8
				Divorced	5.6
Household size	≤5	30.2	Primary occupation	Formal employment	21.7
	6-10	65.7			
	11-14	3.8		Informal employment	78.3
	>15	0.3			
Age bracket	≤35	13.9	Land Sizes (Acres)	<1	16.0
	36-50	49.4		1.5-3	30.5
	>51	36.7		3.1-5	34.8
				5.1-7	14.0
				>7	4.7
Education levels	None	13.7	Marital status	Married	55.5
	Primary	25.9		Single	30.3
	Secondary	28.9		Divorced	5.6
	College	26.2		Widow	8.6
	Adult Education	5.3			

Majority of the respondents undertaking tree-sugarcane agroforestry were of the age group range of 36 – 50 years (49.4%), those above 51 years (36.7%) formed the second largest group while those below 35 years (13.9%) were the minority. Twenty-eight (28.9%) of the respondents had attained secondary level of education, followed by the college graduates at (26.2%), primary (25.9%), none (13.7%) while the minority had adult education (5.3%). These results are not significantly different from the findings of Kenya population census 2019, (KNBS, 2019).

4.2.2 Household characteristics of agroforestry farmers

Fifty five (55.5%) of the households practicing agroforestry were married, single (30.3%), widowed (8.6%) while the minority were separated or divorced (5.6%). The highest number of household members among the respondents were 6 - 10 (65.7%), below 5 were 30.2%, those between 11 -14 members were 3.8% while those with above 15 members were 0.3%. According to the Kenya Population Census of 2019 an average household size of four (4) was reported for Kericho County, (KNBS, 2019). The current results from Soin Ward do not vary significantly from those reported for Kericho County in the 2019 population census.

Primary occupation for the majority of respondents (78.3%) was informal employment with those in formal employment at 21.7%. As at 2009, Kericho County labor force stood at 405,034, majority being male. This was projected to increase to 532,060 in 2018 and to rise further to 608,019 by 2022, (Kericho CIDP, 2018). Land sizes within Soin ward ranged from <1 acres (16.0%), 1.5 to 3 acres (30.5%), 3.1 to 5 acres (34.8%), 5.1 to 7 acres (14.0%) and >7 acres (4.7%). These results corroborate those reported in Kericho CIDP 2018 that put the average land holding size at 2.5 acres for smallholder farmers.

4.3 Classification Characteristics of Agroforestry Systems in Soin Ward

Classification of agroforestry systems in Soin Ward was based on five thematic areas namely: Traditional, functionality, socio-economics, ecological and land utilization. Results for each thematic area are presented in relation to land sizes.

4.3.1 Traditional characterization of agroforestry systems

Table 4.2 shows the traditional characterization of agroforestry systems in Soin Ward. Three types of agroforestry systems were identified namely; agrisilviculture, silvopastrol and agrosilvopastoral.

Table 4.2:

Traditional characterization of agroforestry in Soin ward

Thematic area of classification	Land size (Acres)	Type of agroforestry system	Number of farmers	% Response
Traditional	<1	Agrisilviculture	21	5.5
	1.1-3		33	8.6
	3.1-5		49	12.8
	5.1-7		12	3.1
	>7		6	1.6
	Total		121	31.6
	<1	Silvopastoral	7	1.8
	1.1-3		19	4.9
	3.1-5		22	5.6
	5.1-7		24	6.1
	>7		7	1.8
	Total		79	20.2
	<1	Agrosilvopastoral	33	8.6
	1.1-3		64	17.0
	3.1-5		62	16.1
	5.1-7		21	5.5
	>7		4	1.0
	Total		184	48.2

Thirty one (31.6%) of respondents practiced agrisilvicultural system of agroforestry that involved planting food crops such as maize, sugarcane and trees in the same land in terms of alley cropping or home gardens. Twenty (20.2%) practiced a silvopastoral system that was characterized by grazing of domestic animals such as cows on Napier grass pastures. Majority (48.2%) of the respondents practiced an agrosilvopastoral system that involved planting cypress and eucalyptus trees, animals and crops combined. This was characterized by home gardens, domestic animals and scattered trees on croplands. The growth, development and arrangement of different types of trees and crops such as sugarcane in the same area assume the existence of dynamic system interactions and change over time, (FAO, 2015). This is especially true in areas where there are tree components, due to continued growth in height, crown projection, and leaf area of tree species. Land sizes and the adopted agroforestry system affect the distribution of existing resources, which in turn can cause a constant change in the productivity of species in a system, (Jose, 2004 and Peace Corps, 2021).

4.3.2 Functional characterization of agroforestry systems

Table 4.3 shows the functional characterization of agroforestry systems in Soin Ward. Two types of agroforestry systems were identified namely; protective and productive agroforestry.

Table 4.3:

Functional characterization of agroforestry in Soin ward

Thematic area of characterization	Land size (Acres)	Type of agroforestry system	Number of farmers	% Response
Functionality	<1	Productive	47	12.3
	1.1-3		105	27.3
	3.1-5		121	31.5
	5.1-7		37	9.6
	>7		12	3.1
	Total		322	83.8
	<1	Protective	14	3.7
	1.1-3		11	2.9
	3.1-5		12	3.1
	5.1-7		20	5.2
	>7		5	1.3
	Total		62	16.2

Thematic area of functionality, sixteen (16.2%) of respondents practiced protective agroforestry that aimed at providing functions such as windbreak, shelterbelt, soil conservation, moisture conservation, soil improvement and shade for crops and animals. Majority (83.8%) of the respondents practiced productive agroforestry that aimed at the production of essential commodities such as food, fodder and fuel wood. Protective agroforestry system designed to protect the land, improve climate, reduce wind and water erosion, improve soil fertility, provide shelter, and other benefits, (Urgessa, 2022). On the other hand, productive agroforestry system aims at the production of essential commodities such as food, fodder and fuel wood required to meet society's basic needs. It includes intercropping of trees, home gardens, plantation of trees in and around the crop field, production of animals and fishes associated with trees, (Kebebew, 2022).

4.3.3 Socio-economic characterization of agroforestry systems

Table 4.4 shows the socio-economic characterization of agroforestry systems in Soin Ward. Two types of agroforestry systems were identified namely; subsistence and commercial agroforestry.

Table 4.4:

Socio-economic characterization of agroforestry systems in Soin ward

Thematic area of classification	Land size (acres)	Type of agroforestry system	Number of farmers	% Response
Socio-Economics	<1	Subsistence	54	14.1
	1.1-3		62	16.1
	3.1-5		56	14.5
	5.1-7		3	0.8
	>7		1	0.2
	Total		176	45.7
	<1	Commercial	7	1.8
	1.1-3		54	14.1
	3.1-5		77	20.1
	5.1-7		54	14.1
	>7		16	4.2
	Total		208	54.3

Forty five (45.7%) of the respondents practiced subsistence agroforestry in comparison to 54.3% who preferred commercial type of agroforestry system. Subsistence agroforestry aims at the basic needs of a small family having less land holding and very little capacity for investment. In Soin Ward, this was characterized by marginal surplus production for sale like shifting cultivation, scattered trees in the farms and homesteads. Commercial agroforestry system is a large-scale production on a commercial basis and the main consideration is to sell the products such as tea/ sugarcane under a shade tree. Due to statistical insignificance observed between the two types in Soin Ward, it is suggested that intermediate agroforestry system (intermediate between commercial and subsistence systems) is practiced on the small and medium-sized farms with the aim to produce items that are not only enough to meet the needs of the family but also earn money from the surplus that can be sold, (Kebebew and Urgessa, 2022).

4.3.4 Characterization of agroforestry system based on utilization of land

Table 4.5 shows the characterization of agroforestry systems in Soin Ward based on land utilization. Five types of land utilization under agroforestry systems were identified namely; homestead, forest land, dairy farm, animal farm and integrated farm.

Table 4.5:

Characterization of agroforestry system based on utilization of land

Thematic area of classification	Land size (Acres)	Type of agroforestry system	Number of farmers	% Response
Land Utilization	<1	Homestead	13	3.4
	1.1-3		10	2.6
	3.1-5		3	0.8
	5.1-7		0	0
	>7		0	0
	Total		26	6.8
	<1	Forest land	4	1.0
	1.1-3		10	2.6
	3.1-5		15	3.9
	5.1-7		16	4.2
	>7		5	1.3
	Total		50	13
	<1	Dairy farm	3	0.8
	1.1-3		2	0.6
	3.1-5		0	0
	5.1-7		0	0
	>7		0	0
	Total		5	1.4
	<1	Animal farm	3	0.8
	1.1-3		39	10.1
	3.1-5		56	14.6
	5.1-7		19	4.9
	>7		4	1.0
	Total		121	31.4
	<1	Integrated farm	38	9.9
	1.1-3		55	14.3
	3.1-5		59	15.4
	5.1-7		22	5.7
	>7		8	2.1
	Total		182	47.4

In Soin Ward, integrated farm-based agroforestry system was the most preferred by (47.4%) of the respondents in comparison with homestead (6.8%), animal farm (31.4%), dairy farm (1.4%) and forest land (13%). Homestead agroforestry system focused on production of fruit trees, selected multipurpose trees having less canopy and decorative trees/shrubs and vegetables, spices, and many shade-loving crops. Forest land agroforestry system focused on production of crops in the vacant spaces of the forest, crop farm forestry system focuses on production of crops and trees in the cropland. Animal farm forestry was characterized by farming of poultry birds and trees. Dairy farm forestry was characterized by farming of milk cattle, beef cattle and goats within the same land. Integrated farm forestry was characterized by the production of crops, animals, fishes along with trees and roadside agroforestry, production of deep-rooted tall trees with narrow canopies and soil building grasses or crops along the sides of roads, highways, railways, and embankment, (Kebebew and Urgessa, 2022).

4.3.5 Ecological classification of agroforestry in Soin ward

Table 4.6 shows the characterization of agroforestry systems in Soin Ward based on ecology. Three types of ecological characterization in terms of tree species, planting arrangement and sugar cane species preference were identified.

Table 4.6:

Ecological characterization of agroforestry system in Soin Ward

Thematic area of classification	Land size (Acres)	Type of agroforestry system	Number of farmers	% Response
Ecological	<1	Tree species preference	18	4.7
	1.1-3		36	9.4
	3.1-5		45	11.7
	5.1-7		15	3.9
	>7		7	1.8
	Total		121	31.5
	<1	Planting Arrangement	12	3.1
	1.1-3		51	13.3
	3.1-5		54	14.1
	5.1-7		11	2.9
	>7		6	1.6
	Total		134	34.9
	<1	Sugar cane species Preference	13	3.4
	1.1-3		41	10.7
	3.1-5		57	14.8
	5.1-7		12	3.1
	>7		6	1.6
	Total		129	33.6

The findings from this study show that the majority of the farmers participate in a tree-sugarcane agroforestry system, where planting arrangement is 34.9%, while 33.6% of respondents have preferred sugarcane species and 31.5% for preferred tree species. Pinto *et al.*, (2020) and Elli *et al.*, (2016), have demonstrated viability of sugarcane in agroforestry systems in Brazil. Several studies in Brazil and around the world demonstrate the viability of using annual crops such as maize and soybeans, wheat, oat and ryegrass in agroforestry systems.

4.4 Classification and Characterization of Tree-Sugarcane Agroforestry System in Soin Ward

Studies were carried out to understand tree and sugarcane species preferences in Soin Ward and their planting arrangements in an agroforestry system.

4.4.1 Tree species preferences in Soin ward

Figure 4.1 reports % response on preferences of different tree species in Soin Ward.

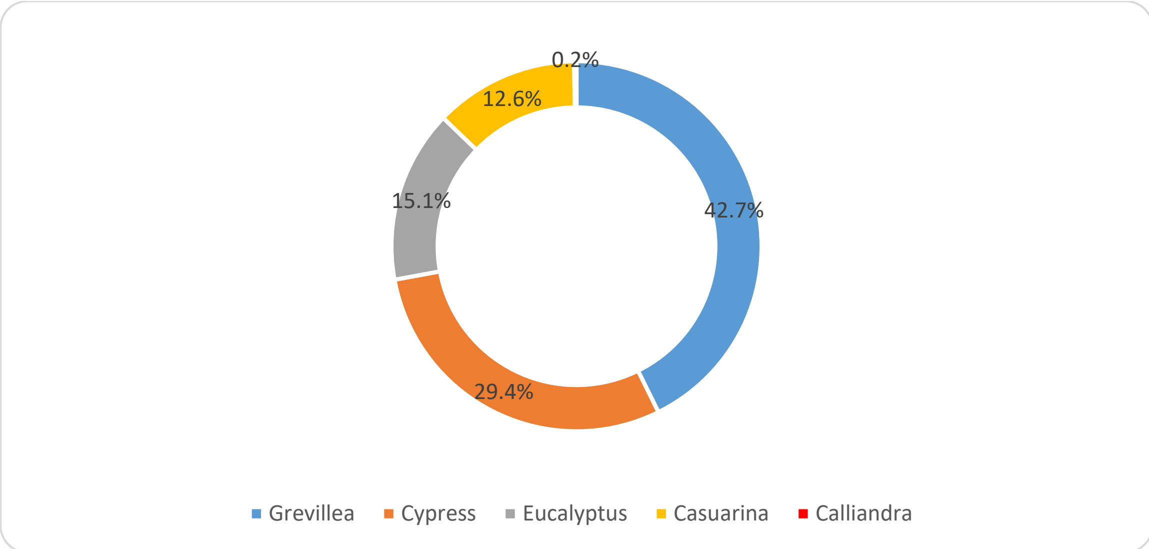


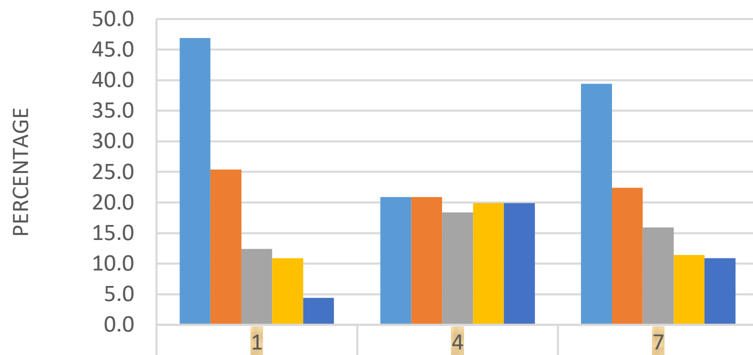
Figure 4.1: Preferred tree species for tree-sugarcane agroforestry system

Source: Author, 2023

Majority (42.7%) of the respondents preferred *Grevillea* tree species for blending with sugarcane in a tree-sugarcane agroforestry system. The other tree species in order of preference were c*ypress* (29.4%), e*ucalyptus* (15.1%), *casuarina* (12.6%) and *calliandra* (0.2%) as illustrated in Fig. 4.1. In Uganda, especially at Bunya County, *Eucalyptus spp.*, *Senna siamea, and Senna spectabilis* tree species have been prioritized based on computed use values and acceptance to be grown by over 30% farmers now and in future, (Obua, 2017).

4.4.2 Sugarcane species preference in Soin ward

Figure 4.2 reports % response on preferences of different sugarcane species in Soin Ward.



	1	4	7
CO 617 (Sindano)	46.9	20.9	39.4
CO 412 (Manywele)	25.4	20.9	22.4
CO 945 (Cheplelachek)	12.4	18.4	15.9
CV 38-22(Chebiriroik)	10.9	19.9	11.4
KEN 83-737(New species)	4.4	19.9	10.9

Figure 4.2: Preference of sugarcane species in Soin Ward

Source: Author, 2023

The most preferred sugarcane species in the tree-sugarcane agroforestry system was CO 617 - Sindano (46.9%), CO 412 – Manywele (25.4%), CO 945 – Cheplelachek (12.4%), CV 38-22 – Chebiriroik (10.9%) and KEN 83 – 737 – New Species (4.4%) for lower land having altitude of 1200-1400m while midland of altitude of 1400-1600m CO 617 - Sindano (20.9%), CO 412 – Manywele (20.9%) leading and lower highland of altitude of 1600-1800m had CO 617 - Sindano (39.4%), CO 412 – Manywele (22.4%), CO 945 – Cheplelachek (15.9%), CV 38-22 – Chebiriroik (11.4%) and KEN 83 – 737 – New Species (10.9%). Base line survey, which was done in western Kenya, is more less the same with is findings (KESREF, 2013). The most common varieties cultivated were Co 945 (42.7%), Co 421 (20.4%), Co 617 (13.4%) and N14 (12.7%). Only 6% of the respondents had adopted newer, improved varieties, with D8484, KEN 83-737 and KEN 82-472 the most popular, Anomymous, 2013. KESREF (2013), reported that old varieties were grown by about 78% of the farmers in the country and Jamoza, (2013), reported that only 6% of the sugarcane area in Western Kenya was devoted to improved varieties; the old varieties were thus dominating at 94%.

4.4.3 Interaction characteristics of tree-sugarcane agroforestry system in Soin ward

Studies were carried out to understand how trees and sugarcane interact together, types and arrangement in the same farm. Results are presented in table 4.7 and figure 4.3 respectively.

Table 4.7:

Interactions of tree-sugarcane agroforestry system in Soin Ward

Serial Number	Interactions	Respondents (No)	Response (%)
1	Boundary	237	61.7
2	Woodlot	92	24.0
3	Hedge raw	34	8.9
4	Intercropping/mixed	12	3.1
5	Alley cropping	9	2.3
Total		384	100.00

The various tree-sugarcane agroforestry plant arrangements in order of preference were; planting trees along the boundary (61.7%), Woodlot (24.0%), Hedge row (8.9%), Intercropping/mixed (3.1%) and alley cropping (2.3%) (Table 4.7). Adoption of hedgerows seems to be the best solution to soil conservation with annual crops (Young, 2020).

Figure 4.3 shows boundary arrangement in a tree-sugarcane agroforestry system.

a) Boundary arrangement

b) Alley cropping

b) Hedge Row

Figure 4.3 *Grevillea, Eucalyptus* – Sugarcane arrangements in Soin Ward

Source: Author, 2023

4.5 Benefits Accrued from Agroforestry Systems

4.5.1 Socio-economic benefits of agroforestry systems

Figure 4.4 reports socio economic benefits derived from agroforestry systems. Twenty one (21.9%) of the farmers benefit from biofuel extraction, soil fertility enhancement (21.1%), bio drainage (20.4%), biodiversity conservation (19.4%) and carbon absorption (17.2%).

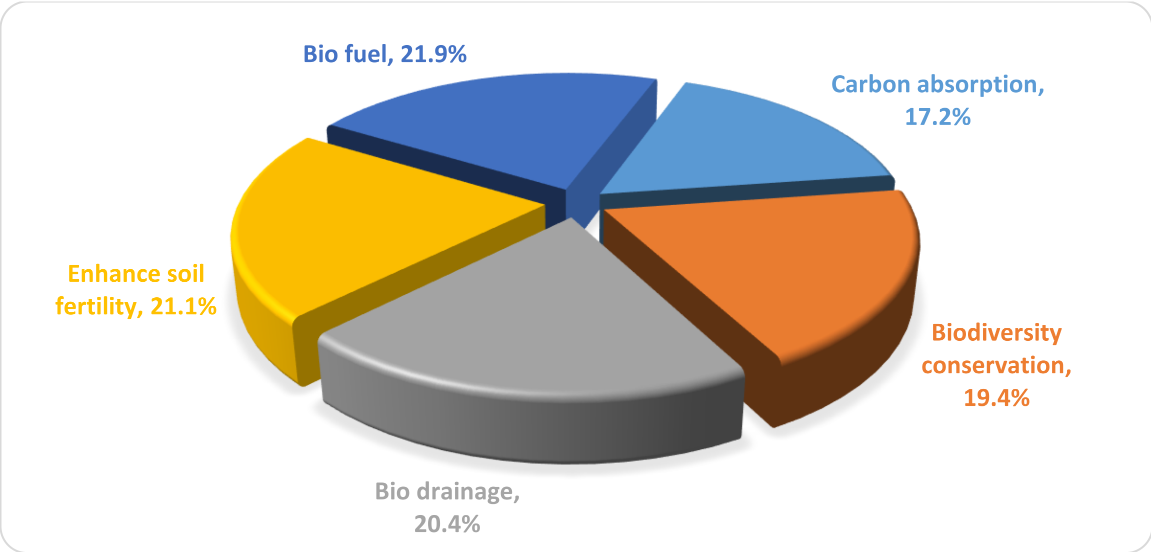


Figure 4.4: Socio- economic benefits of agroforestry systems in Soin Ward

Source: Author, 2023

In terms of its potential to mitigate climate impact and to improve soil quality, agroforestry can offer significant economic and social impact, especially for smallholder farmers in developing countries such as Kenya. This can have a profound impact, especially given the estimates that around 500 million smallholder farmers live on less than 2 dollars a day. Improved soil quality could help farmers produce more crops while introducing trees in traditional agricultural systems can allow for more efficient nutrient cycling, meaning farm output can be substantive and reliable, (Ngugen *et al.*, 2013).

It is well understood that climate change affects disadvantaged populations most, so smallholder farmers around the world could benefit greatly by adopting agroforestry practices. Indeed, crops and products derived from introducing trees in agricultural systems drive positive social and economic change, (Tumwebaze, 2016). A low-cost and sustainable technique to transform any degraded landscapes and improve livelihoods among communities is through agroforestry, (Ngugen, 2013).

4.5.2 Social amenities improved by agroforestry systems in Soin ward

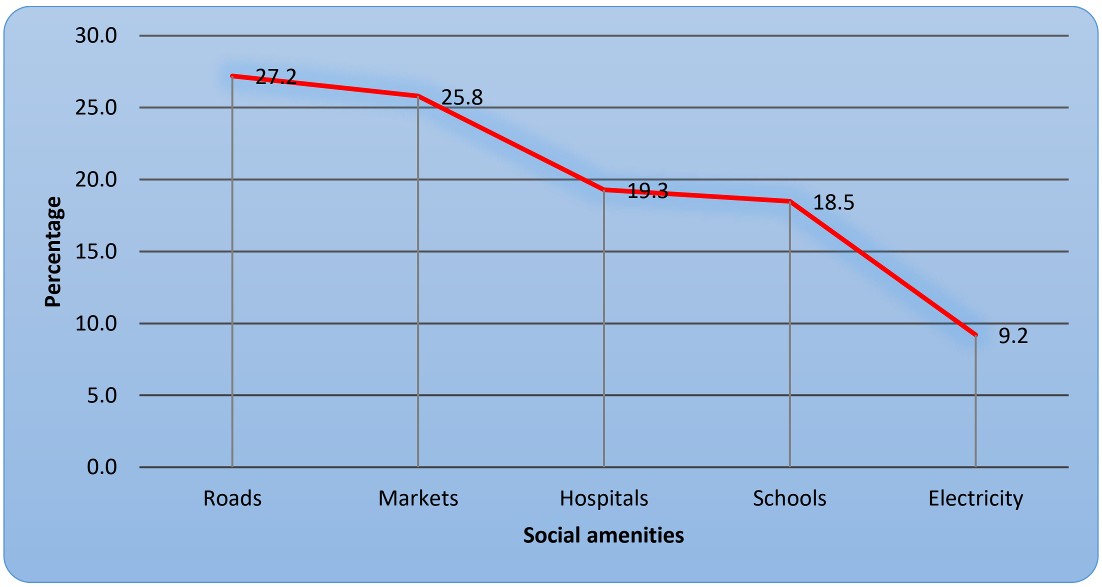


Figure 4.5: Developments Associated with Tree-Sugarcane Agroforestry

Source: Author, 2023

Adoption of agroforestry in Soin Ward has contributed to the improvement of the social amenities such as roads (27.2%), markets (25.8%), hospitals (19.3%), schools (18.5% and electricity (9.2%) as in the above figure 4.5. Research conducted in Transmara, showed that farmers derive direct revenue from harvested cane while indirect revenue comes from opportunities created by the sugarcane industry such as business investments mostly in the form of retail and wholesale shops, transport services (both motorbikes and motor vehicles) and reinvestment in the food crop industry, (Ngugen, 2013).

4.5.3 Direct benefits of agroforestry systems in Soin ward

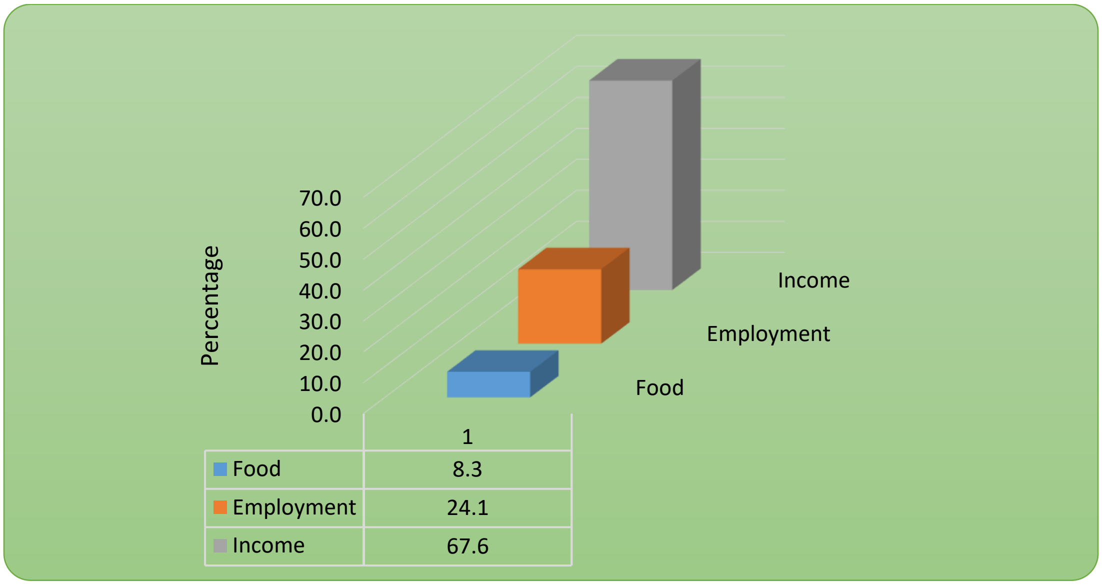


Figure 4.6: Benefits of agroforestry systems in Soin ward

Source: Author, 2023

Products from agroforestry systems could either be direct or indirect. Direct benefits from tree-sugarcane agroforestry systems include; food (8.3%), income (67.6%) and employment (24.1%). Agroforestry farmers derive direct revenue from harvested sugar cane while indirect revenue comes from opportunities created by the sugarcane industry such as business investments mostly in the form of retail and wholesale shops, transport services (both motorbikes and motor vehicles) and reinvestment in the food crop industry. Twenty five (25 %) of the farmers felt that the lump sum of money they received from sugarcane farming acted like a saving scheme while their cane matured in the farm, hence they obtained more income at the end of the maturity period. The remaining 13% of the respondents thought that sugarcane farming had low returns and hence their livelihoods had not improved as compared to when they practiced sugarcane farming, (KSB 2014).

4.6 Socio-Economic Constraints of Agroforestry Systems

Trees integrate with sugarcane to improve yields, diversify products, increase economic resilience, and improve farm viability and sustainability in the long-term. When choosing a tree species for a particular purpose, it is important to consider the multiple uses and functions it can provide, (Mamase, 2017). In this study, the majority of respondents (90.3%) reported land size as the major constraint to the tree and sugarcane agroforestry system in table 4.8.

Table 4.8:

Constraints in tree-sugarcane agroforestry system

	Challenges	Frequency (No)	Percentage (%)
1	Knowledge and technology gap	18	4.7
2	Labor intensive	107	27.8
3	Limited possibilities to sell product	109	28.3
4	Long waiting payback	150	39.2
	Total	384	100.0

Other constraints include; long waiting payback (39.2%), limited possibilities to sell product (28.3%), labour intensive (27.8%) and Knowledge and technology gap (4.7%) as shown in table 4.8. These results are similar to those reported from South Africa that indicated the mean labour for Small-scale sugarcane growers -SSGs in Mona and Sonkombo sugarcane production at 1.66 man-days/ha and ranges from about 1 to 11 man-days/ha. A rapid increase in the human population in the world has led to the widening of the market gap in the supply of various farm produce especially under the forestry and agriculture sectors, (UN, 2016). The gap has forced farmers to encroach on nearby forests in search of more space for settlement and expansion of agricultural fields, (FAO, 2016).

Generally, in South Africa, the small-scale farmers sector has been discouraged by lack of access to financial assistance such as operational loans necessary for the sustenance of sugarcane production. Despite this support, Small-scale sugarcane growers -SSGs still face challenges in their production. Results show that all (100%) of the interviewed SSGs agree that they experience late harvesting (delays in transportation from the field to loading zone and the sugar mill, immature sugarcane burning and sugarcane being left in the field, resulting in livestock encroachment before and after harvesting, (Sibanda, 2012).

CHAPTER FIVE

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary, conclusions and recommendations of the findings. It also gives suggestions for further research based on this study.

5.2 Summary

Demographic data of respondents indicates that sixty-eight (68.1%) were males, while females were minority (31.9%). Fifty-five (55.5%) of these households practicing agroforestry were married, single (12.1%), widowed (26.8%) while the minority were separated or divorced (5.6%). The highest number of household members among the respondents were 6 - 10 (65.7%), below 5 were 30.2%, those between 11 -14 members were 3.8% while those with above 15 members were 0.3%.

Thirty-one (31.6%) of respondents practiced traditional agrisilvicultural system of agroforestry that involved planting food crops such as maize, sugarcane and trees in the same land in terms of alley cropping or home gardens. Twenty (20.2%) practiced a silvopastoral system that was characterized by grazing of domestic animals such as cows on Napier grass pastures. Majority (48.2%) of the respondents practiced agrosilvopastoral system that involved planting cypress and eucalyptus trees, animals and crops combined.

Classification based on the area of functionality indicated that sixteen (16.2%) of respondents practiced protective agroforestry that aimed at providing ecological functions such as windbreak, shelterbelt, soil conservation, moisture conservation, soil improvement and shade for crops and animals. Majority (83.8%) of the respondents practiced productive agroforestry that aimed at the production of essential commodities such as food, fodder

and fuel wood. Forty-five (45.7%) of the respondents practiced subsistence agroforestry in comparison to 54.3% who preferred commercial type of agroforestry system. Subsistence agroforestry aims at the basic needs of a small family having less holding and very little capacity for investment. In Soin Ward, this was characterized by marginal surplus production for sale like shifting cultivation, scattered trees in the farms and homesteads.
In Soin Ward, an integrated farm-based agroforestry system was preferred by (47.4%) of the respondents in comparison with homestead (6.8%), animal farm (31.4%), dairy farm (1.4%) and forest land (13%). Majority of the respondents (42.7%) preferred *Grevillea* tree species for blending with sugarcane in a tree-sugarcane agroforestry system. The other tree species in order of preference were *cypress* (29.4%), e*ucalyptus* (15.1%), *casuarina* (12.6%) and c*alliandra* (0.2%).

The preferred sugarcane species in the tree-sugarcane agroforestry system was CO 617 - Sindano (46.9%), CO 412 – Manywele (25.4%), CO 945 – Cheplelachek (12.4%), CV 38-22 – Chebiriroik (10.9%) and KEN 83 – 737 – New Species (4.4%) for low land (altitude of 1200-1400m) ecosystems. For midland ecosystems (altitude 1400-1600m) CO 617 - Sindano (20.9%) and CO 412 – Manywele (20.9%) were preferred. Preference of sugar cane tree agroforestry system in lower highland of altitude of 1600-1800m ranged from CO 617 - Sindano (39.4%), CO 412 – Manywele (22.4%), CO 945 – Cheplelachek (15.9%), CV 38-22 – Chebiriroik (11.4%) and KEN 83 – 737 – New Species (10.9%).

The various tree-sugarcane agroforestry plant arrangements in order of preference were; planting trees along the boundary (61.7%), Woodlot (24.0%), Hedge raw (8.9%), Intercropping/mixed (3.1%) and alley cropping (2.3%).

According to this study a tree-sugarcane agroforestry system provides products and services which benefits the farmers for example biofuel (21.9%), enhance soil fertility (21.1%), bio drainage (20.4%), biodiversity conservation (19.4%) and carbon absorption (17.2%). Adoption of tree-sugarcane agroforestry system in Soin Ward has led to improvement of the social amenities which include roads (27.2%), markets (25.8%), hospitals (19.3%), schools (18.5%) and electricity (9.2%). Products from agroforestry systems could either be direct or indirect and some direct benefits from tree-sugarcane agroforestry system identified by the study include; income (67.6%), food (8.3%) and employment (24.1%). The agroforestry systems have been facing challenges over time and the main challenges include; long waiting payback (39.2%), limited possibilities to sell product (28.3%), labour intensive (27.8%) and Knowledge and technology gap (4.7%).

5.3 Conclusions

The following conclusions are derived from this study:

1. Four (4) classes of agroforestry systems were identified in Soin Ward that comprised; (48.2% agrosilvopastoral and 31.6% agrosilvicultural and 20.2% silvopastoral); (16.2% protective and 83.8% productive); (45.7% subsistence and 54.3% commercial) and Integrated farm-based agroforestry 47.4%, homestead (6.8%), animal farm (31.4%), dairy farm (1.4%) and forest land (13%) respectively.

2. Majority of the respondents (42.7%) preferred *Grevillea* tree species for blending with sugarcane in a tree-sugarcane agroforestry system in comparison with *cypress* (29.4%), e*ucalyptus* (15.1%), *casuarina* (12.6%) and c*alliandra* (0.2%) respectively. Sixty (61.7%) plant trees along the boundary, as woodlot (24.0%), hedge raw (8.9%), intercropping/mixed (3.1%) and as alley cropping (2.3%).

3. The preferred sugarcane species in the tree-sugarcane agroforestry system was CO 617 (46.9%), CO 412 (25.4%), CO 945 (12.4%), CV 38-22 (10.9%) and a new Kenya species (4.4%) for low land (altitude of 1200-1400m) ecosystems. For midland ecosystems (altitude 1400-1600m) CO 617 (20.9%) and CO 412 (20.9%) were preferred. For lower highland ecosystems (altitude of 1600-1800m) CO 617 (39.4%), CO 412 (22.4%), CO 945 (15.9%), CV 38-22 (11.4%) and a KEN 83-737 (10.9%).

4. Direct benefits from the identified agroforestry systems include; income (67.6%), food (8.3%) and employment (24.1%). Indirect benefits include provision of biofuel (21.9%), enhanced soil fertility (21.1%), bio drainage (20.4%), biodiversity conservation (19.4%) and carbon absorption (17.2%), improvement of social amenities such as roads (27.2%), markets (25.8%), hospitals (19.3%), schools (18.5% and electricity (9.2%).

5. Constraints faced by the agroforestry systems include; long waiting payback (39.2%), limited possibilities to sell product (28.3%), labour intensive (27.8%) and knowledge and technology gap (4.7%).

5.4 Recommendations

The following recommendations were drawn from the conclusion of this study:

1. Governments, companies, and non-governmental organizations need to support the accessibility of quality tree and sugar cane seedlings by the establishment of more seedling nurseries to enable farmers access seedlings and set up standards for certification of other inputs.
2. There is need by government and non-governmental organizations to introduce an agroforestry system model which is a low-cost sustainability approach like Farmer Managed Natural Regeneration-FMNR
3. The Ministry of Agriculture to formulate a policy on payments related to tree-sugarcane agroforestry systems.

5.5 Suggestions for Further Research

This study was based on the objectives that were initially set out to achieve however, a number of issues, topics came up, and they require further study and understanding. Some of the issues that were suggested from the scope of this study are as follows:

1. Determine new agroforestry strategies.
2. Identify common pest and diseases within the agroforestry systems.

3. Establish integrated pest management measures that have been adopted by farmers in the agroforestry systems.
4. Study the roles of women in establishment of agroforestry systems and their benefits.
5. Establish the biodiversity level by developing inventory of different plant species within an agroforestry system
6. Identify different sources of water used within the established agroforestry systems.
7. Determine tools used in management of agroforestry systems
8. Study the effects of climate change on agroforestry systems

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APPENDICES

Appendix I. Observation Check List Form

Observation checklist in this case to guide gather information Characteristics, Socio-economic benefits and Constraints of tree-sugarcane agroforestry system in Soin Ward, Kericho County.

No.	Item	Remarks
1	Type of trees	
2	Type of sugarcane	
3	Arrangement of plants	
4	Social amenities associate with tree-sugarcane agroforestry system	
5	Visible challenges associate with tree-sugarcane agroforestry system	

Appendix II. Data Extraction Form

Data extraction form used in this case to gather information for review Characteristics, Socio-economic benefits and Constraints of tree-sugarcane agroforestry system in Soin Ward, Kericho County.

No.	What to be Extracted	Notes for the Researcher
1	Title of study	
2	Author	
3	Year of publication	
4	Study objectives as stated by author	
5	Inclusion of sufficient data to assess validity of conclusions and information	
6	Data source	
7	Reference citation	

Appendix III. Questionnaire

UNIVERSITY OF KABIANGA

DEPARTMENT OF AGROFORESTRY, ENVIRONMENTAL STUDIES AND INTEGRATED NATURAL RESOURCE MANAGEMENT

Master of science in agroforestry

Classification of agroforestry systems, their Socio-economic benefits and Constraints in Soin Ward, Kericho County

Section A: Demographic information of respondent

1. Gender 1=Male 2=Female

2. Age 1=<35 2=36-50 3=>51

3. Education level 1=None 2=Primary 3=Secondary 4=Tertiary 5=Adult education

4. Marital status 1=Single 2=Married 3=Separated/divorced 4=Widowed

7. Household size 1=<5 2=6-10 3=11-14 4=>15

8. Land Sizes (Acres) 1=<1 2=1.5-3 3=3.1-5 4=5.1-7 5=>7

Section B: Classification of agroforestry systems in Soin ward

1. What type of traditional agroforestry system do you practice?

1 = Agrisilviculture

2 = Silvopastoral

3 = Agrosilvopastoral

2. What is the function of the agroforestry system in your land?

1 = Productive

2 = Protective

3. At what scale do you practice agroforestry in your land?

1 = Subsistence

2 = Commercial

4. What is the utilization of agroforestry system in your land?

1 = Homestead

2 = Forest land

3 = Dairy farm

4 = Animal farm

5 = Integrated farm

5. What ecological characterization do you consider in an agroforestry system?

1 = Tree species preference

2 = Planting arrangement

3 = Sugarcane species preference

Section C: Classification characteristics of tree sugarcane agroforestry systems

1. Do you practice tree-sugarcane agroforestry system on your farm?

1 = Yes

2 = No

2. If "Yes", which agroforestry tree species do you prefer for blending in tree-sugarcane agroforestry system?

1 = Grevillea

2 = Cypress

3 = Casuarina

4 = Calliandra

5 = Eucalyptus

3. Which sugarcane species do you prefer for the establishment of tree-sugarcane agroforestry system?

1 = KEN 83-737 (New species)

2 = CV 38-22 (Chebiriroik)

3 = CO 945 (Cheplelachek)

4 = CO 617 (Sindano)

5 = CO 421 (Manywele)

4. What is the planting arrangement of tree-sugarcane agroforestry in your farm?

1. = Hedge row
2. = Intercropping/Mixed
3. = Boundary
4. = Woodlot
5. = Alley cropping

Section D: Socio-economic benefits of tree-sugarcane agroforestry system

1. Do you get benefits from tree-sugarcane agroforestry system?

1 = Yes

2 = No

2. If "Yes", What are socio-economic benefits of tree-sugarcane system?

1= Biodiversity conservation

2 = Bio drainage

3 = Enhance soil fertility

4 = Carbon absorption

5 = Bio fuel

3. What are the social amenities improved or brought up by tree-sugarcane agroforestry?

1= Schools

2 = Hospitals

3 = Electricity

4 = Roads

5 = Market

4. What direct benefits of tree-sugarcane agroforestry you have achieved from your farm?

1 = Employment

2 = Income

3 = Food

Section E: Socio-economic constraints of tree-sugarcane agroforestry system

1. Do you experience challenges of tree-sugarcane system in your farm?

1 = Yes

2 = No

2. If “Yes”, What are those challenges you have in your farm for tree-sugarcane agroforestry system?

1= Labor intensive

2 = Long waiting payback

3 = Limited possibilities to sell products

4 = Knowledge and technology gap

Thank you

Appendix IV. Key Informant

Below are questions to be used in during interviews with stakeholders'

1. How long have you been serving in this capacity?
2. Which are the well adapted tree and sugarcane species to this area?
3. Do farmers practice agroforestry?
4. What are the constraints of tree-sugarcane agroforestry?
5. What are benefits of tree-sugarcane agroforestry?
6. Which machines/policies have your department put in place to help in promoting and handling challenges facing tree-sugarcane agroforestry.

Appendix V. NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **456536**

Date of Issue: **28/January/2022**

RESEARCH LICENSE

This is to Certify that Mr.. Kipkoech Evans Korir of University of Kabianga, has been licensed to conduct research in Kericho on the topic: CHARACTERISTICS, SOCIO-ECONOMIC BENEFITS AND CONSTRAINTS OF TREE-SUGARCANE AGROFORESTRY SYSTEM IN SOIN WARD, KERICHO COUNTY, KENYA for the period ending : 28/January/2023.

License No: **NACOSTI/P/22/15369**

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Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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Appendix VI. Publication

East African Journal of Forestry and Agroforestry, Volume 5, Issue 1, 2022
Article DOI: https://doi.org/10.37284/eajfa.5.1.904

East African Journal of Forestry & Agroforestry
eajfa.eanso.org
Volume 5, Issue 1, 2022
Print ISSN: 2707-4315 | Online ISSN: 2707-4323
Title DOI: https://doi.org/10.37284/2707-4323

EANSO
EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Classification and Socio-Economic Benefits of Agroforestry Systems in Soin Ward, Kericho County, Kenya

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Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Date Published:

24 October 2022

Keywords:

Agroforestry System, Tree-Sugarcane, Socio-Economic, Classification, Constraints and Benefits.

ABSTRACT

Agroforestry Systems (AFS) are integrated land use systems involving trees, agricultural crops, and animals simultaneously or sequentially, with the objective of sustainably increasing their total productivity per unit area. Despite strong literature evidence describing the benefits of agroforestry to livelihoods in other parts of the world, there is little information as such in Soin Ward of Kericho County, where sugarcane competes with tea as a major cash crop. This study aimed at classifying agroforestry systems and evaluating their socio-economic benefits in Soin Ward, Kericho County, Kenya. The study adopted a qualitative research design through the administration of pretested questionnaires on types of agroforestry systems, the scale of production, land utilisation, preference of trees and sugar cane varieties and their interactions with 384 respondents in lower, upper, and midland parts of Soin Ward. Four (4) classes of agroforestry systems were identified that comprised (48.2% agrosilvopastoral, 31.6% agrosilvicultural, and 20.2% silvopastoral); (16.2% protective and 83.8% productive); (45.7% subsistence and 54.3% commercial), and integrated farm-based agroforestry 47.4%, homestead (6.8%), animal farm (31.4%), dairy farm (1.4%), and forest land (13%) respectively. The majority of the respondents (42.7%) preferred Grevillea tree species for blending with sugarcane in a tree-sugarcane agroforestry system in comparison with cypress (29.4%), eucalyptus (15.1%), casuarina (12.6%), and calliandra (0.2%) respectively. Sixty (61.7%) plant trees along the boundary, 24% as woodlot, hedge raw (8.9%), intercropping/mixed (3.1%), and alley cropping (2.3%). Direct benefits from the identified agroforestry systems include; income (67.6%), food (8.3%), and employment (24.1%). Indirect benefits include provision

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

of biofuel (21.9%), enhanced soil fertility (21.1%), bio drainage (20.4%), biodiversity conservation (19.4%), carbon absorption (17.2%), improvement of social amenities such as roads (27.2%), markets (25.8%), hospitals (19.3%), schools (18.5% and electricity (9.2%).Constraints faced by the agroforestry systems include; long waiting payback (39.2%), limited possibilities to sell products (28.3%), labour intensive (27.8%), and knowledge and technology gap (4.7%). Such results are useful for policy-making decisions towards afforestation and improved livelihoods in Kenya.

APA CITATION

Korir, K. E., Sirmah, P. K., Matonyei T. K & Ole Nampushi J. S. (2022). Classification and Socio-Economic Benefits of Agroforestry Systems in Soin Ward, Kericho County, Kenya *East African Journal of Forestry and Agroforestry*, *5*(1), 252-268. https://doi.org/10.37284/eajfa.5.1.904

CHICAGO CITATION

Korir, Kipkoech Evans, Peter Kipkosgei Sirmah, Thomas Kibiwot Matonyei and James Simiren Ole Nampushi. 2022. "Classification and Socio-Economic Benefits of Agroforestry Systems in Soin Ward, Kericho County, Kenya". *East African Journal of Forestry and Agroforestry* 5 (1), 252-268. https://doi.org/10.37284/eajfa.5.1.904

HARVARD CITATION

Korir, K. E., Sirmah, P. K., Matonyei T. K & Ole Nampushi J. S. (2022), "Classification and Socio-Economic Benefits of Agroforestry Systems in Soin Ward, Kericho County, Kenya", *East African Journal of Forestry and Agroforestry*, 5(1), pp. 252-268. doi: 10.37284/eajfa.5.1.904.

IEEE CITATION

K. E., Korir, P. K., Sirmah, T. K. Matonyei & J. S., Ole Nampushi, "Classification and Socio-Economic Benefits of Agroforestry Systems in Soin Ward, Kericho County, Kenya", *EAJFA*, vol. 5, no. 1, pp. 252-268, Oct. 2022.

MLA CITATION

Korir, Kipkoech Evans, Peter Kipkosgei Sirmah, Thomas Kibiwot Matonyei & James Simiren Ole Nampushi "Classification and Socio-Economic Benefits of Agroforestry Systems in Soin Ward, Kericho County, Kenya". *East African Journal of Forestry and Agroforestry*, Vol. 5, no. 1, Oct. 2022, pp. 252-268, doi:10.37284/eajfa.5.1.904

INTRODUCTION

Agroforestry Systems (AFS) are integrated land-use systems involving trees/shrubs and agricultural and/or animal crops, simultaneously or sequentially, with the objective of sustainably increasing the total productivity of plants and animals per unit area (Catacutan *et al.,* 2017). Similarly, agroforestry comprises land-use systems and technologies in which woody perennial plants (trees, shrubs, palms, or bamboo) and agricultural or animal crops are cultivated on the same plot organised in planned spatial and temporal arrangements (FAO and ICRAF, 2022). Such biodiverse and interactive production agroforestry systems provide social and ecological benefits to the communities and land users (Catacutan *et al.,* 2017).

Agroforestry systems (AFS) are further classified as silvoarable systems (combination of trees/shrubs with crops), silvopastoral (combination of trees with livestock), and agro-silvopastoral (combination of trees/shrubs with both crops and livestock), riparian buffer strips, and home gardens (Mosquera-Losada et al., 2018). Besides providing services such as food, fodder, fibre, and fuelwood production, AFS provide several other ecosystem services, including regulation of nutrient cycling, carbon sequestration, habitat for biodiversity, erosion control, fire and flood control, and recreational and cultural services (Mosquera-Losada et al.,

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

2018). Similarly, AFS improve the resilience of smallholder farmers through more efficient water utilisation, improved microclimate, enhanced soil productivity, nutrient cycling, control of pests and diseases, improved farm productivity, diversified and increased farm income while at the same time sequestering carbon (Fagerholm et al., 2016).

One of the key global agenda of vision 2030 is the achievement of the Sustainable Development Goals (SDGs) (Garrity et al., 2012). The goals promote the world's effort to eliminate poverty and hunger, improve access to health services, basic education, support women empowerment, and regenerate the global environment through conservation and agroforestry. If SDGs are fully attained and implemented, they will benefit everyone by contributing globally towards a greater economic abundance, peace, and security. Similarly, the achievement of SDGs will give ways of overcoming hunger and poverty in a thorough and comprehensive manner through the development of rural communities in developing world such as Kenya (Gennari & D'Orazio, 2020).

Efforts to increase forest cover worldwide have been gaining momentum over the years through climate change mitigation and adaptation measure. Kenya is among the countries putting up the effort through the development of different strategies such as agroforestry and land use management systems with the ultimate aim of achieving 10% forest cover by 2030 (Ongweno et al., 2009). This study aimed at classifying agroforestry systems and evaluating their socio-economic benefits and constraints in Soin Ward, Kericho County, Kenya. Information on the tree-sugarcane agroforestry combination was underpinned by this study.

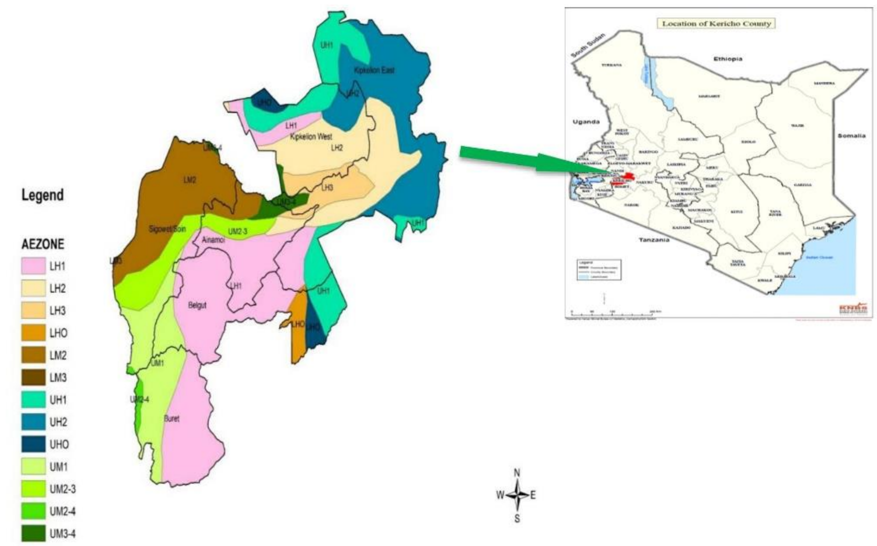
MATERIALS AND METHOD

Study Site

This study was carried out in Soin Ward (longitude 35° 02' and 35° 40' East and latitude 0^0 23' South), Kericho County, Kenya. Kericho County has fertile soils and reliable rainfall with low annual evaporation rates thus suitable for agriculture (Okonya et al., 2013). The variation in altitude within the study site has contributed to gradual variations in weather and agro-ecological (Fig 1) patterns; temperatures range between 10 ºC and 29 ºC with an average temperature of 17 ºC (GoK, 2013) and rainfall range of about 2125 – 1400 mm. The long rains fall between April and June, while the short rains occur between October and December. January and February are usually the driest months in the county.

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Figure 1: Map of Study Site



Source: Kenya Metrological Department – Kericho Office, 2020).

Research Design

The study site was divided according to the three major agro-ecological zones (AEZ), namely: Upper Highlands (UH) and Midlands (ML), suitable for sheep, dairy farming, wheat and pyrethrum production and coffee, tea, maise, and sunflower respectively. Lower Lands (LL) is suitable for commercial sugarcane and cotton growing that is proximal to the Nyanza sugar belt of Kisumu County (KCSAP, 2022). The study site covers 517km^2 with a population of 126,500 (KNBS, 2019).

This study employed a descriptive survey design since it enabled the researcher to get information about a social system and give a description concerning a particular issue. It was used due to its versatility to accommodate various methods of data collection such as questionnaires, interviews, observation, focused group discussion as well as data analysis (qualitative and quantitative) in order to deeply understand the problem under investigation. This design enabled the researcher to obtain information that examines the classification and socio-economic benefits of agroforestry systems in Soin Ward, Kericho County, Kenya.

Target Population, Sample and Sampling Procedure

This study targeted 126,500 sugarcane farmers, households, farm workers, and beneficiaries within Soin Ward. Three hundred (384) respondents were sampled according to the

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Fischer formula described by Kothari and Garg (2014) as follows:

$$n=Z^2*(p)*(1-p)/C^2$$

Equation 1

Where; n = sample size, Z = 1.96, the tabulated Z value for 95% confidence level, p = sample proportion expressed as a decimal (0.5 is the maximum that can yield at least the desired precision; c = degree of accuracy expressed as a decimal (0.05 because the estimate of the study should be within 5% of the true value.

Hence, n=1.96 2 0.5 x (1-0.5)/0.052

n= 384 respondents

The sample size (n) was then apportioned equally (128) in a simple random manner to the three major climatic zones (upper, mid, and lower lands) in the study site.

Data Collection Procedures

Data on the classification and socio-economic benefits of agroforestry systems were collected by using a pretested questionnaire. Pretesting of the questionnaire was carried out in the neighbouring Ward of Kipkelion West three months prior to the commencement of the study. In each climatic zone (upper, mid, and lower lands) within the study site, agroforestry farmers and households were identified and the pretested and structured questionnaire was administered. The questionnaire maintained the anonymity and honesty of respondents (Böhringer, 2003). Additional data captured through observation and photographs were recorded in a checklist.

Secondary data were obtained from various sources such as the internet and journals and entered into data extraction form. Key informant interviews were administered to the Ministry of Agriculture and Forestry employees working in the area, community leaders, and professionals who have first-hand knowledge about the issue being explored. These experts, with their particular knowledge and understanding, can provide insight into the nature of problems and give recommendations for solutions (Carter, 2014).

Classification of Agroforestry Systems

Data relating to the classification of agroforestry systems were collected through the administration of questionnaires, interviews, surveys, and observation. These involved gathering data on types of traditional agroforestry (agrisilviculture, silvopastoral, agrosilvopastoral); functional agroforestry (productive and protective); the scale of practice (subsistence or commercial); land utilisation (homestead, forested land, dairy farm, animal farm, and integrated farm); ecological classification (tree species preference, planting arrangement, and sugarcane species).

Classification Characteristics of the Tree-Sugarcane Agroforestry

Data relating to the characteristics of the tree-sugarcane agroforestry system were collected through the administration of questionnaires, interviews, and observation. These data include the types and preferences of trees, types and preferences of sugarcane, planting arrangements of trees and sugarcane within the farm such as hedge raw, intercropping, boundary, woodlot, and alley cropping.

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Assessing Socio-Economic Benefits of Agroforestry Systems

Data relating to the socio-economic benefits of the agroforestry system were collected through the administration of questionnaires, observation, and interviews. Data on types of benefits {biodiversity conservation, bio drainage, soil fertility, carbon absorption, and biofuel, income, social amenities improvement and employment were captured}, data on demographic information of respondents and households, sex, age, education level and marital status of household heads were also collected, and contribution of agroforestry to social amenities within the study area was underpinned to this study.

Examining Socio-Economic Constraints of Agroforestry Systems

The data relating to the socio-economic constraints of the agroforestry systems were collected through the administration of questionnaires, observations, and interviews. Constraints in terms of labour intensity, payback periods, market accessibility, technology and knowledge were captured. The questionnaire and observation checklist maintained the anonymity and honesty of respondents (Kasomo, 2007). Additional data relating to the socio-economics of the tree-sugarcane agroforestry system was obtained from various secondary sources such as the internet and journals.

Data Analysis and Presentation

Data were analysed using descriptive and inferential statistics such as means and percentages and presented by the use of frequency distribution tables.

RESULTS AND DISCUSSION

DEMOGRAPHIC INFORMATION OF THE HOUSEHOLDS

Table 1 reports the mean demographic distribution of respondents in Soin Ward. Sixty-eight (68.1%) of the respondents were males, while females were a minority (31.9%). In Kenya's population census of 2019, the total population of Soin Ward was 21,072 heads, with the ratio for males to females standing at 49.05% and 50.05%, respectively.

Table 1: Mean Demographic Information of Respondents in Soin Ward

Item	Description	% Response	Item	Description	% Response
Gender	Male	68.1	Marital status	Single	12.1
	Female	31.9		Married	55.5
				Widowed	26.8
				Divorced	5.6
Household size	≤5	30.2	Primary occupation	Formal employment	21.7
	6-10	65.7			
	11-14	3.8		Informal employment	78.3
	>15	0.3			

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Item	Description	% Response	Item	Description	% Response
Age bracket	≤35	13.9	Land Sizes (Acres)	<1	16.0
	36-50	49.4		1.5-3	30.5
	>51	36.7		3.1-5	34.8
				5.1-7	14.0
				>7	4.7
Education levels	None	13.7	Marital status	Married	55.5
	Primary	25.9		Single	30.3
	Secondary	28.9		Divorced	5.6
	College	26.2		Widow	8.6
	Adult Education	5.3			

The majority of the respondents undertaking agroforestry were of the age group range of 36 – 50 years (49.4%); those above 51 years (36.7%) formed the second largest group, while those below 35 years (13.9%) were the minority. Twenty-eight (28.9%) of the respondents had attained a secondary level of education, followed by college graduates (26.2%), primary (25.9%), none (13.7%), while the minority had adult education (5.3%). These results are not significantly different from the findings of the Kenya population census 2019 (KNBS, 2019).

Household Characteristics of Agroforestry Farmers

Fifty-five (55.5%) of the households practising agroforestry were married, single (30.3%), or widowed (8.6%), while the minority were separated or divorced (5.6%). The highest number of household members among the respondents were 6 - 10 (65.7%), below 5 were 30.2%, those between 11 -14 members were 3.8%, and those with above 15 members were 0.3%. According to the Kenya Population Census of 2019, an average household size of four (4) was reported for Kericho County (KNBS, 2019). The current results from Soin Ward do not vary significantly from those reported for Kericho County in the 2019 population census.

The primary occupation for the majority of respondents (78.3%) was informal employment with those in formal employment at 21.7%. As of 2009, Kericho County's labour force stood at 405,034, the majority being males. This was projected to increase to 532,060 in 2018 and to rise further to 608,019 by 2022 (Kericho CIDP, 2018). Land sizes within Soin ward ranged from <1 acre (16.0%), 1.5 to 3 acres (30.5%), 3.1 to 5 acres (34.8%), 5.1 to 7 acres (14.0%) and >7 acres (4.7%). These results corroborate those reported in Kericho CIDP 2018 that put the average land holding size at 2.5 acres for smallholder farmers.

Classification of Agroforestry Systems in Soin Ward

Classification of agroforestry systems in Soin Ward was based on five thematic areas, namely: Traditional, functionality, socio-economics, ecological, and land utilisation. Results for each thematic area are presented in relation to land sizes.

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Traditional Classification of Agroforestry Systems

Table 2 shows the traditional classification of agroforestry systems in Soin Ward against the size of land owned. Three types of agroforestry systems were identified, namely; agrisilviculture, silvopastoral, and agrosilvopastoral.

Table 2: Traditional Classification of Agroforestry in Soin Ward

Thematic area of classification	Land size (acres)	Type of agroforestry system	Number of farmers	% Response
Traditional	<1	Agrisilviculture	21	5.5
	1.1-3		33	8.6
	3.1-5		49	12.8
	5.1-7		12	3.1
	>7		6	1.6
	Total		121	31.6
	<1	Silvopastoral	7	1.8
	1.1-3		19	4.9
	3.1-5		22	5.6
	5.1-7		24	6.1
	>7		7	1.8
	Total		79	20.2
	<1	Agrosilvopastoral	33	8.6
	1.1-3		64	17.0
	3.1-5		62	16.1
	5.1-7		21	5.5
	>7		4	1.0
	Total		184	48.2

Thirty-one (31.6%) of respondents practised agrisilvicultural system of agroforestry that involved planting food crops such as maise, sugarcane and trees in the same land in terms of alley cropping or home gardens. Twenty (20.2%) practiced a silvopastoral system that was characterised by grazing of domestic animals such as cows on Napier grass pastures. The majority (48.2%) of the respondents practiced an agrosilvopastoral system that involved planting cypress and eucalyptus trees, rearing animals and crops combined. This was characterised by home gardens, domestic animals, and scattered trees on croplands. The growth, development, and arrangement of different types of trees and crops such as sugarcane in the same area assume the existence of dynamic system interactions and change over time (FAO, 2015). This is especially true in areas where there are three components due to continued growth in height, crown projection, and leaf area of tree species. Land sizes and the adopted agroforestry system affect the distribution of existing resources,

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

which in turn can cause a constant change in the productivity of species in a system (Jose, 2009; Peace Corps, 2021).

Functional Classification of Agroforestry Systems

Table 3 shows the functional classification of agroforestry systems in Soin Ward against the size of land owned. Two types of agroforestry systems were identified namely, protective and productive agroforestry.

Table 3: Functional Classification of Agroforestry in Soin Ward

Thematic area of classification	Land size (acres)	Type of agroforestry system	Number of farmers	% response
Functionality	<1	Productive	47	12.3
	1.1-3		105	27.3
	3.1-5		121	31.5
	5.1-7		37	9.6
	>7		12	3.1
	Total		322	83.8
	<1	Protective	14	3.7
	1.1-3		11	2.9
	3.1-5		12	3.1
	5.1-7		20	5.2
	>7		5	1.3
	Total		62	16.2

Sixteen (16.2%) of respondents practised protective agroforestry that aimed at providing functions such as a windbreak, shelterbelt, soil conservation, moisture conservation, soil improvement, and shade for crops and animals. The majority (83.8%) of the respondents practised productive agroforestry that aimed at the production of essential commodities such as food, fodder, and fuel wood. A protective agroforestry system is designed to protect the land, improve climate, reduce wind, and water erosion, improve soil fertility, provide shelter, and other benefits (Kericho County Government, 2021). On the other hand, a productive agroforestry system aims at the production of essential commodities such as food, fodder, and fuel wood required to meet society's basic needs. It includes intercropping of trees, home gardens, plantation of trees in and around the crop field, and production of animals and fishes associated with trees (Kebebew & Urgessa, 2011).

Socio-Economic Classification of Agroforestry Systems

Table 4 shows the socio-economic classification of agroforestry systems in Soin Ward against the size of the land owned. Two types of agroforestry systems were identified,

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namely; subsistence and commercial agroforestry.

Table 4: Socio-economic classification of agroforestry systems in Soin Ward

Thematic area of classification	Land size (acres)	Type of agroforestry system	Number of farmers	% Response
Socio-Economics	<1	Subsistence	54	14.1
	1.1-3		62	16.1
	3.1-5		56	14.5
	5.1-7		3	0.8
	>7		1	0.2
	Total		176	45.7
	<1	Commercial	7	1.8
	1.1-3		54	14.1
	3.1-5		77	20.1
	5.1-7		54	14.1
	>7		16	4.2
	Total		208	54.3

Forty-five (45.7%) of the respondents practised subsistence agroforestry in comparison to 54.3% who preferred the commercial type of agroforestry system. Subsistence agroforestry is defined as self-sufficient farming in which farmers focus on cultivating sufficient quantities of trees and sugarcane for their families. It aims at the basic needs of a small family having less land holding and very little capacity for investment. In Soin Ward, this was characterised by marginal surplus production for sales like shifting cultivation and scattered trees in the farms and homesteads. A commercial agroforestry system is a large-scale production on a commercial basis, and the main consideration is to sell the products such as tea or sugarcane or coffee. Seventy (77%) of the farmers have less than five acres of practised commercial agroforestry in Soin Ward. Due to the statistical insignificance observed between the two types (commercial and subsistence agroforestry), it is suggested that an intermediate agroforestry system (intermediate between commercial and subsistence systems) is practised on the small and medium-sized farms with the aim to produce items that are not only enough to meet the needs of the family but also earn money from the surplus that can be sold, (Kebebew & Urgessa, 2011).

Classification of Agroforestry System Based on Utilisation of Land

Table 5 shows the classification of agroforestry systems in Soin Ward based on land utilisation. Five types of land utilisation agroforestry systems were identified, namely, homestead, forest land, dairy farm, animal farm, and integrated farm.

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Table 5: Classification of agroforestry system based on utilisation of land

Thematic area of classification	Land size (acres)	Type of agroforestry system	Number of farmers	% response
Land Utilisation	<1	Homestead	13	3.4
	1.1-3		10	2.6
	3.1-5		3	0.8
	5.1-7		0	0
	>7		0	0
	Total		26	6.8
	<1	Forest land	4	1.0
	1.1-3		10	2.6
	3.1-5		15	3.9
	5.1-7		16	4.2
	>7		5	1.3
	Total		50	13
	<1	Dairy farm	3	0.8
	1.1-3		2	0.6
	3.1-5		0	0
	5.1-7		0	0
	>7		0	0
	Total		5	1.4
	<1	Animal farm	3	0.8
	1.1-3		39	10.1
	3.1-5		56	14.6
	5.1-7		19	4.9
	>7		4	1.0
	Total		121	31.4
	<1	Integrated farm	38	9.9
	1.1-3		55	14.3
	3.1-5		59	15.4
	5.1-7		22	5.7
	>7		8	2.1
	Total		182	47.4

In Soin Ward, an integrated farm-based agroforestry system was the most preferred by (47.4%) of the respondents in comparison with homestead (6.8%), animal farm (31.4%), dairy farm (1.4%), and forest land (13%). The Homestead agroforestry system focused on the production of fruit trees, selected multipurpose trees having less canopy and decorative trees/shrubs and vegetables, spices, and many shade-loving crops. The Forest land

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agroforestry system focuses on the production of crops in the vacant spaces of the forest; the crop farm forestry system focuses on the production of crops and trees in the cropland. Animal farm forestry was characterised by farming poultry birds and trees. Dairy farm forestry was characterised by farming milk and beef cattle and goats within the same land. Integrated farm forestry was characterised by the production of crops, animals, fishes along with trees and roadside agroforestry, the production of deep-rooted tall trees with narrow canopies and soil building grasses or crops along the sides of roads, highways, railways, and embankment (Kebebew & Urgessa, 2011).

Ecological Classification of Agroforestry in Soin Ward

Table 6 shows the classification of agroforestry systems in Soin Ward based on ecology. Three types of ecological classification in terms of tree species, planting arrangement, and sugar cane species preference were identified. Majorities (34.9%) of the farmers participate in a tree-sugarcane agroforestry system in a planting arrangement with sugar cane (33.6%) and tree species (31.5%), respectively.

Table 6: Ecological classification of agroforestry system in Soin Ward

Thematic area of classification	Land size (acres)	Type of agroforestry system	Number of farmers	% response
Ecological	<1	Tree species preference	18	4.7
	1.1-3		36	9.4
	3.1-5		45	11.7
	5.1-7		15	3.9
	>7		7	1.8
	Total		121	31.5
	<1	Planting arrangement	12	3.1
	1.1-3		51	13.3
	3.1-5		54	14.1
	5.1-7		11	2.9
	>7		6	1.6
	Total		134	34.9
	<1	Sugar cane species preference	13	3.4
	1.1-3		41	10.7
	3.1-5		57	14.8
	5.1-7		12	3.1
	>7		6	1.6
	Total		129	33.6

Article DOI: https://doi.org/10.37284/eajfa.5.1.904

Paquette and Messier (2020) and Ellison *et al.* (2016) have demonstrated the viability of sugarcane in agroforestry systems in Brazil. Several studies in Brazil and around the world demonstrate the viability of using annual crops such as maise, soybeans, wheat, oat, and ryegrass in ecological agroforestry systems (Ellison *et al.*, 2016).

Characteristics of Tree-Sugarcane Agroforestry System in Soin Ward

Studies were carried out to understand tree and sugarcane species preferences in Soin Ward and their planting arrangements in an agroforestry system.

Tree Species Preferences and Planting Arrangement in Soin Ward

The majority (42.7%) of the respondents preferred *Grevillea* tree species for blending with sugarcane in a tree-sugarcane agroforestry system. The other tree species in order of preference were c*ypress* (29.4%), e*ucalyptus* (15.1%), *casuarina* (12.6%), and *calliandra* (0.2%). This is different from Uganda, especially in Bunya County, where *Eucalyptus spp., Senna siamea, and Senna spectabilis* tree species have been prioritised based on computed use values and acceptance to be grown by over 30% of farmers now and in future (Obua, 2010).

Trees were planted by (61.7%) of the farmers along the sugarcane farms as a boundary crop, as woodlot (24.0%), hedge row (8.9%), intercropping/mixed (3.1%), and alley cropping (2.3%). The adoption of hedgerows seems to be the best solution to soil conservation with annual crops (Young, 2020).

Plate 1: Characteristics of Tree-Sugarcane Agroforestry in Soin Ward

a. Boundary arrangement

b. Alley cropping

c. Hedge row

Benefits Accrued from Agroforestry Systems

Socio-economic Benefits of Agroforestry Systems

Direct benefits from tree-sugarcane agroforestry systems include income (67.6%) and employment (24.1%). (21.9%) of the farmers benefit from biofuel extraction, soil fertility enhancement (21.1%), bio drainage (20.4%), biodiversity conservation (19.4%), and carbon absorption (17.2%). In terms of its potential to mitigate climate impact and improve soil quality, agroforestry can offer significant economic and social impact,

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especially for smallholder farmers in developing countries such as Kenya (Ngugen, 2013). Improved soil quality could help farmers produce more crops, while introducing trees in traditional agricultural systems can allow more efficient nutrient cycling, meaning farm output can be substantive and reliable (Ngugen, 2013). Crops and products derived from introducing trees in agricultural systems drive positive social and economic change (Tumwebaze & Byakagaba, 2016). A low-cost and sustainable technique to transform any degraded landscapes and improve livelihoods among communities is through agroforestry (Ngugen, 2013).

The adoption of agroforestry in Soin Ward has changed the standards of living among the residents through the construction of new and repairing of roads, schools, hospitals and markets. In the study area, the following social amenities were improved; roads (27.2%), markets (25.8%), hospitals (19.3%), schools (18.5%), and electricity (9.2%). Literature review showed that farmers derive direct revenue from harvested cane while indirect revenue comes from opportunities created by the sugarcane industry such as business investments mostly in the form of retail and wholesale shops, transport services (both motorbikes and motor vehicles) and reinvestment in the food crop industry (Ngugen, 2013).

Socio-Economic Constraints of Agroforestry Systems

Trees integrate with sugarcane to improve yields, diversify products, increase economic resilience, and improve farm viability and sustainability in the long term. When choosing a tree species for a particular purpose, it is important to consider the multiple uses and functions it can provide (Wilson & Lovell, 2016). In the current study, the majority of respondents (90.3%) reported that land size was the major constraint to the tree and sugarcane agroforestry system. Other constraints include; long waiting payback (39.2%), limited possibilities to sell products (28.3%), labour intensive (27.8%), and knowledge and technology gap (4.7%). A rapid increase in the human population in the world has led to the widening of the market gap in the supply of various farm produce, especially in the forestry and agriculture sectors (UN, 2016). The gap has forced farmers to encroach on nearby forests in search of more space for settlement and expansion of agricultural fields (FAO, 2016; Melusi, 2012).

CONCLUSIONS

Four (4) classes of agroforestry systems were identified in Soin Ward that comprised; (48.2% agrosilvopastoral and 31.6% agrosilvicultural and 20.2% silvopastoral); (16.2% protective and 83.8% productive); (45.7% subsistence and 54.3% commercial) and Integrated farm-based agroforestry 47.4%, homestead (6.8%), animal farm (31.4%), dairy farm (1.4%) and forest land (13%) respectively. The majority of the respondents (42.7%) preferred *Grevillea* tree species for blending with sugarcane in a tree-sugarcane agroforestry system in comparison with *cypress* (29.4%), e*ucalyptus* (15.1%), *casuarina* (12.6%) and c*alliandra* (0.2%) respectively. Sixty (61.7%) plant trees along the boundary, such as woodlot (24.0%), hedge raw (8.9%), intercropping/mixed (3.1%) and as alley cropping (2.3%). Direct benefits from the identified agroforestry systems include; income (67.6%), food (8.3%) and employment

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(24.1%). Indirect benefits include provision of biofuel (21.9%), enhanced soil fertility (21.1%), bio drainage (20.4%), biodiversity conservation (19.4%) and carbon absorption (17.2%), improvement of social amenities such as roads (27.2%), markets (25.8%), hospitals (19.3%), schools (18.5% and electricity (9.2%). Constraints faced by the agroforestry systems include; long waiting payback (39.2%), limited possibilities to sell products (28.3%), labour intensive (27.8%) and knowledge and technology gap (4.7%).

ACKNOWLEDGEMENTS

I wish to convey my heartfelt gratitude to my supervisors, Prof. Peter Kipkogei Sirmah, Dr. Thomas Kibiwot Matonyei and Prof. James Simiren Ole Nampushi who supported, guided, advised, and encouraged me. They also took their time to make necessary corrections to my work right from the initial stages of research proposal development, data collection up to the final stages of writing up the thesis. I greatly and sincerely acknowledge their efforts. I am also very grateful to the National Commission for Science, Technology, and Innovation and the University of Kabianga for making it possible to undertake research and production of thesis. Lastly, I wish to thank the entire School of Agricultural Sciences and Natural Resources staff and any other person who helped me directly or indirectly during the study.

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