INFLUENCE OF AGROFORESTRY ADOPTION ON ECOSYSTEM SERVICES AND LIVELIHOODS AMONG SMALLHOLDER FARMERS IN MACHAKOS COUNTY, KENYA

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DECLARATION

Declaration by the candidate

This thesis is my original work and has not been presented in any other university or for any other award. No part of this work should be reproduced without prior permission of the author and or Kenyatta University.

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Declaration by Supervisors

We confirm that the work reported in the thesis was carried out by the candidate under our supervision

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DEDICATION

I dedicate this research thesis to my beloved late mother Serah Muvengi, who went to be with the Lord during the course of my studies and my late father Timothy Malyunga for they both sacrificed for my education. This research thesis is also dedicated to all those who are dear to me. To the Almighty God for His sufficient grace which made me accomplish this work. To my family who prayed, persevered and sacrificed their time, energy and resources to see me through.

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LIST OF ACRONYMS AND ABREVIATIONS

AAS	Atomic Absorption Spectroscopy
CBD	Convention on Biological Diversity
DAP	Diammonium Phosphate
FAO	Food and Agriculture Organization
FBCCESD	Faith Based Climate Change Education for Sustainable Development
IAAST	International Assessment of Agricultural Science and Technology for Development
ICRAF	International Centre for Research in Agroforestry
KALRO	Kenya Agricultural and Livestock Research Organization
KFS	Kenya Forest Service
KOEE	Kenya Organization for Environmental Education
MEA	Millennium Ecosystem Assessment
NACOSTI	National Commission for Science, Technology and Innovation
NARL	National Agricultural Research Laboratories
NGO	Non-Governmental Organizations
PES	Payment for Ecosystem Services
ppm	Parts Per Million
SSA	Sub Saharan Africa
SOC	Soil Organic Carbon
TOC	Total Organic Carbon
TVC	Total Variable Costs
UN	United Nations
UVVS	Ultra Violet Visible Spectrum
WB	World Bank

ABSTRACT

Agroforestry provides a number of ecosystem goods and services. Yet evidence of agroforestry supporting these perceived benefits in rural areas have increased over the last three decades. This study determined influence of agroforestry adoption on ecosystem services and livelihoods for smallholder farmers in Machakos County. The study was conducted using utilized concurrent transformative design where both the qualitative and quantitative data were collected at the same time. The study was based on sample size of 248 households' selected using stratified, random sampling. Qualitative data were collected using questionnaires and interviews while soil data was collected following standard soil sampling techniques and analyzed in the laboratory for textural characteristics, pH, bulk density and micronutrients. Statistical data were done using chi-square (χ^2), binary logistic Model (BLM), ANOVA, *t*-test and bivariate regression. Agroforestry was adopted by 82% of the respondents in the form of boundary tree planting (73.8%), hedgerow (69.4%), scattered trees in rangeland (51.2%) and alley cropping (37.1%). Age, level of education, household size and non-farm income were significant ($P < 0.05$). Socio-economic aspects affecting adoption of agroforestry were access to credit, training and inputs were significant ($P < 0.05$) institutional factors affecting the adoption of agroforestry. Ecosystem services obtained by majority of the households were supporting functions in the form of nutrient recycling and soil formation (81.5%) and regulatory functions in the form of soil erosion, water infiltration and micro-climate regulation (80.8%). Provisioning services was dominated by fuel wood (84%), fruit and nuts (75%), poles (74%) and timber (72%). Total income was higher among adopters of timber, fuel wood, posts/poles and fodder. Adopters also had more money to spend on food, clothing, education, medicine and basic needs. Thus the overall gross revenue was higher among adopters. There were higher net returns above Total Variable Cost (TVC) for the adopters (US$ 346.57) compared to the non-adopters (US$ 94.7), which resulted in positive net returns above Total Cost (TC) for the adopters (US$ 275.77) and positive operational costs above the fixed costs for the non-adopters (US$ 23.9) resulting in higher margins above TVC (%) for the agroforestry adopters (28%) than the non-adopters (12%). The soil physical attributes indicate that the proportion of sand particles was significantly ($P < 0.05$) higher among non-adopters while the proportion of silt and bulk density in the soil was higher among the adopters. The total nitrogen (TN), total organic carbon (TOC), Ca, Mg, Mn, Cu, Fe, Zn and C/N ratio were significantly improved ($P < 0.05$) in soils where agroforestry was being practiced. Overall physical and chemical attributes in the soil improved significantly with increasing age in years of agroforestry adoption. The study recommends adoption of agroforestry to maximize ecosystem benefits. However, more training is required for the farmers to enhance their ability and potential to optimize agroforestry practices and new innovations.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The global demand for forest and forest resources such as wood, food, fuel, medicine, fodder, construction materials among others have surged tremendously over the last five decades (Schyns *et al.*, 2019; Szulecka, 2019; Watanabe, 2020). Accompanying these, is the increased demand for other necessities such as water catchments functions, climate regulations and carbon sinks which have continued to exert more strain on the existing forest ecosystems (Baig *et al.*, 2019; Higginbottom *et al.*, 2019; Hong and Saizen, 2019). Therefore attempts at mitigating the existing and foreseeable pressure on natural forest have been attempted through interventions aimed at increasing the population of trees in the farms (Mackey *et al.*, 2015; Rasolofoson *et al.*, 2015; Chazdon, 2019) through the practice of agroforestry (Nadir *et al.*, 2018; Viswanath *et al.*, 2018).

Agroforestry is the deliberated consortia of trees with crop plants and/or livestock, in determined space arrangements and sequences, presenting varied interactions among their components (Tiwari *et al.*, 2017a). The practice includes attempted integration and management of a consortia of forest and agricultural resources on the same landscape, where farmers grow trees on their farms, pasturelands and homesteads (Tiwari *et al.*, 2017b). As a traditional practice, agroforestry has been associated with positive development of livelihoods, suitable land management and sustainable development (Lentz *et al.*, 2015; Rahman *et al.*, 2015). These include availability of suite of products for utilization (Rahman *et al.*, 2016; Smith and Dressler, 2017; Amatya *et al.*, 2018) including energy in the form of firewood, building materials in the form of posts and timber, food such as fruits and medicine etc (Wulan *et al.*, 2008; Kimaro *et al.*, 2019). In several rural areas, there are other additional products emanating from non-timber product such as wax and honey from bees, safe to eat fruits, nutritious insects, vegetables, herbal medicines, brooms and fibres which can be derived from agroforestry (Leakey *et al.*, 2005; Kalaba *et al.*, 2010). As a result, adoption of agroforestry is currently on the uptrend.

Adoption of agroforestry is global (McAdam and Curran, 2018; Fleming *et al.*, 2019). Subsequently several international bodies including the United Nations (UN) and World Bank (WB), governments and Non-Governmental Organizations (NGOs) have advocated for its adoption at the global level (Cuperus *et al.*, 2018; Quandt *et al.*, 2019). Consequently, between the year 2010 to 2017 there were approximately 300 to 350 million people who had adopted agroforestry (Garrity, 2012; Pastur *et al.*, 2012; Atangana *et al.*, 2013; Abbas *et al.*, 2017). Most of the new adopters of agroforestry reside in the tropical region of the world where conditions are favourable (Alam *et al.*, 2010; Tscharntke *et al.*, 2011; Atangana *et al.*, 2014).

In Africa, agroforestry used to be poorly developed over five decades ago where farmers involved in the practices are always less than 8% but have been improving since the beginning of the new millennium (Mbow *et al.*, 2014a; Minang *et al.*, 2014). Indeed contribution of trees cover from such poorly developed systems rarely meet the minimum threshold of 10% of the national tree demand (Iiyama *et al.*, 2014; Awodoyin *et al.*, 2015). However more recently, the practice is gaining more recognition by many smallholder farmers (Mbow *et al.*, 2014b) with more adoption in the Sub Saharan Africa (SSA) (Franzel *et al.*, 2001; Leakey *et al.*, 2005;

Meijer *et al.*, 2015; Beyene *et al.*, 2019). One of the reasons often cited for large disparity in adoption is due to presence of social and economic challenges.

Several social and economic factors governing the adoption and practice of agroforestry has been highlighted among households (Matata *et al.*, 2010; Zerihun *et al.*, 2014). There is also increasing recognition that institutions that support agroforestry as well as the institutional factors may have an impact on the adoption of agroforestry among the rural populations (Mercer, 2004; Binam *et al.*, 2017). However, there has been less focus on how combination of socio-economic and institutional factors affects adoption of agroforestry in Sub Saharan Africa (Matata *et al.*, 2010; Mwase *et al.*, 2015). Challenges pertaining to socio-economic and institutional factors appears to be more serious in the Sub Saharan Africa as far as adoption of agroforestry is concerned (Akoto *et al.*, 2018).

Previous foci had laid less emphasis on the socio-economic factors and institutional factors on adoption of agroforestry which varies widely in the local context (Tenge *et al.*, 2011; Atangana *et al.*, 2014; Mmbando and Baiyegunhi, 2016). In an attempt to optimize planning for undertaking prudent decision-making about smallholder agroforestry adoption and practices, knowledge of the accrued services from the ecosystem that are of immense benefits to the local community households remains paramount.

Agroforestry contribute to suits of ecosystem goods and services such as fodder, food, fuelwood, medicinal resources, timber and ornamental goods (Atangana *et al.*, 2014). Moreover, there are also indirect benefits mainly through services such as carbon sequestration, soil fertility and enrichment, hydrological regulation and habitat restructuring for inhabiting insects species and wildlife (Fagerholm, 2016; Quandt *et al.*, 2018; Amare *et al.*, 2019). The ecosystem services have already been categorized and include provisioning functions (generate food, fruits or fiber), regulating functions (mainly associated with climatic factors, pests and diseases prevalence), supporting functions (biogeochemical cycling of nutrients) and finally the cultural functions (such as recreational, spiritual and/or aesthetic). Services from the ecosystem and their goods interact and links with humanity is increasingly being highlighted (Daw *et al.*, 2016; Fedele *et al.*, 2017; Brown *et al.*, 2018). To optimize adoption of agroforestry, farmers need to fully understand these ecosystem services comprehensively (Franzel *et al.*, 2001). However, there has been a challenge due to lack of comprehension by the local community members about these ecosystem services, which may hinder adoption and the subsequent economic benefits accruing from the practice.

The option of integrating trees, other cultivable crops and livestock concurrently in the same landscape is considered as an opportunity cost representing a cognisant investment for which other practical economic options are forfeited (Amare *et al.*, 2019). Thus the economic contribution of agroforestry has been recognized through environmental benefits, economic products and social goods (Franzel, 2004; Jose, 2009; Fanish and Priya, 2013; Gao *et al.*, 2014). In most households in rural areas, the multiple utilization of trees as sources of food, fuel, fodder, construction materials, medicine, to meet subsistence needs is rarely quantified in economic terms (Adekunle and Bakare, 2004; Kumar and Thakur, 2017; Jemal *et al.*, 2018). Due to widespread shortage of food, as well as skyrocketing fossil fuel process, the economic benefits of agroforestry has recently been highlighted with an increasing interest from several stakeholders and research communities, especially, in developing countries (Amejo *et al.*, 2018).

Consequently, the insight that trees on farms improve the socio-economic prospects and provide livelihood benefits is increasingly being recognized in the Sub Saharan African Region (Kalaba *et al.*, 2010; Quandt *et al.*, 2018). Yet, in the region, studies pertaining to the contribution of agroforestry to socio-economic status and rural livelihoods are still few (Jama *et al.*, 2006; Iiyama *et al.*, 2014) to provide any meaningful conclusion in any part of the region. While agroforestry can provide several environmentally accrued benefits, and play key roles in enhancing the value of ecosystem services, there is also increasing focus of its effects on soil quality (Cardinael *et al.*, 2015; Weerasekara *et al.*, 2016; Udawatta *et al.*, 2017; Dollinger and Jose, 2018).

Proponents of agroforestry contend that soil fertility and conservation forms the primary benefits derived from the practice (García de Jalón *et al.*, 2017; Sarminah *et al.*, 2018). The most widely held view is that trees in agroforestry can improve soil quality mainly by biological nitrogen (N) fixation and increasing the amounts of aboveground and belowground organic matter inputs (Isaac and Borden, 2019; Sarabia *et al.*, 2020). There are a number of benefits that are directly related to soil quality including preventing soil erosion (Akdemir *et al.*, 2016; Béliveau *et al.*, 2017), improving surface and sub-surface water infiltration (Sahin *et al.*, 2016), increasing soil moisture (Cardinael *et al.*, 2017; Feliciano *et al.*, 2018), maintaining soil fertility (Liu *et al.*, 2018), enhancing water dynamics (Ling *et al.*, 2017; Hasselquist *et al.*, 2018), conserving soil biodiversity (Torralba *et al.*, 2016), improving soil microbial biomass (Buyer *et al.*, 2017) and mitigation of climate change (Newaj *et al.*, 2016; Hasselquist *et al.*, 2018).

In Kenya, agroforestry with multiple designs are adopted in private small-scale farms for multiple objectives such as provision of food, energy and environmental benefits including climate change mitigation (Jerneck and Olsson, 2013; Nyaga *et al.*, 2015; De Giusti *et al.*, 2019). The rate of adoption of agroforestry nevertheless remains low in Kenya due to several constrains (Maluki *et al.*, 2016; Quandt *et al.*, 2017). As a result of the low adoption status of agroforestry, several recommendations have been advanced that advocate for adoption of agroforestry in various regions in the country (Nyaga *et al.*, 2015; Ndegwa *et al.*, 2017; Magugu *et al.*, 2018). Agroforestry is practiced at small scale or sustainable level and thus the role of agroforestry practices in supplying forest products has remained unclear (Rotich *et al.*, 2017).

In Machakos, there has been efforts to encourage adoption of agroforestry to enhance livelihood and resilience of the people (Maluki *et al.*, 2016; Quandt *et al.*, 2017). However, there has been little attempt at establishing the trade-off between adoption of agroforestry and attainment of ecosystem services. While there are several component of livelihood is in the adoption of agroforestry is recognized, most outcomes largely focus on assets and income (Benjamin and Sauer, 2018). Studies in most developing countries deliberately ignore the direct correlation between agroforestry practices and ecosystem benefits to the peasant households.

As the question about agroforestry and its derivative ecosystem benefits continues, there are questions that arise concerning the links between adoption of agroforestry, ecosystem services benefits, rural income and livelihoods as well as impacts on soil quality parameters. Determining these issues at the local level remains one of the cornerstone in achieving sustainable use of agroforestry especially in the developing countries (Liebenow *et al.*, 2012).

1.2 Problem Statement

Many farmers practice agroforestry without full understanding of its contribution to the provisioning of ecosystem services, livelihoods and soil fertility improvement (Cerda *et al.*, 2014). In fact many farmers living adjacent to forests believe that forest resource provide most of these benefits and not trees they plant in their farms. However, with a tremendous decline in the natural forest cover and resources notwithstanding the demand for ecosystem services, the role of natural forests in provision of ecosystem services, livelihoods and soil fertility improvement will further be limited (Catacutan *et al.*, 2017). Agroforestry therefore need to gain more importance in filling the gap of increasing the supply of trees and for resources and information pertaining to their adoption by smallholder farmers remains vital. As a result, the progress in agroforestry due to its contribution to ecosystem services, livelihoods and soil fertility improvement has rather been limited resulting in low acceptance by practitioners, farmers and policy makers (Brown *et al.*, 2018). With progress being made on environmental awareness, this problem is gradually being realized with more recommendation being adduced aiming at enhancing the role of agroforestry in provision of ecosystem services, livelihoods and soil fertility improvement (Crous-Duran *et al.*, 2018). To enable farmers increase adoption of agroforestry, there is need for them to understand the contribution of agroforestry to these suites of benefits (Dawson *et al.*, 2014). However, to date, there is limited information that links agroforestry adoption to provisioning of ecosystem services, rural livelihoods and soil fertility improvement in many dryland areas in Kenya. Moreover, in Kenya, information concerning the adoption of agroforestry practices as strategic enterprise on livelihood improvement is sporadic rare and fragmented.

1.3 Justification of the Study

Advocacy of adopting agroforestry in the dryland areas in Kenya has long been recommended since the early 1900s to halt desertification and soil erosion (Hughes *et al.*, 2020). However, there have been little attempt at establishing the rate of agroforestry adoption in drylands resulting in improved understanding of the factors that affect agroforestry adoption lags behind in many dryland regions in Kenya. Therefore this study will improve the knowledge of adoption of agroforestry and factors that affect agroforestry adoption.

There are a number of ecosystem benefits that accrue to farmers from agroforestry. Therefore information from this study will be useful in contributing to the understanding of the role of agroforestry adoption in provision of ecosystem benefits, rural livelihood and soil fertility especially among the rural farmers in arid and semi-arid areas. In several drylands areas of Kenya, studies addressing contribution of agroforestry to socio-economic status and rural livelihood are limited. Therefore this study will contribute towards an understanding of the role of agroforestry towards rural income and livelihood.

In Kenya, there is a considerable body of information which has described the effects of agroforestry on soils and all have highlighted that agroforestry practices could effectively improve soil physical, chemical and biological properties and maintain improved land productivity. Although the beneficial effects of agroforestry on soil quality is overwhelming, it is still not clear the impact of agroforestry adoption on soil nutrient dynamics under the influence of agroforestry. This study will therefore contribute to fulfilment of such knowledge gaps.

1.4 Research Questions

1) What are the socio-economic and institutional factors influencing adoption of agroforestry among smallholder farmers in Machakos County?
2) How does adoption of agroforestry practices influence ecosystem services among smallholder farmers in Machakos County?
3) To what extent does adoption of agroforestry practices influence rural income and livelihoods of smallholder farmers in Machakos County?
4) To what extent does agroforestry influence on soil physico-chemical parameters in Machakos County?

1.5 Objectives of the Study

1.5.1 Main Objective

The broad objective of the study was to determine the influence of agroforestry practices on ecosystem services and livelihoods for rural smallholders in Machakos County, Kenya.

1.5.2 Specific Objectives

1) To determine the influence of socio-economic and institutional factors on the adoption of agroforestry among smallholder farmers in Machakos County.
2) To assess the influence of agroforestry practices on ecosystem services among smallholder farmers in Machakos County.
3) To evaluate the influence of adoption of agroforestry practices on rural income and livelihoods of smallholder farmers in Machakos County.
4) To analyze the influence of agroforestry practices on soil physico-chemical quality among smallholder farmers in Machakos County.

1.6 Research Hypotheses

1) Socio-economic and institutional factors significantly influence the adoption of agroforestry among smallholder farmers in Machakos County.
2) Agroforestry practices significantly influence the ecosystem services among smallholder farmers in Machakos County.
3) Adoption of agroforestry practices significantly influence the rural income and livelihoods among smallholder farmers in Machakos County.
4) Agroforestry practices significantly influence the soil physico-chemical quality among smallholder farmers in Machakos County.

1.7 Significance of Study

An understanding of agroforestry adoption will enhance improvement of the tree cover in the country is important. In this way, extension staff will be able to address farmers' needs for tree seedlings, tree seeds sourcing, tree establishment, tending and tree management. Farmers will also have improved access to knowledge pertaining to the importance of trees, as well as entrepreneurial and business skills that are required in increasingly seedlings, trees and agroforestry. Knowledge exchange of tree management will help to increase farm productivity and contribute to natural resources conservation.

Farmers in agroforestry tend to abandon the tree nursery programmes and projects midway for alternative crop systems due to low returns and economic benefits thus jeopardize the achievement of improved trees for several services and goods (Hughes *et al.*, 2020). Therefore, a proper perception of the economics of farmers' tree establishment is important to evaluate the profitability of the enterprise and explore reasons for abandonment.

1.8 Conceptual Framework

Figure 1.1 shows the relationship between the construct of variables of the study: both the independent and dependent, with possible moderating role of agroforestry outcomes. As shown in the figure, the four constructs comprising socio-economic and institutional factors, ecosystem services, rural income and livelihood and soil quality parameters were the independent variable in this study. Meanwhile the intended outcomes of adopting these practices were measured in the form of adoption agroforestry, changes in the socio-economic and livelihoods status, changes in ecosystem services as well as soil quality parameters were evaluated as dependent variable. In this study there was need to establish the relationship between the aforementioned independent variable and specific measurable outcomes. Nevertheless, the influence of these independent variables on the dependent variables could also be influenced by the nature of agroforestry practices.

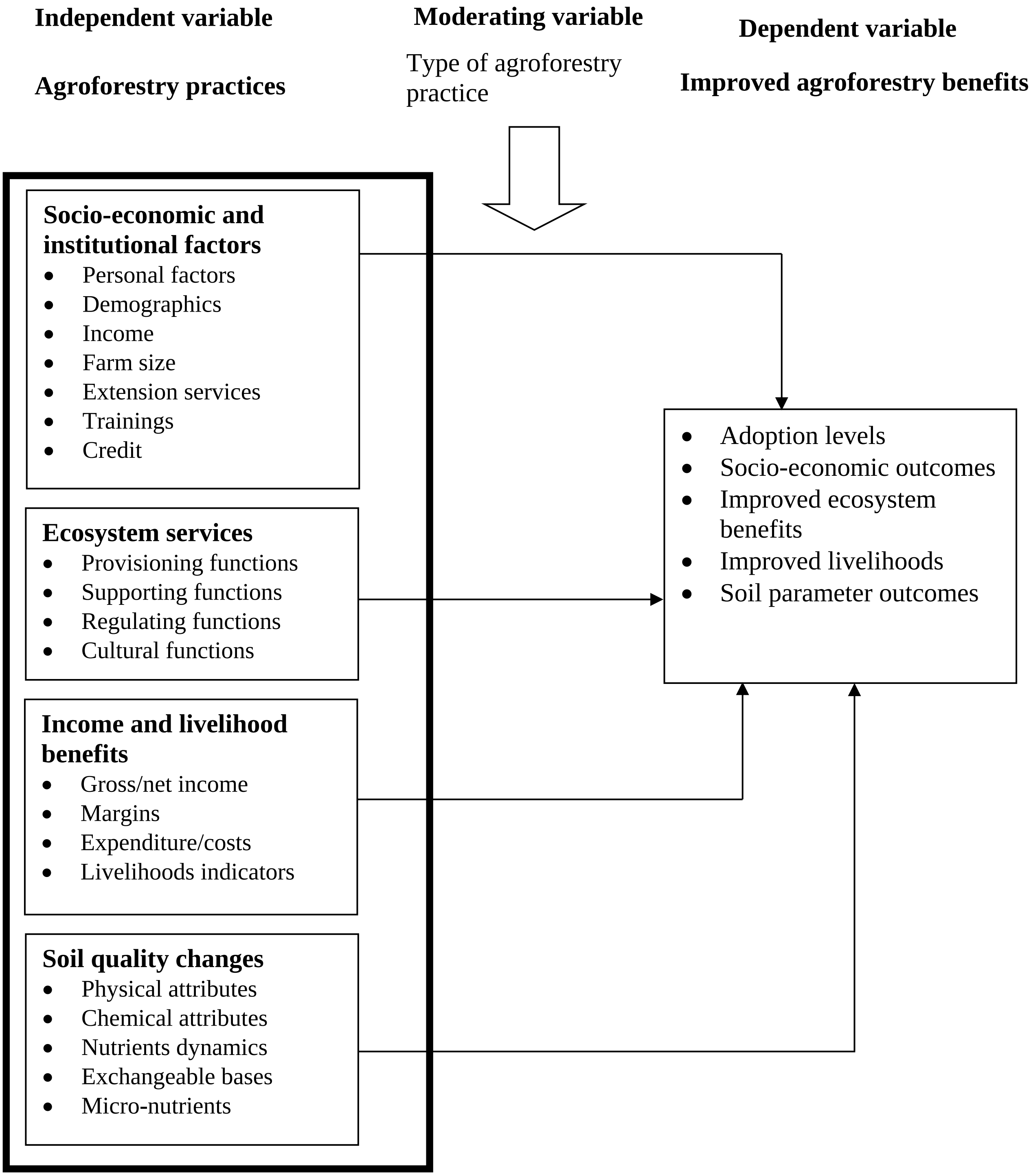

Figure 1.1: Relationships between agroforestry and outcomes of adoption of agroforestry practices

1.9 Definition of Terms

Agroforestry: Integration of trees, cultivable crops and livestock concurrently in the farmland (Abbas *et al.*, 2017)

Ecosystem services: Refers to the benefits derived from adoption of agroforestry. In this study these services were: Provisioning, supporting, regulating and cultural functions (Fagerholm *et al.*, 2016)

Income: Amount of money derived by the farmers from any activity within and from outside the farm (Eshetu *et al.*, 2018)

Institutional factors: These are issues among agroforestry institutions that affect the agroforestry like access to extension services, access to credits, access to formal agroforestry, training, access to information from conservation groups, access to inputs from conservation groups and frequency of extension visits (Alavalapati *et al.*, 2001)

Livelihoods: Conditions under which most of the people live and are able to meet the basic needs (Hanif *et al.*, 2018)

Socio-economic factors: These refer to age, gender, marital status, level of education, household size, land size, location, occupation of the household head, farm household income and non-farm household income (Ipara, 1993)

Soil quality: The sum total of physical attributes, chemical attributes, nutrients dynamics, exchangeable bases and nutrients (micro and macro nutrients) in the soils (Abreu *et al.*, 2016).

1.10 Scope of the Study

The study was limited geographically to Machakos County. In terms of content the study looked at socio-economic and institutional factors, ecosystem services, agroforestry contribution to rural livelihoods and agroforestry contribution to soil quality.

1.11 Limitation of the Study

This study did not take into account details of the tree species that were planted during agroforestry practices but noted the major agroforestry practice done. The low level of education of farmers presented a barrier for majority of the respondents. Therefore an interpreter was required and hence some information might not have been captured. The study aimed to close the gap of knowledge by tapping indigenous knowledge from the farmers who have survived in this environment for long.

1.12 Assumptions of the Study

During the study, the assumptions included:

i. The respondents freely expressed their opinions and feelings about the selected factors during interviews.

ii. Variables not used in the study such as type of agroforestry practice and government policy did not affect the study outcome

CHAPTER TWO

LITERATURE REVIEW

2.1 Background and origin of Agroforestry

In the past, before the ‘Green Revolution’, subsistence farmers globally, planted crops, trees and kept livestock in their farms to obtain resources including tree products (Smith and Mbow, 2014). On the background of pressure of modern agriculture, subsistence agroforestry have continued to raise more attention (Nguyen *et al.*, 2013; Rahman *et al.*, 2015). With time, research has brought to limelight other ecosystems services other than food production, from where agroforestry continue to dominate the limelight. As a result, agroforestry has emerged as an area of study where research transcend agronomic focus and look at the system from social–ecological systems (Smith and Mbow, 2014).

The practice of agroforestry has long cured land use degradation, despite some raising pertinent questions on this assertion (Mosquera-Losada *et al.*, 2018a). The practice of planting tree species at the homesteads in lands devoted for agriculture dates back to ancient times. In earlier literature, this practice was combined with crop farming and livestock rearing and generally referred to as the practice of agroforestry which was coined in 1977 (Leakey, 1996). This original concept of agroforestry encompassed a sustainable land management system where trees are grown, livestock reared and crops cultivated in a unit parcel of land. In such instances, agroforestry describe land-use where there is deliberate introduction of crops, livestock and woody perennials in part of the farm to benefit from economic interactions (Mosquera-Losada *et al.*, 2018a). The definition formulated by Smith has persisted as land-use systems and technologies in which trees, shrubs and herbaceous plants, occur in a spatial arrangement (Smith *et al.*, 2012). The high productivity and sustainable land use makes adoption of agroforestry ubiquitous at the global scale (Dalemans *et al.*, 2018; McAdam and Curran, 2018; Fleming *et al.*, 2019).

In most cases agroforestry refer to human intervention of tree-crop-livestock based systems established on agricultural land (Udawatta *et al.*, 2017). The focus of the farmers should however be biased towards tree to discriminate from traditional crop or livestock husbandry. Most of these trees, crops or livestock within the smallholders projects aim at improving access to sources of high-quality tree planting materials including seeds and seedlings (Wilson and Lovell, 2016). Agroforestry may differ largely in dimension, species components, floral density, and management dynamics (Jemal *et al.*, 2018; Viswanath *et al.*, 2018). Although pilot implementation of agroforestry projects has been undertaken followed by scaling out of successes to relevant agro-ecological zones, large-scale adoption are still facing barriers that should address on-farm tree adoption (Sereke *et al.*, 2015).

In many countries of the world, agroforestry is practiced by smallholder farmers. The practice is widespread in Asian countries like Bangladesh, Sri Lanka, Philippines, Indonesia and Nepal (Ajayi and Place, 2012; Rohadi *et al.*, 2012); several European countries (Nerlich *et al.*, 2013); and in African countries such as Kenya, Uganda, Rwanda, Malawi, Tanzania and Ethiopia (Mosquera-Losada *et al.*, 2012). In Europe, they cleared dead forests, burned the slash, cultivated it for food at some period of time and planted tree species (García de Jalón *et al.*, 2017; Santiago-Freijanes *et al.*, 2018a).

Meanwhile, in several parts of the tropics, humans simulated forest trees in their farms to obtain benefits (Viswanath *et al.*, 2018). In Latin and Central America, farmers imitated floral diversity of tropical forests through planting crops differing in growth forms (Falkowski *et al.*, 2016). In Asia agroforestry was practiced through a complex type of shifting cultivation, by deliberately leaving some trees to provide a partial canopy for new foliage to mature by the end of the rice-growing period (Viswanath and Lubina, 2017). In Nigeria, there was a practice of an intensive mixture of herbaceous plants and trees (Alao and Shuaibu, 2013) while in Zambia, crops were grown in mixture with tree species to provide food and timber (Kabwe, 2010). These examples from all regions of the world depict earlier households as more interested in food production as *raison d'etre*, and trees being integrated in the farms for other benefits.

The tendency to develop agroforestry is always linked to high demand for wood and wood products (Quandt *et al.*, 2017). Therefore agroforestry is viewed as a way to diversify production, reduce risk, and build assets to supplement meagre household incomes (Sharma and Sharma, 2017) and a means of reducing pressure on natural forests (Sistla *et al.*, 2016; Tiwari *et al.*, 2017b). Whether these goals have been realized in many developing countries however remains debatable.

The adoption of agroforestry system, enterprises have allowed a conversion of large areas of the forests into cropland and tree nurseries (Mercer, 2004; Fleming *et al.*, 2019). In most countries, agroforestry rarely exceed 5-10% of the farmlands (Garrity, 2012; Smith *et al.*, 2012; Santiago-Freijanes *et al.*, 2018a). Thus, the productivity from agroforestry in several countries still remain low to make any sustainable contribution or meet the general population demands of tree and their associated products (Sharma and Sharma, 2017). Subsequently most of the agroforestry are always abandoned for other food cropping systems.

2.2 Factors Affecting the Adoption of Agroforestry Practices

In recent years there have been continued campaign and increasing interest in adopting and promoting agroforestry at the global, regional and local scale especially for the smallholder farmers (Simelton *et al.*, 2017; Fleming *et al.*, 2019). Analysis of agroforestry adoption have a tendency to tag along the immeasurable narrative on adoption of agricultural production or conventional agricultural crops (Mattia and Lovell, 2016). A number of features of agroforestry (den Herder *et al.*, 2017; Santiago-Freijanes *et al.*, 2018b), nevertheless, make investigation of its adoption exceptional and justifiable of its own review and subsequent studies.

Adoption of agroforestry is widely acknowledged at the global scale (Dalemans *et al.*, 2018; McAdam and Curran, 2018; Fleming *et al.*, 2019). Much of the adoption occur due to the ability of agroforestry to slow land degradation, sequester atmospheric carbon and make safe rural livelihood through economic benefits such as increase food security (Catacutan *et al.*, 2017; Montagnini and Metzel, 2017; Sharma and Sharma, 2017; Waldron *et al.*, 2017; Saqib *et al.*, 2019). As a result of the beneficial significance of the agroforestry as a practice, its global adoption especially in the rural areas is increasingly being recommended (Munsell *et al.*, 2018) by the United Nations, World Bank, International Centre for Research in Agroforestry (ICRAF) World Agroforestry, government and Non-Governmental Organizations (NGOs) (Ajayi and Place, 2012; Place *et al.*, 2012; Zomer *et al.*, 2016; Callo-Concha *et al.*, 2017). This advocacy has resulted in approximately 350 million agroforestry adopters, who dedicate at least 5 to 10% of their farms in endeavour to practice agroforestry (Binam *et al.*, 2017). As a consequence, there has been significant advances in agroforestry adoption over the past five decades (Place *et al.*, 2012).

There has been an increased surge in adoption of agroforestry especially among rural smallholder farmers located in developing countries (Garrity, 2004; Owombo *et al.*, 2018), resulting to increasing cases of recent adoption of agroforestry in the Sub Saharan Africa (Meijer *et al.*, 2015) compared to more developed countries (Sereke *et al.*, 2016). Regardless of the recent advances, it is still agreeable that adoption of agroforestry including technologies lag behind the scientific as well as the technological advances in agroforestry research in much of these areas.

The scenario in the developing countries of Sub Saharan Africa, occur due to low agroforestry contribution to agricultural productivity and human well-being (Kabiru *et al.*, 2017; Khan *et al.*, 2017; Miller *et al.*, 2017b) in contrast to countries in Europe and North America (Kalaba *et al.*, 2010; Brockington *et al.*, 2016; Sangeetha *et al.*, 2016; Brown *et al.*, 2018). The underlying factors behind these differences are currently being exploited with broad spectrum of suggestions. One research frontier consequently set prerequisites to be met for flourishing agroforestry (Smith and Dressler, 2017) which include extrapolation of the influences of locally successful prerequisites that may influence agroforestry.

One of the most extensively studied conditions influencing agroforestry is the socio-economic factors, as a result of the fact that it determined the living conditions of the people (Callo-Concha *et al.*, 2017; Curry *et al.*, 2019; Fleming *et al.*, 2019). Owing the large disparity in socio-economic status of households in the Sub Saharan Africa, most of the variation in adoption of agroforestry has been reported (Singh, 2017; Magugu *et al.*, 2018). Such large disparity in socio-economic conditions and adoption of agroforestry occur in several countries of the Sub Saharan Africa including Nigeria, (Lambert and Ozioma, 2012; Ekwugha, 2016), Zambia (Kabwe *et al.*, 2016), rural Ethiopia (Beyene *et al.*, 2019), Malawi (Toth *et al.*, 2017a), Democratic Republic of Congo (Etshekape *et al.*, 2018) and Kenya (Mugure *et al.*, 2013; Maluki *et al.*, 2016; Mawuli, 2016).

There are also other studies that link socio-economic proxies such as level of household food security, gender, age, levels of education, income level, occupation etc are the main determinants of agroforestry adoption (Oino and Mugure, 2013; Rotich *et al.*, 2017). In Gutu District, Zimbabwe, the ability or inability to meet the cost of pesticides, seeds and other inputs necessary for adopting agroforestry relied on household income (Chitakira and Torquebiau, 2010). Studies on the combination of the socio-economic factors affecting adoption of agroforestry are still limited.

In order to adopt smallholders' agroforestry enterprise, there is need for support such as the technology requirement, inputs, infrastructure, production facilities, market, credits, training etc (Binam *et al.*, 2017; Lillesø *et al.*, 2018). Specific material inputs required include tree seeds, inoculums, tools and materials for fencing. However, many smallholder farmers rarely get the support needed to successfully adopt the technology (Sanou *et al.*, 2017). In several countries especially those in Africa, provision of agricultural services to rural smallholder farmers still rely on government goodwill (Dumont *et al.*, 2017; Miller *et al.*, 2017a). There is also increasing recognition of institutional support for agroforestry as well as the institutional factors that may have an impact on the adoption of agroforestry among the rural populations (Binam *et al.*, 2017; Benjamin, 2018; Rosenstock *et al.*, 2018; Makate *et al.*, 2019).

The effectiveness of institutional support systems towards adoption of smallholders tree nursery establishment are quantified based on leverage required to achieve food security, and create wealth for the households (Ashiagbor *et al.*, 2018b). For better assessment of the agroforestry adoption, challenges faced by farmers, support systems and impact of tree on individual household farmers should be considered (Alavalapati *et al.*, 2001). Nevertheless, the support system provided in adoption of the tree nursery is not clearly understood in several smallholders farming systems mainly in the developing countries of Africa, including Kenya (Ajayi and Place, 2012; Jerneck and Olsson, 2013; Bernier *et al.*, 2015). Additional, little evidence have been adduced to support the role of public extension services on the adoption of agroforestry.

The potential effects of combination of socio-economic factors together with institutional factors in dictating agroforestry adoption appear to be massive. However, there is less emphasis on how combination of socio-economic and institutional factors affects adoption of agroforestry (Alavalapati *et al.*, 2001; Franzel *et al.*, 2001; Mercer, 2004; Matata *et al.*, 2010; Mwase *et al.*, 2015). This is more consistent in the Sub Saharan Africa where there are numerous constraints to adoption of agroforestry. Therefore, the contribution of both socio-economic factors and institutional factors on adoption of agroforestry need to be understood in the local context to better understand the barriers to adoption of agroforestry.

2.3 Agroforestry Ecosystem Services

There have been worldwide, regional and local attempts to categorize the economic, social, and environmental benefits of agroforestry. These benefits from agroforestry include fuel wood, food, timber, fodder, ornamental and medicinal resources, or indirect benefits comprising services such as carbon sequestration, soil and water regulation and habitat for pollinating insect species and wildlife (Alam *et al.*, 2010). Attainment of these benefits would largely improve food security, rural livelihood and reduce poverty for the millions of small-scale farmers in developing countries (Quandt *et al.*, 2019). Attempts at defining these benefits derived from agroforestry have seen the coinage of the term ecosystem services. These are benefits derived from the ecosystems by humans (Ouyang *et al*., 2016). Because of the accrued benefits, the Millennium Ecosystem Assessment (MEA) advocates that ecosystems should be conserved to allow them to benefit humans (Finlayson, 2018). However, it is the extension of the concept to agroforestry that has attracted much research attention where it delineates the advantages humans derive from agroforestry as an ecosystem (Brown *et al.*, 2018). Ecosystem services in essence are benefits derived from nature as espoused by the United Nations Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (Jonsson *et al.*, 2017; Díaz-Reviriego *et al.*, 2019).

Much advocacy for the maintaining ecosystems was to allow for the increased supply of ecosystem services which can sustain the planet as they directly benefit the people (Kuyah *et al.*, 2017). Much of the anecdotal evidence of ecosystem service benefits occur in the developing countries, due to over-reliance on natural ecosystems without the residence even noticing the true benefits (Chaudhary *et al.*, 2015; Hein *et al.*, 2016; Salzman *et al.*, 2018). The benefit derived from ecosystem in these countries occur due to close proximity to forest ecosystems and dependency on subsistence agriculture (Meijer *et al.*, 2015; Benjamin and Sauer, 2018).

The practice of agroforestry has added another dimension to the literature on ecosystem services. These benefits are largely emphasized by the Millennium Ecosystem Assessment and the International Assessment of Agricultural Science and Technology for Development (Fagerholm *et al.*, 2019). Yet the key challenges in many African countries are the ability to conduct studies that quantify ecosystem services from agroforestry. In most of these countries a comprehensive understanding of the role of agroforestry in enhancing biodiversity, improving soil fertility, reducing erosion, improving hydrological regimes, and sequester atmospheric carbon etc (Newaj *et al.*, 2016; Perks *et al.*, 2018) are not evident. Applying these models to farm levels to help in understanding the role of agroforestry on ecosystem service benefits remains even scantier.

Ecosystem services in agroforestry are crucial to farming and human well-being such as soil conservation, nutrient retention and cultural services (Kay *et al.*, 2018). By evaluating and incorporating such vital information into decision-making, more informed resolutions can be made about natural capital for human well-being and livelihood (Arkema *et al.*, 2015) to guide the management initiatives and policies for various ecosystem service objectives (Guerry *et al.*, 2015; Sangha *et al.*, 2018). The quantification of ecosystem services has also continued to attract renewed attention due to its ability to capture long-term sustainability (Wood *et al.*, 2018).

Quantification methods for ecosystem services exist with large variations in the outcomes based on methods used. Nevertheless, main point of departure involves the ability to accurately estimate the values obtained from the ecosystem service. These rely on market cycles, production efficiency, margin trade-off, and preference methods of estimating opportunity costs (Clinton *et al.*, 2018; Schild *et al.*, 2018). Whist ecosystem services are substitutable based on the available input, the economic value of attribute regardless of the substitution effects are discernable (Bagstad *et al.*, 2018; Harrison *et al.*, 2018). Until now there is a lot of information available on the factors that can affect the price and value outputs (Clinton *et al.*, 2018) but less research has been conducted to establish how these variations affect the provision of ecosystem services in local context.

The historical definition of agroforestry concentrated on its subsistence production role (Somarriba, 1992) but currently seen in light of economic terms stressing the enhancement of the economic return of the system (Kareem *et al.*, 2016; Mercer *et al.*, 2017; Paul *et al.*, 2017; Bruck *et al.*, 2019). Therefore, opting for agroforestry have assisted the farmers through several soil improvements methodologies as well as improving fallows and fodder, which have resulted in increased ecosystem service benefits. Indeed through such initiatives, smallholder agroforestry have helped to alleviate poverty in most rural households (Leimona *et al.*, 2017).

The nature of these ecosystem services and their link with human well-being has increasingly been the subject of increasing research undertakings (Daw *et al.*, 2016; Fedele *et al.*, 2017; Brown *et al.*, 2018), stemming from the recognition that economic and social components must be understood jointly, taking cognizance of the feedbacks and trade-offs between them (Hori and Makino, 2018; Mace *et al.*, 2018; Turkelboom *et al.*, 2018). The underlying assumption is that provisioning of these ecosystem services will automatically translate to improvement in livelihood of the smallholder agroforestry adopters (Quandt *et al.*, 2018). However, in some studies, it has been established that ecosystem services tend to only provide marginal sustenance of livelihood and/or preventing communities or households from poverty, rather than actively contributing to a steadily improvement of the situation for the household (Feintrenie *et al.*, 2019).

It has been widely noted that most empirical studies dealing with reports of ecosystems are valuation studies, demonstrating the intrinsic monetary value of ecosystem services (Mercer *et al.*, 2017; Temesgen *et al.*, 2018; Kay *et al.*, 2019). Valuation and monetary contribution of ecosystem services appear to work well in the developed countries where detailed valuation tools are available but rarely work in the developing countries especially in Africa. There are several reports that indicate that African agroforestry improve energy, food and housing through tree domestication (Ofori *et al.*, 2014; Benjamin *et al.*, 2018; Temesgen *et al.*, 2018). Yet there is little attention which has been paid to understanding whether the local community members comprehend the ecosystem services and the trade-off between ecosystem services and livelihood in smallholder agroforestry.

Large parts of African landscape fall under the arid and semi-arid area characterized by prolonged droughts and scarcity of water and food (Huang *et al.*, 2016). There are several studies that have established that there are more agroforestry adoption in the semi-arid areas (Iiyama *et al.*, 2017; Quandt *et al.*, 2017). In the semi-arid areas of

Kenya, there has been concerted efforts to encourage adoption of agroforestry to help in building livelihood resilience to floods and drought (Maluki *et al.*, 2016; Quandt *et al.*, 2017). However, there has been little attempt at establishing the trade-off between adoption of agroforestry and knowledge of the ecosystem services.

Further, while the multi-dimensionality of livelihood is increasingly recognized, analyses to date remain heavily focused on income and assets, rather than in combination with non-income dimensions of poverty (Benjamin and Sauer, 2018). Few studies have examined relationships at anything less than a macro or aggregate level and mostly ignore whether there is actually any ecosystem benefits to the poor in developing countries.

Inevitably, enquiries remain about linkages between adoption of agroforestry, ecosystem services and dimensions of poverty. Deterministic pathways of these issues is critical to unravel the right and effectual policies to achieve both the sustainable management of ecosystem services and poverty alleviation (Liebenow *et al.*, 2012). Therefore, this study aimed at determining the indigenous knowledge of the ecosystem services from agroforestry and its links to rural livelihood in semi-arid areas in Kenya.

2.4 Agroforestry, Rural Income and Livelihoods

Globally, dryland areas characterized by low moisture content due to low rainfall and high rates of evaporation, and a gradient of low agricultural productivity, comprise of approximately 100 countries and cover 42% of the global surface landmass (6.4 billion ha) (Prăvălie, 2016; Bastin *et al.*, 2017; Prăvălie *et al.*, 2019). Despite the wide coverage, concern have been raised on human conditions in dryland environments in Africa, calling for significant development assistance and frequent humanitarian aid (De Leeuw *et al.*, 2014).

The gravity of the situation in drylands of Africa is clearer since it accounts for nearly 400 million people who live and derive their livelihood in these areas (Aleman *et al.*, 2018; Gaur and Squires, 2018). The situations within the dryland areas have been orchestrated by innumerable challenges such as climate variability, frequent droughts, natural resources degradation, declining agricultural productivity and high population increment (Syano *et al.*, 2016). Therefore, there is a consensus that most of the agro-based activities within these landscapes must be geared towards solving foreseeable challenges (Krishnamurthy *et al.*, 2019). Agroforestry integrates trees on farms and in agricultural landscapes has been under consideration as an integral component of dryland regions (Ceperley *et al.*, 2016).

The multiple perceived benefits and merits of agroforestry for providing ecosystem benefits, economic goods and social services are well known and widely recognized (Franzel, 2004; Jose, 2009; Fanish and Priya, 2013; Gao *et al.*, 2014). In rural households, trees can be used as sources of food, fuel, fodder, construction materials, medicine, to meet subsistence needs (Adekunle and Bakare, 2004; Kumar and Thakur, 2017; Jemal *et al.*, 2018).

Agroforestry has been accredited with providing suits of economic terms stressing the enhancement of the economic return of the system that is important to affect rural livelihoods (Kareem *et al.*, 2016; Mercer *et al.*, 2017; Paul *et al.*, 2017; Bruck *et al.*, 2019). With changes in prices of food, increasing costs of energy and payments made to environmental goods, the economic benefits derived from agroforestry has continued to witness unfathomable interest from the research communities, especially in developing countries (Amejo *et al.*, 2018).

Agroforestry is currently practiced by many smallholder farmers in Africa (Mbow *et al.*, 2014b) and has experienced recent increase in adoption by farmers in many parts of the continent particularly in the Sub Saharan Africa (Franzel *et al.*, 2001; Leakey *et al.*, 2005; Meijer *et al.*, 2015; Beyene *et al.*, 2019). The practice is still common regardless of persistent attempts at introducing monoculture crop production (Djurfeldt *et al.*, 2005; Altieri *et al.*, 2012). The option of integrating and managing trees with crops and livestock on the same landscape is considered as an opportunity cost representing a conscious opportunity cost (Amare *et al.*, 2019).

The suits of goods and services derived from the practice of agroforestry include energy in the form of firewood, building materials in the form of posts and timber, food such as fruits, medicine and seldom valuable environmental services (Wulan *et al.*, 2008; Kimaro *et al.*, 2019). In rural areas, there are other additional non-timber products which can boost annual income of households in the region (Leakey *et al.*, 2005; Kalaba *et al.*, 2010). Consequently, the insight that trees on farms improve the socio-economic prospects and provide livelihoods benefits is increasingly being recognized in the Sub Saharan African Region (Kalaba *et al.*, 2010; Quandt *et al.*, 2018).

Profitability of the various agroforestry practices has been analysed by various workers and the results show large degree of variation among research as to the overall socio-economic and livelihoods impacts (Kang and Akinnifesi, 2000; Roshetko *et al.*, 2007; Steffan-Dewenter *et al.*, 2007; Akinnifesi *et al.*, 2008). Nevertheless, in several drylands of Sub Saharan Africa, studies addressing contribution of agroforestry to socio-economic status and rural livelihood are limited (Jama *et al.*, 2006; Iiyama *et al.*, 2014) and thus may be inconclusive. Therefore, more studies on agroforestry adoption and socio-economic conditions are needed.

Trees planted by smallholders farmers form an opportunity cost for other alternatives (Kubo *et al.*, 2018). Therefore the aim of smallholders' tree nursery establishments or the desire of every commercial smallholder's tree farmer is to maximize production and eventually the tree yields that are reflected in improved profits (Thomas *et al.*, 2018). In smallholders tree nursery establishments, there are fixed costs associated with purchase of land, nursery construction, heavy equipment and machinery as well as land rates (Kareem *et al.*, 2016).

Also there are variable costs such as the cost of fertilizers, seedlings, labour, transport, purchase of fertilizers and pesticides among other operating overheads like electricity, which must be factored in during economic analysis (Araújo *et al.*, 2019). Fertilizers, pesticides and seedlings or quality seeds are usually the highest variable cost averaging around 20% to 40% of total costs (de Jalón *et al.*, 2018; Blanc *et al.*, 2019). This implies that profitability of intensive smallholders' tree nursery establishments is closely related to cost of these inputs.

The second highest variable cost is seed or seedling costs which range from 10% to 15% of variable cost. The overall fixed and operating costs are supposed to be met by revenue obtained from trees. Therefore, any aspect of tree management that is likely to affect tree yield is worthy of understanding. In most of the places where smallholders tree nursery establishments is practiced, land costs, water, manpower and other facilities are always limiting and may limit the overall level of investments in tree nursery establishments programme. The desire to continue with the venture will be determined by the amounts of profits earned from the enterprise (Keat *et al.*, 2018). Therefore, economic feasibility of smallholders' tree growing must be known to ensure that farmers do not incur losses during operations.

Profitability of a business enterprise is often evaluated using gross profits, net profits (margins) or in some instances a cost-benefit analysis (Chiladze, 2018). In both tools, the variation in profits beyond the operating and fixed cost is evaluated and breaks even known so that prices for selling the tree are set above the break-even levels. Several studies have used this method to evaluate the profitability of smallholder's tree nursery establishments with relatively large success (Kassa, 2015; Kareem *et al.*, 2016; Shode and Amanuel, 2016; Blanc *et al.*, 2019). Nevertheless, such evaluations remain limited in Kenya among smallholder farmers.

From a simplistic view, higher tree seedlings may enhance yield and more profit from the business (Jerneck and Olsson, 2013). However, in realistic terms, the relationship between tree seedling and yields may not be that simplistic or linear, such that at very high tree seedling numbers, some tree will be starved of nutrients and some will not reproduce. However, a number of studies have indicated that seedling density may actually affect total tree yield and lead to higher gross and net return at a lower cost of production (Garcia de Jalon *et al.*, 2017; Dalemans *et al.*, 2019). A high yield of up to 9,800 kg/ha/year in growing system has been reported for *Eucalyptus grandis* at higher tree seedling density (Dhiman and Gandhi, 2017).

In Kenya, the yield was 1,136 kg/ha/year at low density and 18,795 kg/ha/year at high density (Eshetu *et al.*, 2018; Chemuliti *et al.*, 2019). Overpopulation of seedlings in confined nursery is a major problem which causes stunted growth due to shortage of space and nutrients at high density (Kluthe and Chen, 2017). The total production of seedlings ranged from 33.7 to 83.0 kg hactare^{-1} with an individual weight of 11 to 137 kg, where the seedlings production was 62.8 to 80.0 kg hactare^{-1} with a mean individual of 0.367 to 0.408 kg. However, (Eshetu *et al.*, 2018) did not obtain any better economic benefits from experiments involving variation in tree seedling density on trees.

From the foregoing discussion on the relationships between tree seedlings and tree yields and profitability it is clear that the relationship is never simplistic and when designing tree nursery establishments, and most likely to be adopted by the farmers it is often necessary to establish the correct tree seedlings parameters that will maximize profit from the farmers. Therefore, this study would most likely add to knowledge on the economic benefits of tree nursery establishments.

Agroforestry practices often result in the production of various goods and services which often result in the overall improvement of the livelihoods in several countries where adoption has been done (Tiwari *et al.*, 2017b; Hanif *et al.*, 2018; Quandt *et al.*, 2019). Contribution of agroforestry to rural livelihoods is well understood in Asian countries such as Bangladesh (Chakraborty *et al.*, 2015; Shams *et al.*, 2015; Hanif *et al.*, 2018), China (Djanibekov *et al.*, 2016), Mongolia (Tsvegemed *et al.*, 2018), Pakistan (Farooq *et al.*, 2018), India (Handa et al., 2016) among other areas.

In the African continent, massive benefits from agroforestry have been established in Ethiopia (Jemal *et al.*, 2018; Amare *et al.*, 2019) and Nigeria (Akpabio and Ibok, 2009; Usman and Nichol, 2019). However, an understanding of the contribution of agroforestry to rural livelihoods in Kenya still lags, which requires further research in this realm.

2.5 Influence of Agroforestry on Soil Quality

Agroforestry helps in arresting land degradation, enhance long-term soil productivity, quality and sustainability (Cardinael *et al.*, 2015; Weerasekara *et al.*, 2016; Udawatta *et al.*, 2017; Dollinger and Jose, 2018). This has seen large body of information on the influence of agroforestry on many aspects of soil. Although proponents of agroforestry contend that soil management is the primary role (García de Jalón *et al.*, 2017; Sarminah *et al.*, 2018), there are continued debate about soil quality that are improved. A consensus is that agroforestry may improve the soil chemical, physical and biological properties resulting in numerous investigations in the last decade. Thus, an understanding of the dynamics of the impacts of agroforestry on soil requires an understanding of the soil quality parameters.

Most of the soil's capacity in performing biological functions can be adduced by evaluating the physical, chemical and biological components (Bünemann *et al.*, 2018).

Trees in agroforestry improve soil quality by fixing atmospheric Nitrogen (N_2) which ultimately increase soil Nitrogen (N) content (Nasielski *et al.*, 2015; Bayala *et al.*, 2018). Through root system accumulation and litter fall, agroforestry trees help concentration of several nutrients from the soil (Solanki and Arora, 2015; Bhatt *et al.*, 2017). Trees furthermore augment above and belowground microclimate within the soil (Desta *et al.*, 2018; Kar *et al.*, 2019), while meso-fauna, micro-fauna and micro-flora surrounding the plant roots may alter soil chemical, biological, and physical properties (Bhaduri *et al.*, 2017; Lenci *et al.*, 2018).

The main benefits of agroforestry often are how it impacts the physical properties of soil. Physical function of agroforestry involves the cover function where agroforestry trees reduce the rainfall and wind action on soil aggregates (Muoni *et al.*, 2019). On this account, there are numerous studies that have proved that agroforestry improve soils physical properties (Udawatta *et al.*, 2017; da Cunha Salim *et al.*, 2018; Corbeels *et al.*, 2019).

There are a number of benefits that are directly related to soil quality including preventing soil erosion through litter cover and understory flora (Akdemir *et al.*, 2016; Béliveau *et al.*, 2017), improving water infiltration (Sahin *et al.*, 2016), increasing soil moisture content (Cardinael *et al.*, 2017; Feliciano *et al.*, 2018), maintaining soil fertility (Liu *et al.*, 2018), enhancing water dynamics (Ling *et al.*, 2017; Hasselquist *et al.*, 2018), conserving soil biodiversity (Torralba *et al.*, 2016), improving soil microbial biomass (Buyer *et al.*, 2017) and mitigate climate change through the mechanisms of carbon sequestration (Newaj *et al.*, 2016; Hasselquist *et al.*, 2018).

The presence of trees with ability to biologically fix nitrogen is common in tropical agroforestry. Subsequently, the most widely held view is that trees in agroforestry can improve soil quality mainly by biological nitrogen (N) fixation and increasing the amounts of aboveground and belowground organic matter inputs (Isaac and Borden, 2019; Sarabia *et al.*, 2020). Non N-fixing trees improve the soils complex properties by adding the organic matter and recycle nutrients in agroforestry.

Trees in agroforestry improve soil quality by fixing atmospheric N_2 which ultimately increase soil Nitrogen (N) content (Nasielski *et al.*, 2015; Bayala *et al.*, 2018). Through root system accumulation and litter fall, agroforestry trees concentrates nutrients near the soil surface (Solanki and Arora, 2015; Bhatt *et al.*, 2017). In the tropical regions, agroforestry may effectively improve soil physical, chemical and biological properties (Sistla *et al.*, 2016; Atapattu *et al.*, 2017a; Sun *et al.*, 2017; Mulyono *et al.*, 2019).

Exchangeable bases include potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) in the soil (Islam and Weil, 2000; Celik, 2005; Lang *et al.*, 2016; Atapattu *et al.*, 2017b; Mulyono *et al.*, 2019). During adoption of agroforestry these exchangeable bases are compared to the non-adopters to determine how agroforestry affect the soil exchangeable bases. There is also a need to determine how length of agroforestry adoption affects exchangeable bases, which lacks in several studies. Agroforestry affect the decomposition of organic matter which may affect the exchangeable bases (Behera and Shukla, 2015; Ngo-Mbogba *et al.*, 2015; Sharma *et al.*, 2016b; Prakash *et al.*, 2018; Mulyono *et al.*, 2019). The possible application of organic residues during agriculture should be considered as one of the main factors affecting exchangeable bases. Therefore, it seems these exchangeable bases may be considered limiting nutrient for plant growth in the region and thus should be studied relative to agroforestry practices.

The micronutrients including manganese (Mn), copper (Cu), iron (Fe) and zinc (Zn) which are rarely studied relative to adoption of agroforestry and age of agroforestry practice (Bhatt *et al.*, 2016; da Cunha Salim *et al.*, 2018; de Freitas *et al.*, 2018; Mulyono *et al.*, 2019). Manganese has its origin from crustal sources, including direct atmospheric deposition, wash-off from plant and other surfaces, leaching from plant tissues, or excretion of material such as leaves, dead plant and animal material (Parjono *et al.*, 2019). Copper present as an impurity in silicate minerals or carbonates (Gautam *et al.*, 2017). In some soils, organic matter and soil pH influence copper availability where an increase in organic matter positively influence the binding of copper from the free state and liberate the copper when it decomposes (Mounissamy *et al.*, 2017).

Most iron in soil exist as silicate minerals or iron oxides and hydroxides, forms that are not readily available for plant use (Pandey *et al.*, 2000; De Souza *et al.*, 2012). Most of the iron are derived from organic matter and organic matter pool in the soils (Yadav *et al.*, 2011). Iron can also have been increased by spraying the soils with supplemental iron containing fertilizers. Zinc can be increased in the soil by application of fertilizers containing zinc, of which the most common are zinc chelates, zinc sulphate and zinc oxide which are common in most fertilizers formulation (Meena *et al.*, 2019).

In the Sub Saharan Africa, there is a large body of literature which has described the effects of agroforestry on soils and all have highlighted that agroforestry practices could effectively improve soil properties and maintain long-term land productivity (Githae *et al.*, 2011; Lagerlöf *et al.*, 2014; Bayala *et al.*, 2018; Corbeels *et al.*, 2019). The effect of agroforestry on soil quality has shown some contrast, where the practices caused either increase (Lambert and Ozioma, 2012; Sistla *et al.*, 2016), decrease (Bayala et al., 2018) in soil quality variables, or had limited effects (Ashiagbor *et al.*, 2018a). One consensus from these studies is that the effects of agroforestry on the soil may be affected by the age of adoption. However, there are few empirical studies that determined the stand age on soil nutrient dynamics under the influence of agroforestry.

2.6 Summary of Research Gaps

The foregoing section has reviewed literature related to agroforestry adoption, ecosystem services, rural income and livelihoods due to agroforestry and how agroforestry influence soil quality. In the study of adoption of agroforestry it is clear that there is increasing adoption of agroforestry in African countries including Kenya but remain challenges in the advancement of the adoption of the agroforestry which has been linked with weak socio-economic and institutional factors. But there are few studies that have analyzed the challenges of agroforestry adoption with regard to combined socio-economic and institutional factors. Concerning the ecosystem services, it is clear that many agroforestry provide suites of ecosystem goods and services which the adopters should be benefiting from, yet there are few studies that have looked at benefits from the adopters’ perspective.

It is also clear from several studies that agroforestry provide goods that can be directly sold by the locals to help in improving their life status, yet studies on the contribution of agroforestry to income and rural livelihoods has received very little attention. Finally it is clear from numerous studies that agroforestry influence many aspects of soil attribute. However, in Kenya, such studies are limited and beside it are not clear how length of adoption of agroforestry drives the soil quality among the adopters.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

3.1.1 Background, Location and Size

The study was conducted in Machakos County (Figure 3.1). Machakos County is the sixteenth county of Kenya in the Kenya Constitution of 2010 (Schedule 5). The county's capital is called Machakos (formerly known as Masaku) located approximately 63 km from Kenyan Capital Nairobi. Machakos County covers an area of 5,953 km². It lies between latitudes 0º45´South and 1º31´South and longitudes 36º45´East and 37º45´East. The Western part of the County is bordered by Nairobi and Kiambu while to the North is Embu County and Kitui to the East, Makueni to the South, Kajiado to the South West, and finally Murang'a and Kirinyaga Counties border to the North West.

Machakos County covers an area of 5,953 km² with most of it being semi-arid and population of 1,098,584 as per the 2009 national census (Kenya National Bureau of Statistics, 2010b). Administratively the County is divided into 11 divisions: Kalama, Kangundo, Kathiani, Machakos Central, Masinga, Matungulu, Mavoko, Mwala, Ndithini, Yathui and Yatta. In terms of political structure, the county has eight constituencies including: Kangundo, Kathiani, Machakos Town, Masinga, Matungulu, Mavoko, Mwala and Yatta.

Among the Sub-Counties and Constituencies, Kathiani, Mavoko, Matungulu, Kangundo. Mwala and Machakos Town practice agroforestry. Four hilltop sites where agroforestry are highly practiced and included: Mua hills (Mavoko, Machakos Town, Kangundo, Matungulu and Kathiani) and Iveti hills (Machakos Central, Mwala, Kangundo and Kathiani), Kima-Kimwe hill and Kalama hills in Machakos Constituency.

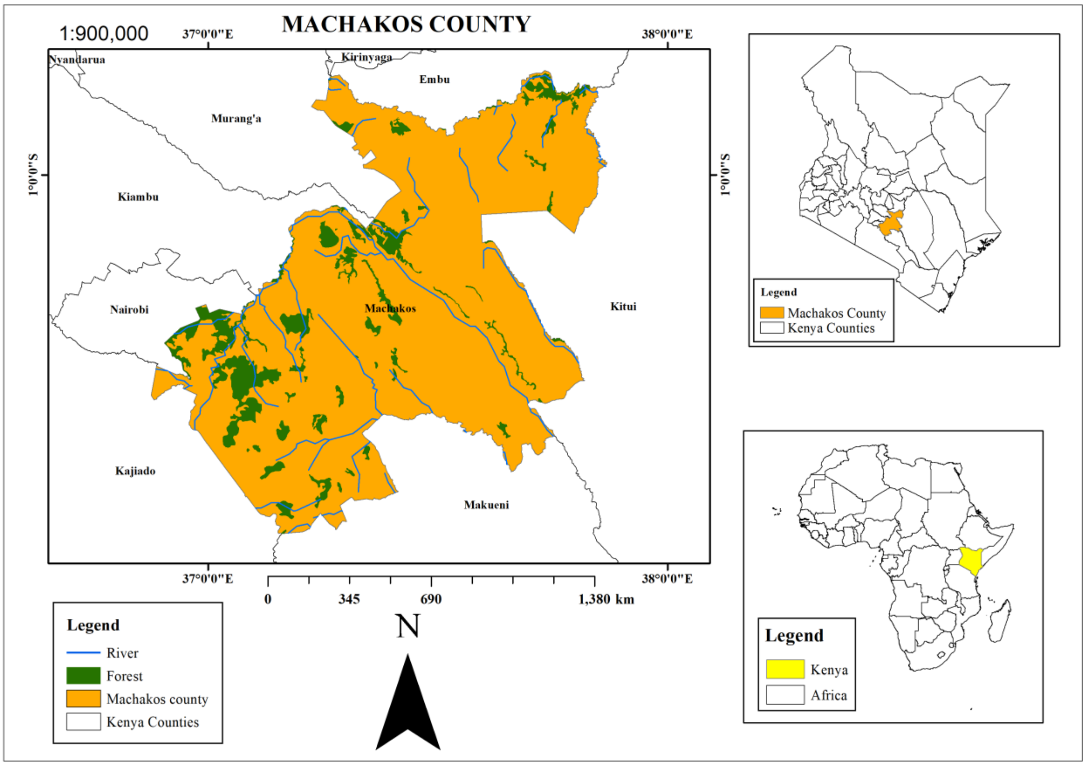

Figure 3.1: Map of Kenya showing the location of Machakos County, Study Area

Data source: Department of Resource Surveys and Remote Sensing, 2018

3.1.2 Climate and Hydrology

The local climate is semi-arid with an altitude of 1,000 to 2,100 metres above sea level. The area is composed of hilltops rising to 1,594 – 2,100m above sea level. Bimodal rainfall is experienced, with short rains October to December and long rains in March to May. The annual average rainfall is 1,000 mm, ranging between 500 mm and 1,300 mm. The rainfall is unevenly distributed and unreliable. Temperatures range between 18.7°C and 29.7°C during the hot months of September and February (Kenya Institute of Public Policy Research, 2009).

3.1.3 Soils

The soils are well drained shallow dark red volcanic on hilltops in the high altitudes areas but clay soils dominate the low altitude areas (Tiffen *et al.*, 1994). The soils are used for agricultural activities and exhibit low water holding capacity and low amount of humus hence low in Nitrogen (N) and phosphorus (P). Irrigation farming is practiced in tributaries of Athi River and other smaller sized streams that flow from the hilltop catchment areas towards South Eastern region. Boreholes are drilled in order to provide access to water during the dry season (Kenya Institute of Public Policy Research, 2009).

3.1.4 Economic Activities

Economic activities are agricultural crop production maize, beans, pigeon peas, vegetables, livestock keeping, dairy and beef cattle, sheep, goat and tree growing *Eucalyptus*, Cypress, Pines and *Grevillea*. These activities are very important as they help to enhance food security and provide income to the farmers.

3.2 Research Design

This was a mixed methods research which involves collecting, analysing, and interpreting quantitative and qualitative data in a single study or in a series of studies that investigate the same underlying phenomenon (Bentahar and Cameron, 2015). The current study utilized concurrent transformative design where both the qualitative and quantitative data were collected at the same time. In this research design qualitative and quantitative data was collected and analysed simultaneously allowing for perspectives from each to be explored. Surveys are normally used to systematically gather factual quantifiable information necessary for decision-making.

Surveys designs enable efficiency in the collection of descriptive data characterizing populations (Nardi, 2018). Costs can also be immensely reduced through the use of this design. This study used survey study research design in order to capture descriptive data from the samples and generalize the findings to the populations.

3.3 Target Population

The study targeted members from households from Mua Hills (Mavoko, Machakos Town, Kangundo, Matungulu and Kathiani), Iveti Hills (Machakos Central, Mwala, Kangundo and Kathiani), Kima-Kimwe and Kalama Hills in Machakos County. The actual population of farmers practising agroforestry in the region was estimated to be 80% of the household in a previous study (Nzilu, 2015). The current study adopts 80% as the proportion of the households that practice agroforestry.

3.4 Sampling Design

Since the actual population was not easy to determine due to changes in the rate of adoption with respect to time, the determination of sample size followed earlier protocols based on proportion of the households adopting agroforestry (Nzilu, 2015). According to Nzilu, 80% of the households had adopted agroforestry in Machakos County. The appropriate sample size was therefore computed using the cited formula (Mugenda and Mugenda, 2003): $n = \frac{z^2 p(1-p)}{d^2}$

Where: n = the desired sample size

z = the z score at the required confidence level α = 0.05 (1.96)

p = the proportion in the target population assumed to be adopters (0.8 based on (Nzilu, 2015)

d = permissible marginal error (the level of statistical significance, set at α = 0.05).

Using the values of *z, p* and *d*, the value of *n* was computed as follows

$$n = \frac{1.96^2 \times 0.8(1-0.8)}{0.05^2} = \approx 246$$

The sample size was 246 in addition to information obtain from two additional households who were experienced and had long period of agroforestry practice in the region giving a total of 248 respondents.

The respondents were selected through stratified, random sampling at each of the selected spatial units and used to identify the adopters and non-adopters. Adopters were households practising any form of agroforestry.

Table 3.1: Population and sample size in various sub-counties during the study

Sub-County	Population	Sample
Kangundo	96,255	27
Kathiani	98,836	28
Machakos Town	197,779	56
Matungulu	119,900	34
Mavoko	212,724	61
Mwala	146,291	42
Total	**871,785**	**248**

Source of the population: (Kenya National Bureau of Statistics, 2010b)

3.5 Research Instruments

Data gathered during the study was primary data. Data on socio-economic and institutional factors affecting adoption of agroforestry, ecosystem services of agroforestry adoption, income levels of agroforestry and livelihood derived from agroforestry were collected using structured questionnaires (Appendix 1). The designing of the instruments were such that they endeavoured to ensure an in-depth exploration of personal views, feelings and opinions on agroforestry and benefits accrued.

3.6 Field Survey of Agroforestry Practices

Field surveys of agroforestry adoption were conducted for three months from March to May 2017 among the selected group of respondents. Identification of agroforestry adopters was conducted by field observation of the households practicing any form of agroforestry.

3.7 Validity and Reliability of the Instruments

The researcher developed the research instruments based on the research objectives, hypotheses and the related literature. The salience of the instruments was sought by having the supervisors and other experts from the Department of Environmental Science and Education of Kenyatta University review the items. This was to purposely ascertain the item’s construct and content validity. The experts examined the face, content and construct validities in order to determine whether items measured what they were supposed to determine. They established whether the numbers of items are adequate for the purpose of the intended research and thus their expert judgements ensured validity of the instruments.

The reliability of instruments was established through a pilot study among 12 household members who did not participate in this study. The reliability of the current instrument was evaluated using Cronbach’s coefficient alpha. The study considered the instrument reliable and acceptable when the computed reliability coefficient was

0.7 and above (Taber, 2018). For this study, the coefficient was 0.85 which was determined to be suitable for the research.

3.8 Data Collection Procedure

Before data collection, the respondents were contacted two weeks in advance and asked to organize their time for the research. Two research assistants were trained to aid in the collection of data. The questionnaires were self-administered by the researcher and research assistants (Plate 4.1). The entire interview with the respondents took one hour. The researcher made prior visits to the households to help in defining timings and distribution of research instruments.

Plate 4.1: Interview schedule between the researcher and research assistance with a section of the respondents

3.9 Soil Sampling and Analysis

Soils were sampled from the farmlands of the adopters and non-adopters using soil augers (Plate 4.2). To ensure clean samples were taken a small sampling hoe, a knife and a shovel were used to clear the sampling spots before using the soil auger. At least five sub-samples to enhance consistency were collected from the farmers at top 15 cm depth and the soils mixed to get an integrated soil sample for analysis.

Plate 4.2: Soil sampling exercise during the study

The soil were packaged in two kg khaki paper bags and transported to Kenyatta University and for control analysis at Kenya Agricultural and Livestock Research Organization (KALRO) laboratories at Machakos and National Agricultural Research Laboratories (NARL) Nairobi Kabete laboratories. All soil analysis were conducted by the researcher at the Kenyatta University laboratory (Plate 4.3).

Plate 4.3: Pictures showing a section of the laboratory setup for soil analysis at the Kenyatta University laboratory.

3.9.1 Bulk Density

Triplicate soil samples from each plot was obtained using coring devices (50 mm diameter × 50 mm height coring tubes and 42.2 mm diameter PVC tubes to preserve the moisture) and analyzed for bulk density. A mallet was used to carefully drive the coring auger into the soil to avoid compaction. To determine bulk density, the soil was weighed and then dried in an oven at 105°C for 2 hours and allowed to cool then weighed again. Bulk density was calculated from the oven-dried soil core weight and volume. The bulk density was calculated as:

$$\text{Bulk density} = \frac{\text{Weight of soil(g)}}{\text{Volume of dry soil(cm}^3\text{)}}$$

3.9.2 Determination of Sand, Clay and Silt

An estimated 10% Calgon (Sodium hexametaphosphate) solution was prepared by dissolving 100 grams in a litre of distilled water. This solution creates dispersion in the soil particles into sand, clay and silt. A Bouyoucos Hydrometer was used to measure the dispersion. A total of 50 grams of the air dried soil samples were taken and put in a glass containers and 10 ml of Calgon solution added. The solution was topped up to 350 ml with distilled water and shaken using a reciprocating shaker for two hours. After shaking, the solution was transferred into a graduated cylinder and made up to 1000 ml. The hydrometer was then inserted and a reading taken after 40 seconds alongside a temperature reading, and both recorded. A second reading of each was taken after letting the solution stand for two hours to settle.

3.9.3 Soil pH

The pH of the soil samples was measured using a standard bench Hanna pH meter. The soil samples were air dried and crushed, then sieved using a 2 mm sieve. The pH was measured in a 2.5:1 ratio of water to soil. A total of 50 ml of distilled water was added to 20 grams of the soil sample. The mixture was shaken using a reciprocal shaker for approximately 30 minutes for consistency followed another 30 minutes of settling before taking the readings. The reading was then taken by inserting the calibrated pH meter’s probe into the solution.

3.9.4 Phosphorous

Phosphorus (P) was determined using ascorbic method. In the method, a total of 5 ml of the supernatant extracted with the double acid was mixed with 20 ml of distilled water and 10 ml of ascorbic acid reducing agent. The mixture was left to settle and stand for an hour. A blue colour developed and absorbance was read at 880 nm on an Ultra Violet Visible Spectrometer (UVVS) UV/Visible spectrophotometer. A standard series of known concentration was prepared with the samples and from the resulting standard curve, concentrations of P in the samples was calculated (Estela and Cerdà, 2005).

3.9.5 Analysis of Sodium, Potassium and Calcium

After extraction with the double acid solution 2 ml of the supernatant was taken and added to 14 ml of distilled water. 1 ml of 2% Lanthanum Chloride solution was added. A standard series for each element was prepared and a blank included for each. The standards and samples were then aspirated on a flame photometer using the filter for each element consecutively (Peitzman, 2010).

3.9.6 Analysis of Manganese, Magnesium, Copper, Iron, Zinc

The cations were read on the Atomic Absorption Spectrophotometer (AAS) after extraction. Standard series were prepared separately for each element. A blank was included for the elements at the point of extraction and given the same treatment as the standards and the samples. The AAS used was the Thermo Scientific Model Type: iCE 3300AA, Serial No. C113300039. A standard curve was generated by the computer from the standard series and concentration of the samples calculated using the formula given.

3.9.7 Total Nitrogen

Total Nitrogen was determined following sodium salicylate methods (Association, 2005). For total nitrogen extraction, 0.2 grams of the sample were digested with 10 ml sulphuric acid-selenium powder mixture on a block digester at a maximum temperature of 330^{o}C for a maximum of 4 hours. The supernatant was then treated with 5 ml of a mixed reagent N1 (34 grams sodium salicylate, 25 grams sodium citrate and 25 grams sodium tartrate and 0.12 grams sodium nitroprusside in a litre of distilled water), and 5 ml of reagent N_2 (30 grams sodium hydroxide and 10 ml sodium hypochlorite mixed well in one litre of distilled water). The mixture was allowed to stand and settle for two hours for colour development and read at 650 nm on a UV spectrophotometer (Pasekova *et al.*, 2001).

3.9.8 Total Organic Carbon

Total organic carbon was determined using the calorimetric method (Schumacher, 2002). Samples and standards were treated using potassium dichromate-sulphuric acid mixture and barium chloride as an indicator. One gram of soil sample screened with a 0.15 mm sieve was taken and mixed in a digestion tube with 10 ml of 5% potassium dichromate and 5 ml of concentrated sulphuric acid. The mixture was hydrated with 2 ml of distilled water and heated at a maximum of 155°C on a block digester for 30 minutes. After cooling, the supernatant was treated with 50 ml of 0.4% barium chloride and shaken, it was then allowed to stand overnight and absorbance read at 600 nm on the UV spectrophotometer (Association, 2005).

3.10 Statistical Analyses

Differences in socio-economic and institutional factors between the adopters and non-adopters were done using chi-square analysis. To test influence of individual socio-economic and institutional factors on adoption of agroforestry, chi-square was computed. Combined effects of the socio-economic and institutional factors on adoption were done using binary logistic regression model (Horowitz and Savin, 2001). Significance of the variables in the binary logistic regression was tested using Wald statistics. Comparison of ecosystem service was done using percentage Likert scores (Wu, 2007). Difference in household, income and expenditure among the members was computed using Analysis of Variance (ANOVA). Differences in rural livelihoods due to agroforestry adoption were evaluated using Enterprise budget. Soil physical and chemical parameters were analyzed using ANOVA and Bivariate regression (Currie and Korabinski, 1984), significantly different means were compared using post-hoc, Duncans Multiple Range Test. All analyses were declared significant at $P < 0.05$.

3.11 Logistic and Ethical Considerations

The go-ahead to conduct the study was sought and granted from the Graduate School, School of Environmental Studies of Kenyatta University and National Commission for Science, Technology and Innovation (NACOSTI). This study adhered strictly to the ethical standards required in human research vis-a-vis as stipulated (Bell *et al.*, 2018): anonymity, confidentiality, voluntary and informed consent. Anonymity was ensured by not collecting identifying information of individual subjects (name, address, Email address). Confidentiality was ensured by not divulging the identity of the respondents or their organizations. Informed consent to participate in the study was obtained from the study participants. These measures were expected to enhance the willingness and objectivity of the respondents.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results, analysis and discussion of influence of agroforestry adoption on ecosystem services and livelihoods for smallholder farmers in Machakos County in Kenya. Section 4.2 provides information the influence of socio-economic and institutional factors on the adoption of agroforestry in Machakos County. Section 4.3 then presents the results and discusses the influence of agroforestry adoption on ecosystem services from smallholder farmers. Section 4.4 presents information concerning influence of adoption of agroforestry on socio-economic, rural income and livelihoods of smallholder farmers in Machakos County. Section 4.5 determined influences of adoption of agroforestry on physico-chemical soil quality parameters.

4.2 Influence of Socio-economic and Institutional Factors on the Adoption of Agroforestry in Machakos County

In this study the influence of socio-economic and institutional factors on the adoption of agroforestry practices was examined. The independent (X_i) variables of the logistic regression model describing agroforestry adoption, (X) in this research refer to observation, (X_i) is the first observation and are defined in Table 4.1. The summary statistics of the independent variables (X_i) in the logistic regression are presented in Table 4.2.

Table 4.1: Description of explanatory variables used in the agroforestry binary logistic model of adoption model

Variable	Description
Age (X_1)	Age in years
Gender (X_2)	Gender is 1 if the respondent is male, 0 otherwise
Marital status (X_3)	Status is 1 if the respondent is married, 0 otherwise
Level of education (X_4)	Level is 1 = None; 2 = Primary; 3 = Secondary; 4 = Tertiary
Household size (X_5)	Number of people in the household
Land size (X_6)	Land size in acres
Location (X_7)	Household residential areas: Index for location 1= Mua Hills; 2 = Iveti Hills; 3 = Kiima Kimwe Hills; 4 = Kalama Hills
Occupation of the household head (X_8)	Occupation is 1 if the respondent is a farmer, 0 otherwise
Farm household income (X_9)	Amount of income earned by the respondents from the farms (Ksh)
Non-farm household income (X_{10})	Amount of income earned by the respondents not from the farms (Ksh)
Access to extension services (X_{11})	Access is 1 if the respondent had access to information, 0 otherwise
Access to credits (X_{12})	Access is 1 if the respondent had access to credits, 0 otherwise
Access to formal Agroforestry training (X_{13})	Access is 1 if the respondent had access to agroforestry training, 0 otherwise
Access to information from conservation groups (X_{14})	Access is 1 if the respondent had access to information from conservation groups, 0 otherwise
Access to inputs from conservation groups (X_{15})	Access is 1 if the respondent had inputs from conservation groups, 0 otherwise
Frequency of extension visits (X_{16})	Index for extension visits: Value 1 = None; 2 = Rarely; 3 = Yearly; 4 = Monthly; 5 = Often

Table 4.2: Characteristics of agroforestry adopter and non-adopter used in the logistic regression model. Values represent means ± SD

Variables	**Agroforestry adopters (n = 204)**	**Non adopters (n = 44)**
Age (years)	51.2 ± 12.4	49.2 ± 11.4
Gender	0.42 ± 0.12	0.94 ± 0.23
Marital status	0.95 ± 0.22	0.88 ± 0.33
Level of education	8.74 ± 3.01	8.57 ± 3.92
Household size	6.97 ± 2.64	6.15 ± 2.49
Land size	2.70 ± 1.93	2.35 ± 1.67
Occupation of the household head	0.91 ± 0.28	0.88 ± 0.33
Farm household income (US$ pm)	290 ± 0.22	228 ± 16
Non-farm household income (US$ pm)	350 ± 36.0	96 ± 18
Access to extension services	0.43 ± 0.12	0.16 + 0.02
Access to credits services	0.67 ± 0.24	0.03 ± 0.02
Access to formal AF training	0.35 ± 0.07	0.12 ± 0.02
Access to information from conservation groups	0.62 ± 0.12	0.03 ± 0.01
Access to inputs from conservation groups	0.15 ± 0.04	0.04 ± 0.02
Frequency of extension visits	1.69 ± 1.14	1.25 ± 0.21

Table 4.3: Respondents' socio-economic characteristics

Variable	Response category	Agroforestry adopters (%)	Non adopters (%)
Age (years)	18-25	5.4	6.9
	26-35	13.7	18.2
	36-55	41.2	31.8
	> 55	39.1	36.4
Gender	Female	56.9	59.1
	Male	43.1	40.9
Marital status	Single	5.9	2.3
	Married	94.1	97.7
Level of education	None	2.5	15.9
	Primary	54.9	40.9
	Secondary	35.8	31.8
	Tertiary	6.8	11.4
Household size	< 3	1.5	0.0
	3-5	36.8	61.4
	6-10	51.5	38.6
	>10	10.3	0.0
Land size	< 2 acres	35.3	31.8
	2-5 acres	52.0	59.1
	5.1-10 acres	12.7	9.1
Farm household income (pm)	< 50	8.8	6.9
	500-100	26.0	31.8
	101-200	21.1	31.8
	201-500	27.9	25.0
	> 500	16.2	4.5
Non-farm household income (US$ pm)	< 50	33.3	38.6
	500-100	22.5	22.7
	101-200	14.2	15.9
	201-500	14.7	22.8
	> 500	15.2	0.0

The age distribution of the agroforestry adopters showed significant variations (χ^2 = 81.537, df = 3, p = 0.0000) where 40% were aged 36-55 years, and 39% aged over 55 years while respondents aged 26-35 years were 14% and those aged 18-25 years were 5.4% (Table 4.3). Similarly, the age distribution of the non-adopters was also significantly different (χ^2 = 12.517, df = 3, p = 0.0011), where majority of the respondents were aged above 55 years, followed by those aged 36-55 years and the least age group was 18-25 years. There was however, no significant differences in the age structure between adopter and non-adopters ($\chi^2 = 4.989$, df = 3, p = 0.173). The present results suggest that about 80% of the adopters of agroforestry practices were aged 36 year or above suggesting that adoption practices of agroforestry occurred among the older people. This concurs with other studies in Turbo, Uasin Gishu (Mukungei *et al.*, 2013), Machakos (Nzilu, 2015). This is attributed to possession of land for agroforestry and financial resources to purchase inputs among the elderly smallholder farmers as reported in other similar studies elsewhere (Sood and Mitchell, 2009; Oino and Mugure, 2013).

Gender disparity occurred among the adopters ($\chi^2 = 3.8413$, df = 1, p = 0.0487) and non-adopters ($\chi^2 = 3.8123$, df = 1, p = 0.0499) but no differences were observed between the adopters and non-adopter ($\chi^2 = 0.073$, df = 1, p = 0.786) (Table 4.3). In the study, 37.7% of the respondents were male, while 62.3% were female, indicating that there more females among the adopters as well as the non-adopters during the study. These results although unexpected since men are the head of the households, could be attributed to two explanations: population structure and societal norms. According to the Kenya National Bureau of Statistics, the ratio of males: females was 98:100 in Kenya based on the results of the census of 2009 published in 2010 (Kenya National Bureau of Statistics, 2010a). Furthermore, there have also been other statistics which indicate that male: female ratio of 25-55 years was 95:100 and at later ages beyond 55 years the male: female ratio stood at 79:100 (World Atlas Data Kenya, 2015). The current male: female ratios are also similar to those obtained for the Sub-Counties from the 2009 Kenya National Population census. Secondly, the societal norms have changed such that it is not hard to find female being the leaders in farms, which indicates that woman in Machakos have started taking over management in the farms. The societal norms can also reflect a scenario where majority of men spend their time far away from the farms either on employment, doing business or looking for opportunities for income generation to support their families (Nyanga *et al.*, 2016). During the study it was also observed that most of the males migrated to town areas to look for formal employment leaving behind most women to tend the farms and the large disparity between the males and females in adoption appear to originate from absence of males in villages and in farms. Whatever the case, the findings cannot tell whether women have some control over agroforestry trees existing on their farms. In the region, there is also high proportion of women (>60%) in conservation groups, which allow them to get some source of funds through microfinance institutions, which push more women to adopt the agroforestry practices.

The study also revealed there was significant differences in marital status among the adopters (χ^2 = 14.5563, df = 1, p = 0.0000) and non-adopters (χ^2 = 23.5627, df = 1, p = 0.0000) but no significant differences was observed in marital status between the adopters and non-adopter (χ^2 = 0.9492, df = 1, p = 0.3331) (Table 4.3). During the study, 95% of the people were reported to be married in the current study, which is similar to other studies done elsewhere on adoption of agroforestry (Johnson and Delgado, 2005; Kabwe *et al.*, 2009; Meijer *et al.*, 2015; Akoto *et al.*, 2018). The high number of married respondents is attributed to majority being of age groups over 35 years. At this age group most people are already in their homes as married couples and therefore it is not surprising that most adopters were married.

There were differences in the level of education among the adopters (χ^2 = 3.8413, df = 1, p = 0.0487) and non-adopters (χ^2 = 3.8123, df = 1, p = 0.0499). The level of education between the adopters and non-adopters was however similar (χ^2 = 4.0912, df = 3, p =0.0991). Majority of the respondent had primary and secondary levels of education while those who attained tertiary education constituted only 8% of the respondents (Table 4.3). Kenya has a literacy level of 78% where 54% have secondary education (Kenya National Bureau of Statistics, 2010b). Several studies have also indicated that most of the rural population often attend education up to secondary schools and then drop out to look for a job and earn a living owing to the lack of school fees to proceed to tertiary levels of education. The high proportion of primary level of education in the current study concurs with other studies that have determined that majority of Kenyan farmers often drop out of primary or secondary schools to concentrate in farming activities (Marenya and Barrett, 2007; Amudavi *et al.*, 2009; Ng'ang'a *et al.*, 2010; Wanjala and Muradian, 2013).

The study established there was a significant difference in household size among the adopters (χ^2 = 4.0912, df = 3, p = 0.0991) and non-adopters (χ^2 = 3.8413, df = 1, p = 0.0487). The distribution of household size did not however differ significantly between the adopters and non-adopters of agroforestry (χ^2 = 1.3214, df = 3, p = 0.2991). The distribution of household size however differed significantly between the adopters and non-adopters of agroforestry (χ^2 = 4.0912, df = 3, p = 0.0991) where most adopters had household size ranging between 6-10 family members compared to 3-5 for most non adopters (Table 4.3). This therefore reveals that adopters had larger household sizes than the non-adopters.

The land size ranged between 0.4 to 10 acres. The study established a significant difference in land size among the adopters ($\chi^2 = 3.113$, df = 3, p = 0.0003) and non-adopters ($\chi^2 = 3.8413$, df = 1, p = 0.0487) but no differences in land size between adopters and non-adopters ($\chi^2 = 0.4436$, df = 3, p = 0.34291). Majority of the households had land size ranging between 2-5 acres followed by those with less than 2 acres. Land size ranging less than 2 acres as well as between 2 to 5 acres are typically small scale farmers and have been reported in most agroecosystems in Sub Saharan African region (Emerton and Snyder, 2018; Salako *et al.*, 2018; Tafere and Nigussie, 2018; Amare *et al.*, 2019). Although the actual amount of land size dedicated to agroforestry was not determined, the small land size appears to limit adoption and expansion of agroforestry.

The monthly household income showed significant differences between the adopters ($\chi^2 = 9.5622$, df = 3, p = 0.0021) and non-adopters ($\chi^2 = 13.7813$, df = 1, p = 0.0001). The annual household farm income for 75% of the respondents in the households ranged between US$ 50 to 500, where 25% each ranged between US$ 50-100, 101 to 200 and 201 to 500 (Table 4.3). These results suggest that low earning among the farmers. Low income among farmers in Sub Saharan Africa is often associated with vicious cycle of poverty and low production from the farms as a result of the low land sizes. There was no differences in monthly income between the adopters and non-adopters ($\chi^2 = 0.4436$, df = 3, p = 0.34291) suggesting that there was almost similar sources of earning between the adopters and non-adopters.

At the sometime the distribution of non-farm income had significant differences between the adopters ($\chi^2 = 9.5622$, df = 3, p = 0.0021) and non-adopters (χ^2 =

13.7813, df = 1, p = 0.0001). There was no differences in the distribution of the non-farm income (χ^2 = 1.3202, df = 3, p = 0.5621). Majority of the respondents earned non-farm income levels below Ksh. 5,000 followed by income levels between Ksh. US$ 50 to 100 pm (Table 4.3). These results show that non-farm income among the members was low and appear therefore cannot influence the decision on agroforestry.

The study further established out of 248 households, 204 had adopted agroforestry while 44 had not adopted which translated to 82.3% adoption of agroforestry practices concurs with previous studies on adoption of agroforestry in Machakos (Nzilu, 2015), Makueni (Maluki *et al.*, 2016), Nakuru (Makori, 2017), Kapseret (Rotich *et al.*, 2017) and in other countries of Sub Saharan Africa (Oloyede and Ayinde, 2016; Ashiagbor *et al.*, 2018a). Most of the farmers intercropped grain, vegetables and tree crops. The grain crops cultivated in the land use system included maize, bean, millet, sorghum, pigeon peas, peas, green chili, etc. with horticultural products such as avocado, carrot, kales, oranges, mangoes, pawpaw, onions, tomatoes, cabbages, gourd, bitter gourd, pumpkin, and pineapple, which are often sold to increase livelihood indices. Nevertheless, caution should be exercised when using the term ‘adoption’, which has been previously applied to mean farmers who are using a technology at a particular point in time as adopters.

The types of agroforestry practiced by the adopters are shown in Figure 4.1. Majority of the respondents adopted boundary tree planting (73.8%), hedgerow (69.4%) and scattered trees in rangeland (51.2%) while alley cropping was the least preferred agroforestry practice (37.1%). This concurs with other studies that have indicated that farmers prefer hedgerow agroforestry which provides shelter, prevents frosts and act as wind breaks (Jose and Bardhan, 2012; Feintrenie *et al.*, 2019). A number of the farmers also adopted boundary tree planting act as wind breakers and to demarcate boundaries of the farmers perhaps in order to avoid trespassers.

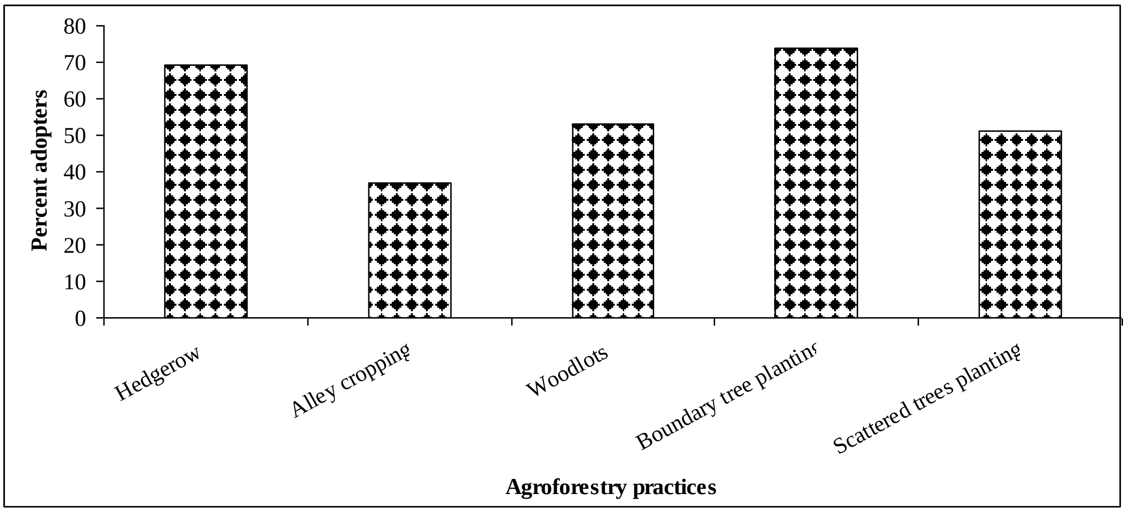

Figure 4.1: Types of agroforestry practiced by the local community members who adopted the practice

The relationships between the socio-economic status and adoption rates of agroforestry in Machakos County, and with the relevant test of significance in provided in Table 4.4.

Table 4.4: Relationships between the socio-economic status and adoption of agroforestry in Machakos County

Variables	**Attributes**	**Agroforestry adopter (n = 204)**	**Agroforestry non adopters (n = 44)**	χ^2	**p-value**
Age†	18-25	5.4	13.6	**6.7566**	**0.0328**
	26-35	13.7	18.2		
	36-55	41.2	31.8		
	> 55	39.7	36.4		
Gender	Male	43.1	40.9	0.7421	0.7864
	Female	56.9	59.1		
Marital status	Single	5.9	2.3	0.9493	0.3363
	Married	94.1	97.7		
Level of education†	None	2.5	15.9	**16.019**	**0.0012**
	Primary	54.9	40.9		
	Secondary	35.8	31.8		
	Tertiary	6.9	11.4		
Household size†	< 3	1.5	0.0	**11.7132**	**0.0081**
	3-5	36.8	61.4		
	6-10	51.5	38.6		
	>10	10.3	0.0		
Land size	< 2 acre	35.3	31.8	0.8712	0.6478
	2-5 acres	52.0	59.1		
	5.1-10 acres	12.7	9.1		
Farm household income (US$)	< 50	8.8	6.8	6.0287	0.1972
	500-100	26.0	31.8		
	101-200	21.1	31.8		
	201-500	27.9	25.0		
	> 500	16.2	4.5		
Non-farm income (US$)†	< 50	8.8	6.8	**8.4992**	**0.0081**
	500-100	26.0	31.8		
	101-200	21.1	31.8		
	201-500	27.9	25.0		
	> 500	16.2	4.5		

Based on Table 4.4, there was significant ($P < 0.05$) influence of age on agroforestry adoption. The study established that adoption of agroforestry was better with increasing age. This may be attributed to the fact that older people have land for adoption of the agroforestry practices compared to the young people as established in Turbo, Uasin Gishu (Mukungei *et al.*, 2013), Machakos (Nzilu, 2015). Nevertheless, the current finding on age was not in agreement with that of (Uisso and Masao, 2016) who found a significant negative correlation between age and adoption of agroforestry and concluded that young people were more active in the adoption of agroforestry practices than the old ones.

Level of education also affected adoption of agroforestry (Table 4.4). Education improves knowledge, management skills and extension services in agroforestry. Agroforestry was adopted better among those with primary and secondary levels of education which concurs with other studies (Akpabio and Ibok, 2009). Farmers who acquire education are more inclined to practice and benefit from agroforestry trees compared to the ones who have no formal education due to their higher levels of technical knowledge like application of fertilizers, use of pesticides and improved planting materials (Meijer *et al.*, 2015). The literacy level of farmers also determines the rate of adoption of improved technology and directly affects their capacity to absorb new ideas. This therefore gives a strong indication that the level of education plays a key role in tree planting and at the same time level of utilization.

In terms of adoption of agroforestry at the household, the best household size that favoured adoption of agroforestry was large household size with 6-10 people (Table 4.4). This seems to suggest that the larger household sizes favoured adoption of agroforestry (Sebukyu and Mosango, 2012) mainly due to the availability of family labour to take care of the farms. Labour from the majority of household members who fall in lower age brackets is restricted because these groups spend most of their time studying in schools and colleges. However, these studies are not in agreement with those of (Uisso and Masao, 2016) who did not find any significant relationship between household size and agroforestry adoption and practices and stated that adoption occurred due to financial ability of the farmer.

Meanwhile adoption of agroforestry was also affected by non-farm household income with the most adoption occurring at household size ranging between US$ 50 to 500 (Table 4.4). Although the level of household non-farm income was low, it appears to affect the adoption of agroforestry practices. During the study, it was observed that most of these non-farm incomes were derived from agroforestry resulting to more inclination to adopt agroforestry. Similar observation have been previously reported (Kiptot *et al.*, 2007).

The study also considered the institutional factors affecting adoption of agroforestry. The results are as shown in Table 4.5. Among the analyzed institutional factors, it was established that access to credit facilities, access to formal agroforestry training, access to information of conservation groups and access to inputs from conservation groups significantly affected adoption of agroforestry in the study area. Presences of extension tactic, such as farmers' field days, exchange visits and training, are effectual ways of disseminating agroforestry information. Unfortunately, Agricultural extension officers concentrated on crops and animal production, while on the other hand, Forest Extension officers embarked on tree planting activities only. Many agricultural extension workers are not familiar with trees and shrub species that could fit into an agroforestry. These agriculturally trained extension agents have little knowledge about agroforestry trees with respect to their vernacular names, ecology, propagation, management and uses. On the other hand, forestry extension workers tend to view tree species from a purely "forestry" point of view, and neglect the needs and constraints identified by farmers. In a similar study, most of the respondents in Kapsaret cited faulty extension services, with inadequate follow up visits or insufficient time for training and advice. Hence, the extent of general smallholder farmer extension services is declining (Kiptot and Franzel, 2012). It has been observed that extension services in many parts of Kenya is poor which is a bottlenecks to agroforestry technology adoption (Abdi *et al.*, 2017). Likewise, farmers in Kapsaret believe that there is a direct influence of extension services. It was further determined that access to extension visits as well as frequency of visits did not significantly ($P > 0.05$) influence adoption of agroforestry.

Table 4.5: Institutional factors affecting adoption of agroforestry in Machakos County

Variable	**Response**	**Adopters (n = 204)**	**Non adopters (n = 44)**	χ^2	**p-value**
Access to extension services	Yes	31.4	20.5	2.198	0.138
	No	68.6	79.5		
Access to credit facilities†	Yes	8.8	0	**7.329**	**0.007**
	No	91.2	100		
Access to formal AF training†	Yes	27.9	4.5	**14.161**	**0.0002**
	No	72.1	95.5		
Access to information†	Yes	41.7	4.5	**27.998**	**0.001**
	No	38.3	95.5		
Access to inputs†	Yes	8.8	2.3	**4.82**	**0.033**
	No	91.2	97.7		
Frequency of extension visits	Rarely	25	13.6	5.317	0.251
	Yearly	1	0		
	Monthly	2	0		
	Quite often	4.9	2.3		

The result of the binary logistic regression showing the relationship between 14 socio-economic and institutional factors on adoption of agroforestry practices are shown in Table 4.6. Binary logistic regression utilize both the continuous and categorical variables even without full fit in the distribution (Harrell, 2015). A combination level of education, household size, access to credit and training significantly affected adoption. These results corroborate other findings whereby, socio-economic characteristics of the smallholder farmers affected the adoption of agroforestry (Basamba *et al.*, 2016; Coulibaly *et al.*, 2017; Zeweld *et al.*, 2017). This suggests that successful adoption of agroforestry relied on the levels of education, the size of the household and training. In this study those with primary and/or secondary level of education, with 6-8 members of the household and with access to training were more likely to adopt agroforestry. The combinations of these factors are crucial in providing the adopters with knowledge, manpower and technical ability to undertake agroforestry practices.

Table 4.6: Binary logistic regression showing the relationship between 14 socio-economic and institutional factors on adoption of agroforestry practices

Variables in the equation	Coefficient	S.E.	Wald	p-value
Gender	-0.081	0.404	0.04	0.841
Marital status	-1.608	1.143	1.98	0.159
Age	0.248	0.231	1.151	0.283
Level of education†	**1.379**	**0.301**	**5.588**	**0.021**
Occupation of the household	-0.001	0.642	0.0043	0.998
Household size†	**1.219**	**0.392**	**9.679**	**0.002**
Land size	-0.561	0.333	2.831	0.092
Farm income	0.261	0.175	2.221	0.136
Non-farm income	0.059	0.151	0.151	0.697
Access to extension	-1.001	0.616	2.641	0.104
Access to credit†	**2.616**	**0.8**	**10.686**	**0.001**
Access to training†	**1.682**	**0.844**	**3.974**	**0.046**
Frequency of extension visits	0.073	0.33	0.048	0.826
Constant	-1.752	1.786	0.962	0.327

4.3 Influence of Agroforestry Adoption on Ecosystem Services from Smallholder Farmers

The study also determined the influence agroforestry practices on ecosystem services among smallholder farmers. In determining the ecosystem services, the researcher relied only on the farmers who had adopted the practices of agroforestry. The ecosystem services by the smallholders who adopted agroforestry practices are shown in Table 4.7, while the computed percent ranks scores of the value of the aggregated ecosystem services obtained by the local community members are provided in Figure 4.2. Based on calculated percent rank scores, the most common benefit derived from the local community members was ecosystem supporting functions (82.5%) followed by regulatory functions (80.8%). Provisioning ecosystem service was the third most important function as perceived by the local community members (73.5%) while least was cultural functions (61.4%). These results have also been previously reported in the region (Tiffen *et al.*, 1994).

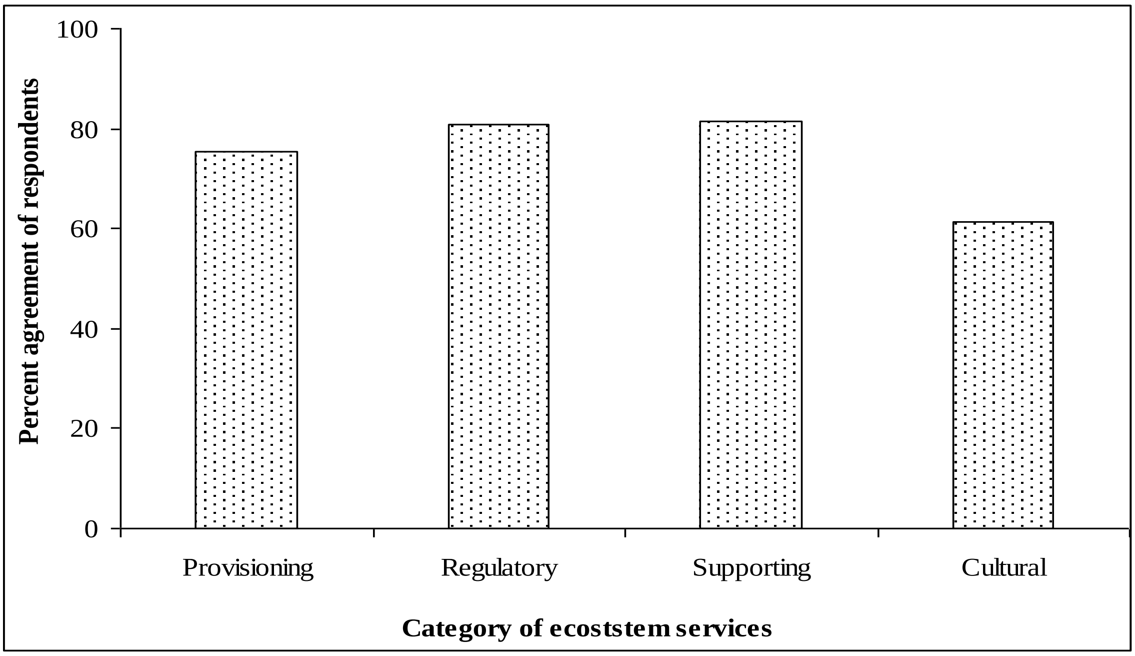

Figure 4.2: Percent rank scores for the value of aggregated ecosystem services obtained by the local community members

Smallholder agroforestry contribution to multiple ecosystem services that support rural livelihood of smallholder farmers is widely recognized. Given the dearth of information on local knowledge of the ecosystem services in semi-arid drylands within the Sub Saharan Africa, this study determined the local community understanding of the ecosystem benefits derived from smallholder agroforestry in Machakos County in Kenya.

The study established that ecosystem supporting functions which included nutrient recycling and soil formation was the most important. This is one of the reasons often stated for the adoption of agroforestry with a view of provision of service such as climate regulation and restoration of soil quality (Edwards *et al.*, 2014; Lal, 2015). The study by Edwards *et al.* (2014) describes improved soil fertility as the main benefit derived from practicing agroforestry.

However, in other studies in the Sub Saharan Africa, ecosystem supporting function is often lowly ranked by local community members due to lack of knowledge about nutrient recycling and soil formation (Jose and Bardhan, 2012; Corbeels *et al.*, 2019), which also concur with other studies in the Amazon basin (Pinho *et al.*, 2012). Therefore, it is inherent that due to the poor quality of soil and nutrient levels in the area (Maluki *et al.*, 2016) makes local knowledge of any activity that help to improve the soil a priority.

Table 4.7: Frequency of responses among the respondents concerning ecosystem services by the smallholder farmers who adopted agroforestry practices

Category of services	Specific ecosystem services	Agroforestry provide the following ecosystem services				
		Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
Provisioning	Fuel wood	9	0	7	68	40
	Timber	29	2	7	63	23
	Poles	19	4	8	75	18
	Fodder	21	4	9	71	19
	Fruits and Nuts	13	8	16	61	26
Regulatory	Soil erosion control	4	1	11	76	32
	Water infiltration	3	2	10	79	30
	Micro climate	3	1	12	68	40
	Flood control	6	14	16	61	27
	Disease/pests control	7	18	17	59	23
Supporting	Nutrient Recycling	3	1	14	79	27
	Soil formation	3	4	22	72	23
Cultural	Spiritual	76	8	10	25	5
	Recreation	9	2	17	74	21
	Education	40	5	14	56	9
	Aesthetic	34	2	10	58	20

The percent rank scores for each of the individual provisioning ecosystem services among the local community respondents is shown in Figure 4.3. According to computed aggregated Likert scoring scheme used, the highest percentage rank on ecosystem provisioning services among the local community members was fuelwood (84%), followed by fruit and nuts (75%), poles (74%), timber (72%) and least for fodder (64%). Provisioning ecosystem services such as fuelwood, fruit and nuts, poles, timber and fodder was the third most important function as perceived by the local community members. These ecosystem services have been highlighted as of great importance when it comes to fuelwood for energy in the region (Maingi, 2019) and within the Sub Saharan Africa (Toth *et al.*, 2017b). In support of the current study, provisioning functions including the provision of fuel wood, timber, poles, fodder and fruits is often ranked as the most important services derived from agroforestry (Waldron *et al.*, 2017).

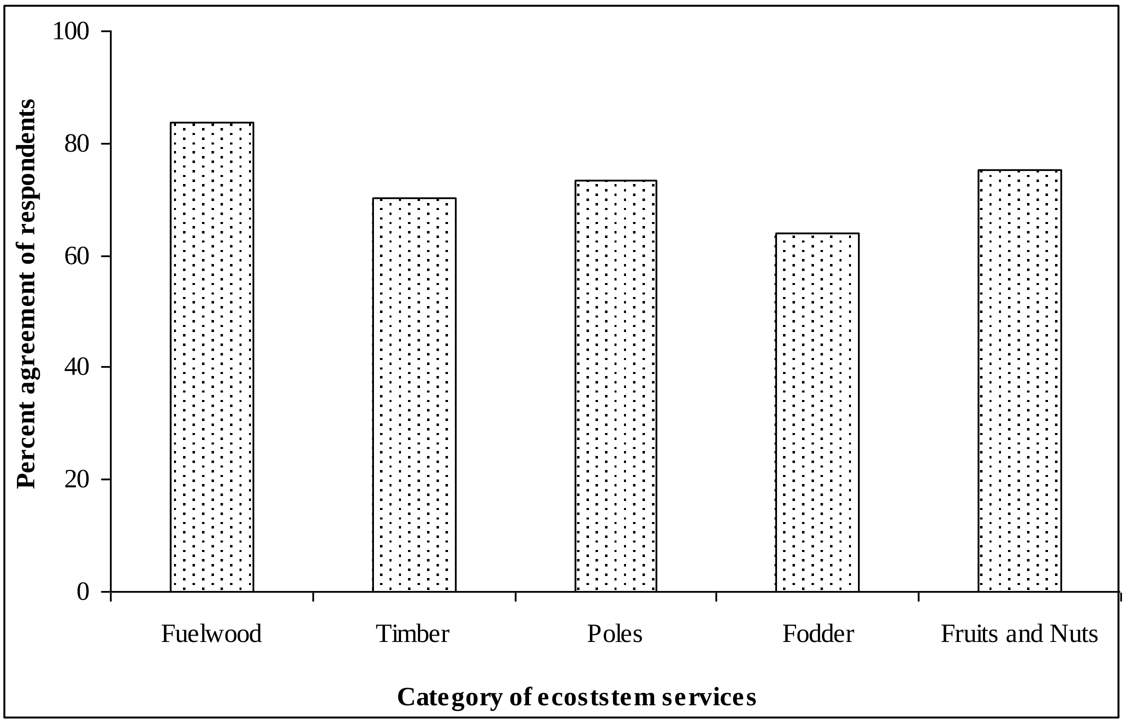

Figure 4.3: Percent rank scores for individual provisioning ecosystem services

The percent rank scores for individual ecosystem regulatory services among the respondents were also determined (Figure 4.4) where it was established that the highest percentage rank on the ecosystem regulatory functions was micro-climate regulation (85%), followed by soil erosion control (83.5%), water infiltration (83%), flood control (51%) and least for disease and pest control (44%). Regulatory functions (soil erosion control, water infiltration, micro-climate regulation, flood control and disease/pest control) were the second most important ecosystem services. The use of agroforestry as a mitigation for climate change among smallholder farmers is a practice now gaining much relevance (Mbow *et al.*, 2014a) which has also been practiced within the region in the past (Quandt *et al.*, 2018). The region also has incidences of soil erosion which is high due to the hilly terrain of the study area (Karuma *et al.*, 2014; Baaru and Gachene, 2016), the climate is also quite hot and dry and therefore agroforestry practices will modify these micro-climate to noticeable levels. Moreover, frequency of flooding was often high and therefore any action of the agroforestry crops towards control of floods would easily be noticed by the local community members.

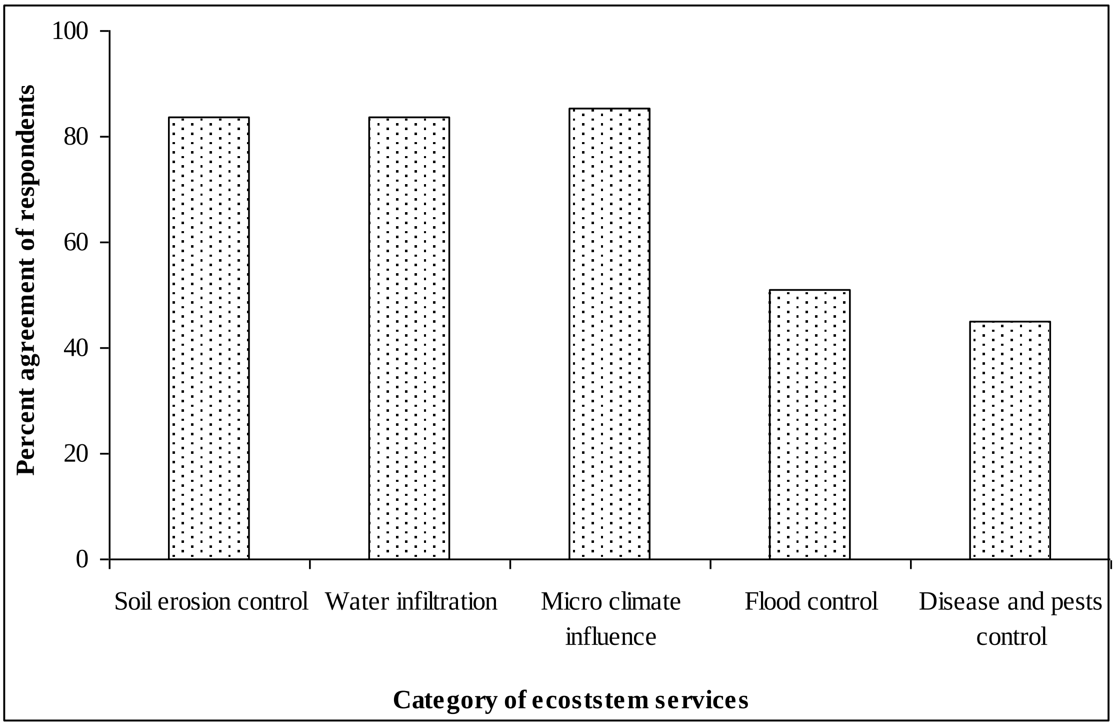

Figure 4.4: Percent rank scores response for regulatory ecosystem services

Percent rank scores for individual ecosystem supporting services among the respondents are provided in Figure 4.5. The highest percentage rank on the ecosystem supporting functions among the local community members was for nutrient cycling (83%) followed by soil formation (81%).

The percent rank scores for individual ecosystem cultural functions among the respondents are shown in Figure 4.6. Based on the aggregated Likert scoring scheme, the highest percentage rank on the ecosystem cultural functions among the local community members was for recreation (77.5%), followed by aesthetic function (66.7%), education (54%) and least in spiritual functions (41.2%). In ecosystem based studies, cultural services appear to have lost its relevance among household and therefore unlikely to be significance in ecosystem service studies (Meijer *et al.*, 2015).

Most households in the area are currently moving away from several cultural undertakings and therefore it seems that there was not much importance attached to the cultural practices except for recreation which is not considered a very strong cultural value.

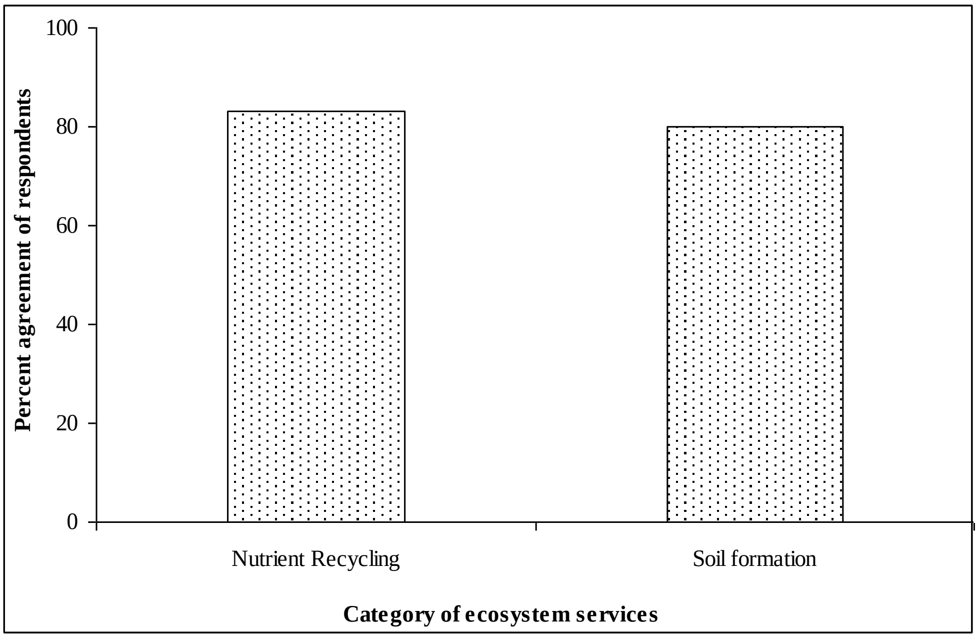

Figure 4.5: Percent rank scores response for supporting ecosystem services

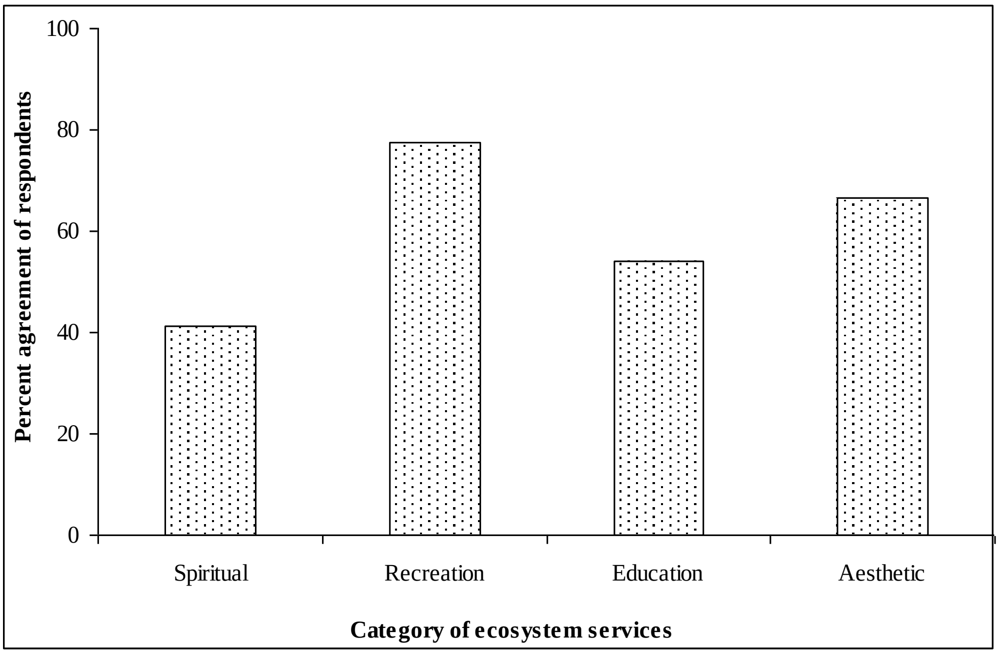

Figure 4.6: Percent rank scores response for cultural ecosystem services

4.4 Influence of Adoption of Agroforestry on Socio-economic, Rural Income and Livelihood of Smallholder Farmers in Machakos County

In determining the incomes, the researcher relied on both the adopters and non-adopters of agroforestry practices. The computed average income from crops, livestock, trees and total income from the adopters and non-adopters of agroforestry in Machakos County are provided in Table 4.8. The income derived from crop, livestock, tree seedlings and tree products as well as the farm and total income of the farmers were all significantly higher for the adopters than non-adopters ($P < 0.05$). This concurs with other studies which indicated that earning from crops, livestock and trees among agroforestry adopters is often higher owing to the income earned from sales of the crops, livestock and trees from the agroforestry (Neupane and Thapa, 2001; Franzel, 2004; Namwata *et al.*, 2012; Kareem *et al.*, 2016; Kassie, 2018). Indeed, agroforestry increases livelihood benefits for people such as food security, employment and income generation among others. Meanwhile the average annual farm income from livestock proceeds displayed significant differences since it was established that agroforestry adopters did keep higher number of animals than those not practicing agroforestry thus the earnings from livestock were not similar.

Table 4.8: Average income from crops, livestock and total income computed between adopters and non-adopters of agroforestry in Machakos County. Values are in US $.

Income	Adopters	Non-adopters	t- Test	*p*- value
Average annual farm income from crop proceeds[†]	2784	154	30.13	0.000
Average annual farm income from livestock[†]	2284	156	9.53	0.002
Average annual income from tree seedlings[†]	205	109	17.39	0.000
Average income of wood/non wood products[†]	271	143	16.68	0.000
Average farm income per annum[†]	253	196	5.99	0.006
Total income from agroforestry[†]	5,797	758	60.104	0.0000

[†] Differences are significant at $P < 0.05$

The average income on wood and non-wood products from the adopters and non-adopters of agroforestry in Machakos County are provided in Table 4.9. The income derived from timber and fuel wood as well as the total income derived from wood and non-wood products was significantly higher for the adopters than non-adopters ($P < 0.05$). However, the income derived from posts/poles and from fodder was similar for the adopters and non-adopters.

The study also established a higher income from timber, fuel wood and non-wood products among agroforestry adopters which concurs with several other studies (Scherr, 2004; Bertomeu, 2006). Apart from domestic use of the timber and fuel wood, there are instances where farmers with larger scale practice of agroforestry can sell some of their products and earn income higher than those without any form of agroforestry. Nevertheless, the incomes derived from posts/poles and from fodder were similar for the adopters and non-adopters which may be attributed to low production of these wood products among farmers and the fact that they do not sell posts/poles and fodder.

Table 4.9: Income derived from wood and non-wood products between the adopters and non-adopters in Machakos County. Values are in US$

Wood income	**Adopters**	**Non-adopters**	**t Test**	***p*-value**
Income realized annually from timber†	162	78	**14.09**	0.000
Income realized annually from fuelwood†	9,61	67	**3.18**	**0.041**
Income realized annually from post/poles^{NS}	602	54	0.25	0.619
Income realized annually from fodder^{NS}	63	65	0.01	0.955
Total annual income of wood/non wood products†	897	264	**16.68**	**0.000**

†Differences are significant at $p < 0.05$

Annual expenditure on basic needs for adopters and non-adopters of agroforestry in Machakos County are shown in Table 4.10.

Table 4.10: Annual expenditure on basic needs between adopters and non-adopters of agroforestry in Machakos County. Values are in US$

Expenditure on basic needs	**Adopters**	**Non adopters**	**t Test**	***p*-value**
Annual household expenditure on food†	222	87	**74.95**	**0.000**
Annual household expenditure on clothing†	157	69	**62.94**	**0.000**
Annual household expenditure on education†	206	152	**11.39**	**0.001**
Annual household expenditure on medicine†	92	57	**9.30**	**0.003**
Annual household expenditure on basic needs†	646	329	**111.85**	**0.000**
Total	1323	694		

†Differences are significant at $P < 0.05$

The annual expenditure on food, clothing, education, medicine and total household expenditure on basic needs were all significantly higher for the adopters than non-adopters ($P < 0.05$). This was due to the higher disposal income from agroforestry that enabled them spending more on food, clothing, education and medicine.

Given one of the largest costs of most rural areas is on fuel wood as a source of energy (Sharma *et al.*, 2016a; Waldron *et al.*, 2017), most of the farmers with trees in their farms will save the income and use it to purchase food, built better houses and spend more on quality education as well as search for better healthcare (Borish *et al.*, 2017).

The annual expenditure budget for wood and non-wood products between adopters and non-adopters is shown in Table 4.11. The household annual expenditure on timber, poles as well as the total expenditure on wood and non-wood products was significantly higher for the non-adopters than adopters ($P < 0.05$). This study concurs with other studies (Leakey *et al.*, 2005) due to the fact that most of the adopters have these agroforestry products in their farms and hence they do not need to buy these products from outside their farms. During adoption of agroforestry, farmers have access to wood and non-wood products and the amount of money going towards purchase of such are expected to be lower than those who have no wood from any agroforestry practice. However, expenditure on fodder was not different between the adopters and the non-adopters mainly because most of the agroforestry practices were not planting fodder trees in their farms.

Table 4.11: Annual expenditure budget for wood and non-wood products between adopters and non-adopters. Values are in US$

Wood/wood product expenditure category	**Adopters**	**Non adopters**	***t* Test**	***p*-value**
Household annual expenditure on timber†	7,1	165	**4.28**	**0.023**
Household annual expenditure on fuel wood†	46	50	**0.43**	**0.043**
Household annual expenditure on poles/posts**NS**	52	50	0.05	0.832
Household annual expenditure on fodder**NS**	31	3	2.80	0.342
Total expenditure on wood/wood products†	137	268	**10.67**	**0.000**

†Differences are significant at $p < 0.05$
NS denotes not significantly different

The enterprise budget for adopter and non-adopters of agroforestry practices in Machakos County are shown in Table 4.12. Gross revenue for the adopters (US$ 1,236) was higher than the non-adopters (US$ 758). Higher gross revenue for the adopters shows that they get money from various agroforestry sources compared to the non-adopter. Also, the overall expenditure on variable cost by the adopters (US$ 890) was consistently higher than the non-adopters (US$ 663). The total fixed cost of the agroforestry adopters was nevertheless similar to the non-adopters (US$ 71). As a consequence, there were higher net returns above Total Variable Costs (TVC) for the adopters (US$ 346) compared to the non-adopters (US$ 95), which resulted in positive higher net returns above Total Cost (TC) for the adopters (US$ 276) compared to the non-adopters (US$ 24).

Analysis of enterprise budget yielded several observations. First the gross revenue for the adopters (US$ 1236) was higher than the non-adopters (US$ 758) indicating higher income derived from agroforestry practices. Similarly, the overall expenditure on total variable cost by the adopters (US$ 890) was consistently higher than the non-adopters (US$ 64) which was attributed to the adopters having higher disposal incomes. The total fixed cost of the agroforestry adopters was nevertheless similar to the non-adopters (US$ 70) suggesting that fixed cost for the adopters and non-adopters tend to be somewhat similar. As a consequence, there were higher net returns above TVC for the adopters (US$ 346) compared to the non-adopters (US$ 95), which resulted in positive higher net returns above TC for the adopters (US$ 275) compared to the non-adopters (US$ 24).

Based on the above statistics, the computed margins above TVC (%) was therefore higher for the agroforestry adopters (28.02%) than the non-adopters (12.48%) and margins above the total cost for the adopters was 22.30% and 3.15% for the non-adopters. These results suggest that income was higher for the adopters resulting in overall profitable operational margins that render adoption as a good enterprise.

Table 4.12: Computed enterprise budget for adopter and non-adopters of agroforestry practices in Machakos County. Values are in US$

Parameters	Adopters	Non-adopters
Revenues		
Average annual farm income from crop proceeds	278.39	154.16
Average annual farm income from livestock	228.38	156.05
Average annual income from tree seedlings	205.18	109.83
Average annual income from wood/wood products	271.34	142.91
Average annual farm income	253.44	195.61
Total income from agroforestry	1236.73	758.56
Variable costs		
Household expenditure on food per year	222.27	86.82
Annual household expenditure on clothing	157.02	69.89
Annual household expenditure on education	206.28	151.09
Annual household expenditure on medicine	92.42	57.55
Total Annual household expenditure on basic needs	646.55	329.52
Household annual expenditure on timber	71	164.62
Household annual expenditure on fuel wood	45.81	49.91
Household annual expenditure on poles/posts	52.09	50.3
Household annual expenditure on fodder	31.03	37.51
Total expenditure on wood/ non wood products	199.93	302.34
Miscellaneous	43.68	32
Total Variable Cost (TVC)	890.16	663.86
Fixed costs		
Amortization	60	60
Interest on fixed cost	10.8	10.8
Total fixed cost	70.8	70.8
Total Cost (TC)	960.96	734.66
Net returns above TVC	346.57	94.7
Net returns above TC	275.77	23.9
Margins above TVC (%)	28.02	12.48
Margins above TC (%)	22.30	3.15

The indicators of improved livelihood among the adopters and non-adopters of agroforestry were also determined (Table 4.13). There were significant differences in the responses to the contribution of agroforestry to livelihoods between the adopters and non-adopters ($\chi^2 = 45.2312$, df = 8, $p < 0.001$). Among the adopters of agroforestry, majority attested that indeed there was increased food supply, improved educational attendance and increased energy in the household. This study also determined the influence of adoption of agroforestry practices on rural livelihood of smallholder farmers and found that adopters of agroforestry had increased food supply, improved educational attendance and increased energy in the household, which concurs with several studies among agroforestry adopters (Quandt and McCabe, 2017; Quandt *et al.*, 2018).

The diversification of crops, keeping of livestock and trees in the same farm create opportunities for improved rural income (Kassie, 2018). Agroforestry have also been determined to combine short-term and long-term benefits for the farm households with the aim of livelihood sustainability in utilizing resources in semi-arid areas (Quandt *et al.*, 2017).

Table 4.13: Indicators of improved livelihoods among adopters of agroforestry. Values in percentage.

Livelihoods indicators	Percent Adopters (n = 204)	Percent non adopters (n = 44)
Reduced use of fertilizers	82.4	34.1
Increased energy in the household	85.3	38.6
Increased food supply	87.3	25.0
Increased household income	60.8	34.1
Improved educational outcomes	49.5	34.1
Improved medical attendance	38.2	27.3
Improvement in employment	59.8	18.2
Improved educational attendance	86.8	25.0
Increased land size	52.0	15.9

The scores of the indicators of household livelihood between the adopters and non-adopters are shown in Figure 4.7. The scores of the indicators of household livelihood were consistently higher rank scores for all the livelihood indicators among adopters compared to the non-adopters except for improved educational outcomes, improved medical attendance, and increased land sizes. Improvement of livelihood among agroforestry adopters have been identified in several studies (Alavalapati and Mercer, 2006; Amatya *et al.*, 2018). Nevertheless it was observed that income generating activities in the study area were not diversified as compared to other regions of the world (Burgess *et al.*, 2017; Mosquera-Losada *et al.*, 2018b).

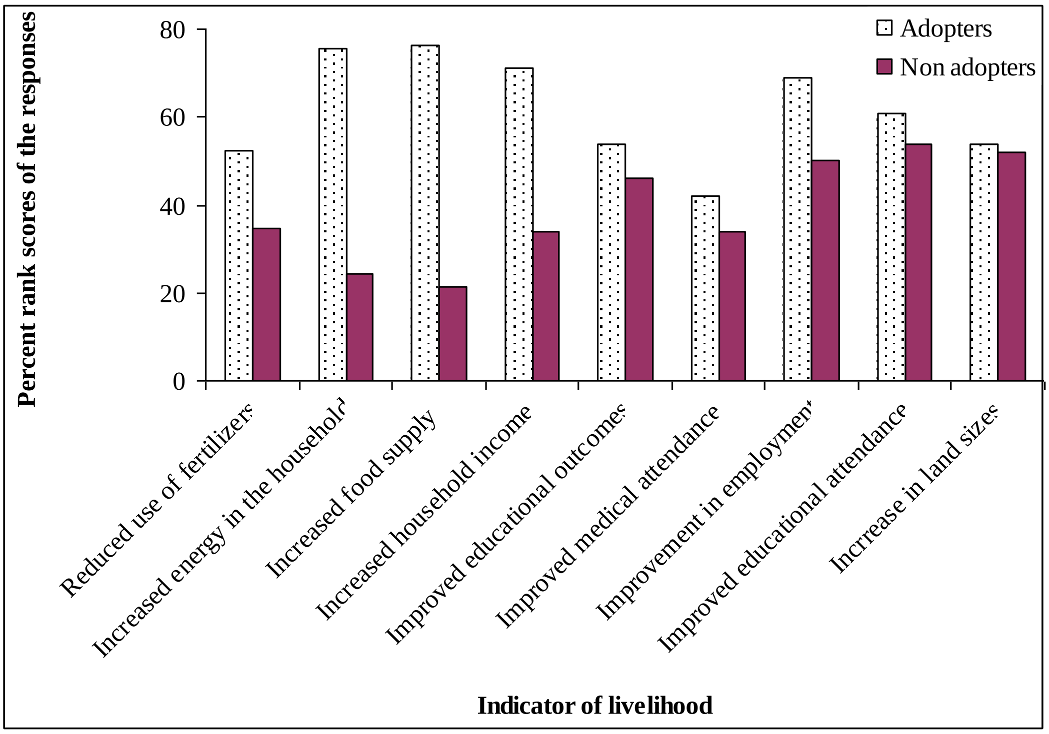

Figure 4.7: Scores of the indicators of household livelihood among adopters and non-adopters in Machakos County

The study established that production, and income from agroforestry has been increasing the innovativeness of the farmers and also for the spatial arrangement of multiple crops. The majority of the smallholders asserted that they had better production after the adoption of agroforestry which resulted to more money to send their children to schools, purchase medicine, buy clothes and other necessities that eventually improved the livelihood. It can be concluded that agroforestry adoption had a significant impact on the livelihood of most smallholder farmers and their households.

4.5 Influence of Adoption of Agroforestry on Physico-chemical Soil Quality Parameters

This study established the influence of agroforestry practices on physico-chemical soil quality parameters. In determining the soil quality parameters, the researcher relied on both the adopters and non-adopters of agroforestry practices.

4.5.1 Physical Attributes of the Soils

The physical attributes of the soil sampled between farmers practicing agroforestry and those not practising was determined (Table 4.14).

Table 4.14: Physical attributes of the soil between farmers practicing and those not practicing agroforestry

Age of adoption (years)	Sand	Clay	Silt	Bulk density
0 (Non adopter)	62.15 ± 0.69^{a}	28.52 ± 0.23	9.13 ± 0.58^{a}	10.36 ± 0.22^{a}
1-5	60.75 ± 0.99^{b}	28.59 ± 0.26	10.42 ± 1.14^{b}	10.47 ± 0.17^{a}
6-10	60.41 ± 1.37^{c}	28.47 ± 0.24	11.08 ± 1.53^{b}	10.39 ± 0.11^{a}
11-20	58.99 ± 1.11^{c}	28.49 ± 0.20	11.45 ± 2.13^{b}	10.58 ± 0.13^{b}
>20	57.15 ± 0.67^{d}	28.53 ± 0.19	13.71 ± 2.28^{c}	10.76 ± 0.18^{c}
ANOVA				
F	50.598	0.494	13.577	13.634
df	4	4	4	4
p-Values	0.000	0.740	0.000	0.000

Values with different letters as superscript in the columns differ significantly ($p < 0.05$)

Sandy particles proportion in the soil ranged from 56% to 63.2% among adopters and 61.2% to 63.2% for the non-adopters of agroforestry. Based on the age of adoption, the proportion of sand in agroforestry adopters for 1-5 years was 60.75 ± 0.99%, 60.41 ± 1.37%, for those with 6-10 years adoption, 58.99 ± 1.11% among farmers with 11-20 years of agroforestry practice and 58.99 ± 1.11% for farmers with over 20 years practice of agroforestry practice. Further statistical analyses establish significant differences in percentage of sand based on the age of agroforestry practice ($p < 0.05$). Generally the proportion of sand particles was higher among non-adopters compared to adopters of agroforestry and decreased in proportion with age of agroforestry adoption and practise (Figure 4.8). The present studies report that agroforestry reduced proportion of sand in the soil which concurs with other studies (Pandey *et al.*, 2000; Puttaso *et al.*, 2011; Bhatt *et al.*, 2017; Cardinael *et al.*, 2017; Hewins *et al.*, 2017). The decrease in sand particles could be attributable to the fact that the agroforestry tree species adopted contributed to the process of leaf litter and soil microbes helped in decomposition and may therefore result in reduction of sandy particles (Weerasekara *et al.*, 2016). Agroforestry also increase soil organic matter which increases the proportion of silt and other organic debris in the soil at the expense of sand particles (Weerasekara *et al.*, 2016).

The percentage of clay in the soil ranged from 28.2 to 28.98% in soils practising agroforestry while those that were not, the proportion of clay particle was 28.2 to 28.9%. Generally, the percentage of clay where agroforestry is practiced for 1-5, 6-10, 11-20 and over 20 years did not change substantially between 28.59 to 28.9%. Subjected to further analysis, the results indicate that there was no differences in the clay particles between agroforestry adopters and non-adopters ($p > 0.05$) regardless of the age of the agroforestry practice which concurs with other studies (Alfaia *et al.*, 2004; Alam *et al.*, 2010; Akdemir *et al.*, 2016). Probably due to the overall nature of the soil being in semi-arid landscape and that may also be related to the inability of the tree litter to add much clay to the existing soils. Clay soil are result of microbial degradation of the soil and organic matter particles (Cardinael *et al.*, 2017) which was not possible under the condition of the soils in Machakos County.

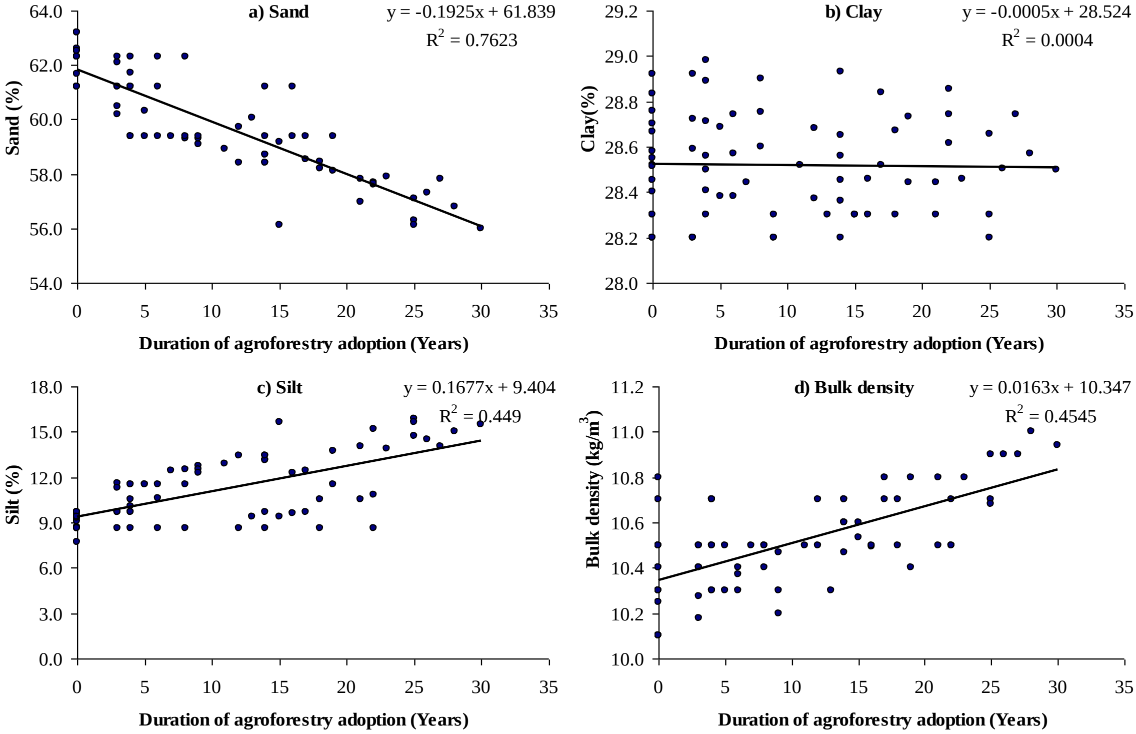

Figure 4.8: Physical attributes of the soil sampled among farmers with different durations of agroforestry adoption

The percentage of silt in the soil ranged from 8.6 to 15.9% in soils with agroforestry practices but in soil without any agroforestry practice, the proportion of silt was 7.7 to 9.7%. The percentage of silt among framers with 1-5 years agroforestry practice was 9.13 ± 0.58%, those with 6-10 years practice it was 11.08 ± 1.53%, then for farmers with 11-20 years of agroforestry practice it was 11.45 ± 2.13% while those with over

20 years of agroforestry practice the percent was 13.71 ± 2.28%. Further statistical analysis indicates that there was a significant difference in percentage of silt based on the age of agroforestry practice ($p < 0.05$). These results indicate that the proportion of silt was significantly higher among the adopters compared to the non-adopters and increased with increasing age of adoption (Figure 4.8). Increased proportion of silt in soil where agroforestry is practiced has been widely reported (Li *et al.,* 2015; Bhaduri *et al.*, 2017; Deng *et al.*, 2017; Dhaliwal *et al.*, 2019). Silt particles are formed due to decomposition of soil organic matter, allochthonous organic matter as well as soil microbial and biochemical processes (Hassink, 1997; Paul, 2016) which appears to originate from the agroforestry trees and thus agroforestry appears to improve the silt content of the soil, which was confirmed by the increasing silt with age of adoption of agroforestry.

The bulk density in the soil ranged from 10.18 to 11.00 kg/m^3 in soils where agroforestry was practiced but in soil without any agroforestry practice, the bulk density was 10.1 to 10.8 kg/m^3. The bulk density in soils for farmers with 1-5 years agroforestry practice was 10.47 ± 0.17 kg/m^3, those with 6-10 years practice it was 10.39 ± 0.11 kg/m^3, then among farmers with 11-20 years of agroforestry practice it was 10.58 ± 0.13 kg/m^3 and those with over 20 years of agroforestry practice the percent was 10.76 ± 0.18 kg/m^3. Further statistical analysis indicates that there was a significant difference in bulk density based on the age of agroforestry practice ($p < 0.05$). Bulk density in the soil was higher for the adopters as compared to the non-adopters and increased with increasing age of agroforestry adoption. These studies concurs with those of (Udawatta and Anderson, 2008; Udawatta *et al.,* 2009; Gama-Rodrigues *et al.*, 2010; Silva *et al.*, 2011; Chaudhari *et al.*, 2013) who showed a significant increase in soil bulk density associated with agroforestry practices. The increase in bulk density in the soil could be due to increased compaction of the soil (Hairiah *et al.*, 2006), addition of organic matters from decomposition leaves (Udawatta *et al.*, 2006) and wood debris in the soil. However, the current results differed from those by (Throop *et al.*, 2012) who showed no differences in the bulk density between agroforestry adopters and non-adopters. The authors did not provide any explanation and thus it is not clear why the current results differ from those of these authors.

4.5.2 Chemical Composition of the Soils

The pH and concentration of TN, TP, TOC, C/N and C/P ratios in the soils between farmers with different age of agroforestry adoption in Machakos County are provided in Table 4.15.

Table 4.15: Chemical composition in the soils between farmers with different age of agroforestry adoption in Machakos County

Age of adoption (years)	pH	TN	TP	TOC	C/N	C/P
0	6.33 ± 0.34	0.04 ± 0.01^{a}	83.83 ± 21.95	1.09 ± 0.25^{a}	12.06± 3.57^{b}	0.01± 0.01^{a}
1-5	6.26 ± 0.29	0.14 ± 0.04^{b}	77.61 ± 24.21	1.50 ± 0.25^{b}	9.95± 2.40^{a}	0.02± 0.01^{b}
6-10	6.02 ± 0.31	0.14 ± 0.05^{b}	67.47 ± 29.04	1.61 ± 0.30^{b}	9.23± 1.60^{a}	0.02± 0.01^{bc}
11-20	6.06 ± 0.27	0.19 ± 0.03^{c}	74.91 ± 19.21	1.97 ± 0.25^{c}	9.31± 1.74^{a}	0.03± 0.01^{cd}
>20	6.28 ± 0.39	0.26 ± 0.05^{d}	82.00 ± 21.82	2.26 ± 0.32^{d}	8.08± 1.73^{a}	0.03± 0.01^{d}
ANOVA						
F	2.215	30.673	1.642	3.951	5.445	7.112
df	4	4	4	4	4	4
p-Value	0.134	0.000	0.237	0.000	0.024	0.007

Values with different letters as superscript in the columns differ significantly ($p < 0.05$)

The study revealed that pH of the soil ranged from 5.42 to 6.80 in farms practising agroforestry but was 5.53 to 6.82 in soil without agroforestry practice. The median pH in soils where agroforestry had been practiced for 1-5 years was 6.26 ± 0.29, those with 6-10 years practice was 6.02 ± 0.31, for 11-20 years of agroforestry practice was 6.06 ± 0.27 and those with over 20 years of agroforestry practice the median pH was 6.28 ± 0.39. Statistical analysis indicates that there was no a significant difference in pH based on the age of agroforestry practice ($p > 0.05$). According several studies (Behera *et al.*, 2015; Singh, 2016; Rocha Junior *et al.*, 2018; Sousa Neto *et al.*, 2018; Yu, 2018), the indifferences in the pH is attributed to the soil geology and most trees planted rarely affect soil pH. The indifferences in the pH between adopters and non-adopters could be attributed to similarity in the geology of the region which was similar for the study area.

The study revealed that Total Nitrogen (TN) in the soil in agroforestry farms showed variations with age of the practice. The TN in soils ranged from 0.14 ± 0.04 ppm in farms where agroforestry had been practiced for 1-5 years, those with 6-10 years practice it was 0.14 ± 0.05 ppm, among farmers with 11-20 years of agroforestry practice was 0.19 ± 0.03 ppm and those with over 20 years of agroforestry practice the median TN was 0.26 ± 0.05 ppm. Further statistical analysis indicates that there was a significant difference in TN based on the age of agroforestry practice ($p < 0.05$). The results show that TN was significantly higher among the adopters compared to the non-adopters and increased with increasing age of adoption (Figure 4.9).

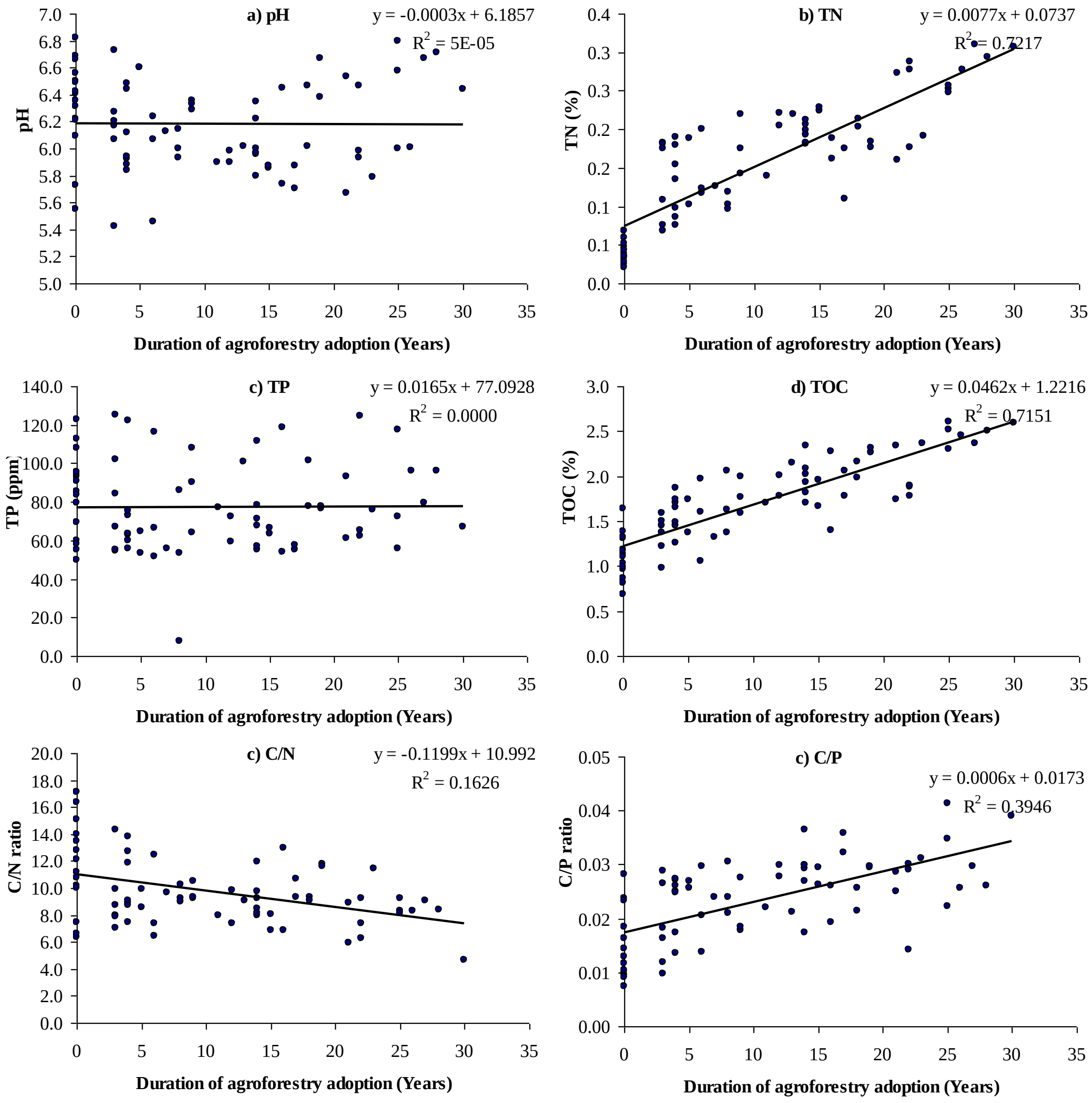

Figure 4.9: Variation in pH, and concentration of TN, TP, TOC, C/N and C/P ratios in the soils among farmers with different durations of agroforestry adoption

The increased proportion of TN in soil with increase in age of agroforestry practice could be attributed to the fact that as agroforestry trees grows, the plants become more effective in fixing nitrogen from the atmosphere which eventually get to the soil and increase nitrogen content in the soil. In plants, the nutrients are stored in leaves which drop as the plant age leading to release of nitrogen into the soil. Total Nitrogen in soil could have increased due to the use of nitrogenous fertilizers during planting of vegetables and autochthonous organic matter within the agroforestry complex. These results indicate that long term practice of agroforestry therefore increased nitrogen in the soil through nitrification and microbial breakdown of the leaves.

The Total Phosphorus (TP) of the soil ranged from 8 to 125.4 ppm in agroforestry soils but was 50.03 to 122.7 ppm in soil without any agroforestry practice (Table 4.15). The TP in soils increased with age of agroforestry practices. For farmers with 1-5 years agroforestry practice was 77.61 ± 24.21 ppm, those with 6-10 years practice was 67.47 ± 29.04 ppm, for farms with 11-20 years of agroforestry practice it was 74.91 ± 19.21 ppm and those with over 20 years of agroforestry practice the percent was 82.00 ± 21.82 ppm. There was no significant difference in TP based on the age of agroforestry practice ($p > 0.05$). These results indicate a similarity of TP between the adopters compared to the non-adopters and showed no significant change with age of adoption. Similarity in the TP in the soils between adopters and non-adopters of agroforestry could be due to lack of any phosphate fertilizers during cropping system. Leaves of the trees also rarely contribute to any TP addition in the soils, beside the soil could be low in phosphorus content which is common in arid soils in the tropics (Roy *et al.*, 2016; Maranguit *et al.*, 2017; Meyer *et al.*, 2018).

The Total Organic Carbon (TOC) of the soil ranged from 0.98 to 2.60% in agroforestry soils but was lower at 0.69 to 1.64 ppm in soil without any agroforestry practice (Table 4.15). The TOC in soils for farmers with 1-5 years agroforestry practice was 1.50 ± 0.25%, those with 6-10 years practice it was 1.61 ± 0.30%, then among farmers with 11-20 years of agroforestry practice it was 1.97 ± 0.25% and those with over 20 years of agroforestry practice it was 2.26 ± 0.32%. Statistical analysis indicates that there was a significant difference TOC based on the age of agroforestry practice ($p < 0.05$). The concentration of TOC was also increased significantly with age of adoption (Figure 4.9). Higher concentration of TOC in soils where agroforestry is practiced has been reported in several studies (Benbi *et al.*, 2015; Bhaduri *et al.*, 2017; Bayala *et al.*, 2018; Lim *et al.*, 2018). The extensive root system in trees may allow the plants to derived C from the critical Soil Organic Carbon (SOC) pool in deeper soil horizons (Shi *et al.*, 2013) by stabilizing the soil physico-chemical interactions than shoots (Johnson *et al.*, 2006; Kukal and Bawa, 2014). Thus, agroforestry store more C in soil layers near trees than away from trees (Nair *et al.*, 2015).

The Carbon Nitrogen (C/N) ratio of the soil ranged from 4.66 to 14.32 in agroforestry soils but was 6.39 to 17.16 in soil without any agroforestry practice (Table 4.15). The C/N in soils for farmers with 1-5 years agroforestry practice was 9.95± 2.40, those with 6-10 years practice it was 9.23± 1.60, then among farmers with 11-20 years of agroforestry practice it was 9.31± 1.74 and those with over 20 years of agroforestry practice the percent was 8.08± 1.73. There was a significant difference in C/N ratio based with the age of agroforestry practice ($p < 0.05$). The concentration of C/N ratio was decreasing significantly with age of adoption (Figure 4.9). The current results suggest that the net increase in carbon in the soil was less than the net increase in Nitrogen in the soil after long period of agroforestry practice.

Higher concentration of Nitrogen relative to Carbon in soils where agroforestry is practiced has been reported in several studies (Benbi *et al.*, 2015; Bhaduri *et al.*, 2017;

Bayala *et al.*, 2018; Lim *et al.*, 2018). The accumulation of nitrogen in the soil may be added by leaf litter decomposition in addition to inorganic and organic fertilizers used during cultivation of food crops likely to increase at higher accumulation than carbon over a long period of time. The resulting enhanced tree and crop plant growth by subsequent increase in nitrogen (N) nutrition may result in an increase in SOC sequestration (Ziter and MacDougall, 2013). In land where N-fixing trees are planted, there are more tendencies for SOC sequestration from deeper soil horizons which may enhance humification. The changes are improved in soils containing microbial decomposer which tend to retain SOC (Prescott, 2002).

The Carbon:Phosphorus (C/P) ratio of the soil ranged from 0.01 to 0.04 in agroforestry soils and was 0.01 to 0.03 in soil without any agroforestry practice. The C/P ratio in soils for farmers with 1-5 years agroforestry practice was 0.01± 0.01, those with 6-10 years practice it was 0.02 ± 0.01, then among farmers with 11-20 years of agroforestry practice it was 0.02 ± 0.01 and those with over 20 years of agroforestry practice the percent was 0.03 ± 0.01 (Table 4.15). Statistical analysis indicated that there was a significant difference in C/P ratio according to the age of agroforestry practice ($p < 0.05$). The results show that the proportion of C/P ratio was significantly higher among the adopters compared to the non-adopters and increased with increasing age of adoption (Figure 4.9).

Increased proportion of C/P in soil has been reported to occur in soils where agroforestry is practiced (Lu *et al.*, 2015; Gurmessa *et al.*, 2016; Kim *et al.*, 2016; Atapattu *et al.*, 2017a; Bhatt *et al.*, 2017). These results suggest that carbon accumulated in the soil increased at a higher rate than phosphorus. The low rate of TP accumulation in the soils could be due to lack of any phosphate fertilizers during cropping system. Leaves of the trees also rarely contribute to any TP addition in the soils, beside the soil could be low in phosphorus content as reported for several tropical soils (Roy *et al.*, 2016; Maranguit *et al.*, 2017; Meyer *et al.*, 2018).

4.5.3 Exchangeable Bases in the Soil

The concentration of exchangeable bases in the soils between the adopters and non-adopters in Machakos County is shown in Table 4.16. The concentration of potassium (K) in the soil ranged from 1.02 to 1.32 ppm in soil practising while in soils without such practices, potassium ranged from 0.83 to 0.97 ppm. The potassium concentration in soils for farmers with 1-5 years agroforestry practice was 1.16 ± 0.14 ppm, those with 6-10 years practice it was 0.89 ± 0.14 ppm, and among farmers with 11-20 years of agroforestry practice it was 1.16 ± 0.10 ppm and those with over 20 years of agroforestry practice was 1.02 ± 0.13 ppm. Statistical analysis indicated that there was a significant difference in potassium based with age of agroforestry practice ($p < 0.05$). The concentration of potassium in soils was higher among the adopters as compared to the non-adopters and exhibited an increasing trend with increasing age of agroforestry adoption (Figure 4.10).

Higher potassium in soils practicing agroforestry has been reported in several other studies (Islam and Weil, 2000; Celik, 2005; Lang *et al.*, 2016; Atapattu *et al.*, 2017b; Mulyono *et al.*, 2019). The increased concentration of K in agroforestry may be due to litter decomposition (Clark *et al.*, 1998). The increased potassium in soils could also be due to decomposition of organic matter in soil which is higher in soils practising agroforestry.

The calcium (Ca) in the soil ranged from 2.8 to 5.4 ppm in soils where agroforestry was practiced but in soil without any agroforestry practice it was 2.5 to 3.2 ppm. The calcium concentration in the soils for farmers with 1-5 years agroforestry practice was 3.39 ± 1.17 ppm, those with 6-10 years practice it was 3.58 ± 1.32 ppm, then among farmers with 11-20 years of agroforestry practice it was 3.99 ± 1.00 ppm and those with over 20 years of agroforestry practice the percent was 4.02 ± 0.46 (Table 4.16). Statistical analysis indicates that there was a significant difference in calcium based on the age of agroforestry practice ($p < 0.05$). Concentration of calcium in the soil was higher among the adopters as compared to the non-adopters and increased with increasing age of agroforestry adoption (Figure 4.10). Increasing calcium in soils due to agroforestry has been reported in several studies (Behera and Shukla, 2015; Ngo-Mbogba *et al.*, 2015; Sharma *et al.*, 2016b; Prakash *et al.*, 2018; Mulyono *et al.*, 2019). The increase in calcium in the soil could be due to addition of soil additives such as lime during tillage operation.

The magnesium (Mg) in the soil was low in soils devoid of agroforestry practices 5.72 to 5.99 ppm but was higher in soils practising agroforestry 5.79 to 6.32 ppm. The magnesium content in soils for farmers with 1-5 years agroforestry practice was 5.82 ± 0.21 ppm, those with 6-10 years practice it was 6.37 ± 0.24 ppm, for 11-20 years it was 5.93 ± 0.35 ppm and those with over 20 years of agroforestry practice the content was 6.08 ± 0.51 (Table 4.16). Statistical analysis revealed a significant difference in magnesium with age of agroforestry practice ($p < 0.05$).

The concentration of magnesium in the soil was higher among the adopters as compared to the non-adopters and increased with increasing age of agroforestry adoption (Figure 4.10). These results concurs with those of others who showed a significant increase in magnesium in soil which is associated with agroforestry practices (Bhatt *et al.*, 2016; da Cunha Salim *et al.*, 2018; de Freitas *et al.*, 2018; Mulyono *et al.*, 2019). Absorption of Mg occur in the form of Mg^{2+} ion and is transportable in plants, moving from the older to the younger leaves (Tongkaemkaew *et al.*, 2018) most likely to increase in areas adopting agroforestry trees. Magnesium can also be increased in the soil due to liming which may not raise soil pH (Solanki, 2017). Therefore, higher magnesium content in the soils with a constant pH could have signalled that lime was the main sources of magnesium in the soil.

The sodium (Na) in the soil without agroforestry practice was 2.54 to 2.66 ppm while in soil practising agroforestry it was 2.56 to 3.63 ppm. Sodium content in soils for farmers with 1-5 years agroforestry practice was 2.88 ± 0.93 ppm, those with 6-10 years practice it was 2.52 ± 0.57 ppm, and among farmers with 11-20 years of agroforestry practice it was 2.68 ± 0.74 ppm and those with over 20 years of agroforestry practice, it was 3.51 ± 0.89 (Table 4.16). Statistical analysis indicates that there was a significant difference in sodium with age of agroforestry practice ($p < 0.05$). Sodium in the soil was higher among the adopters as compared to the non-adopters and increased with increasing age of agroforestry adoption. This study concur with other studies which found a significant increase in sodium during agroforestry (Githae *et al.*, 2011; Lagerlöf *et al.*, 2014; Bayala *et al.*, 2018; Corbeels *et al.*, 2019). The possible application of organic residues during farming agricultural crops could be sources of sodium and the use of organic manure in the soils could have increased sodium in the soils resulting in long term accumulation overtime.

Table 4.16: Concentration of exchangeable bases in the soils between the adopters and non-adopters in Machakos County

Age of adoption (years)	**Potassium**	**Calcium**	**Magnesium**	**Sodium**
0	0.96 ± 0.14^{a}	3.27 ± 1.05^{a}	5.91 ± 0.29^{a}	2.57 ± 0.82^{a}
1-5	1.16 ± 0.14^{ab}	3.39 ± 1.17^{a}	5.82 ± 0.21^{b}	2.88 ± 0.93^{ab}
6-10	0.89 ± 0.14^{b}	3.58 ± 1.32^{a}	6.37 ± 0.24^{bc}	2.52 ± 0.57^{ab}
11-20	1.16 ± 0.10^{c}	3.99 ± 1.00^{b}	5.93 ± 0.35^{c}	2.68 ± 0.74^{b}
>20	1.02 ± 0.13^{c}	4.02 ± 0.46^{c}	6.08 ± 0.51^{d}	3.51 ± 0.89^{c}
ANOVA				
F	8.674	13.455	13.423	7.951
df	4	4	4	4
p - Value	0.00242	0.0001	0.0001	0.0007

Values with different letters as superscript in the columns differ significantly ($p < 0.05$)

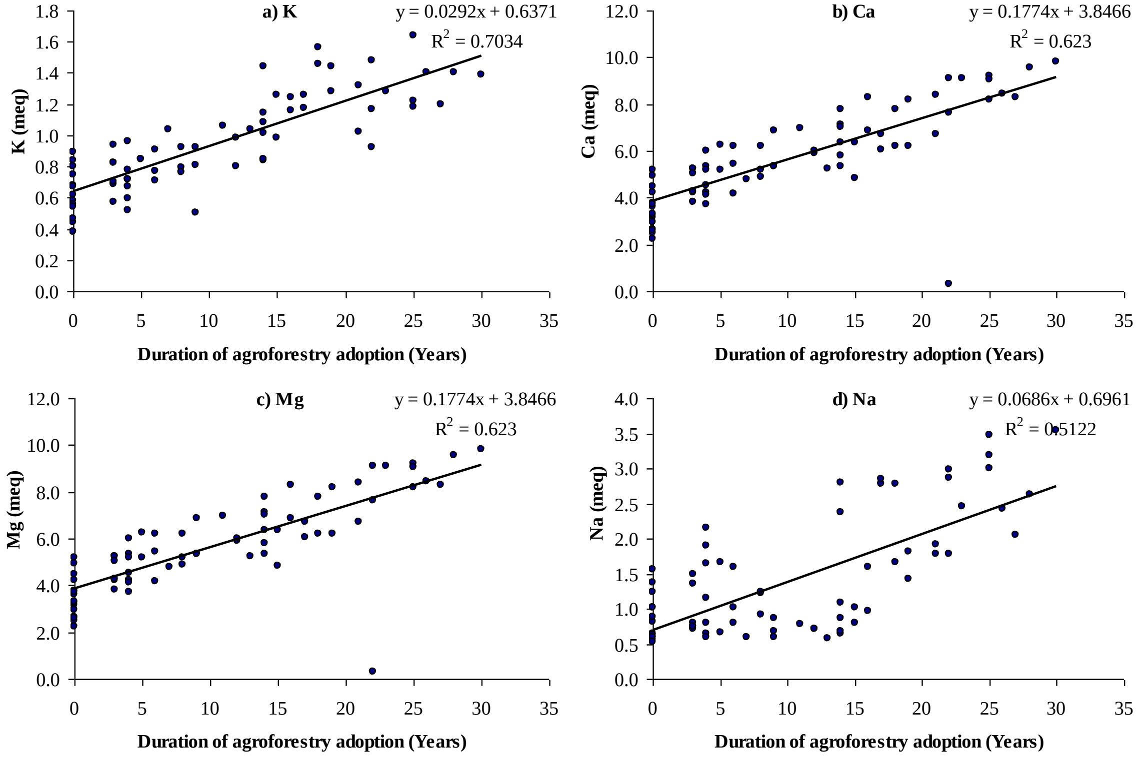

Figure 4.10: Variation in concentration of exchangeable bases in the soils among farmers with different durations of agroforestry adoption.

The foregoing findings regarding higher exchangeable bases in the agroforestry soils may indicate that these nutrients are absorbed from the zone of higher tree root density and accumulate in the tree biomass. Moreover, it seems these exchangeable bases may be considered limiting nutrients for plant growth in the region where plants were able to extract them from the soil and accumulate them above ground or within the soils.

4.5.4 Micronutrients in the Soils

The overall concentrations of micro-nutrients of the soils between the adopters and non-adopters in Machakos County are shown in Table 4.17 while the trends in micro-nutrients with age are provided in Figure 4.11. The Manganese (Mn) of the soil ranged from 1.32 to 1.39 ppm in soils practising agroforestry, but was 1.30 to 1.32 in soil without any agroforestry practice. The manganese in soils for farmers with 1-5 years agroforestry practice was 1.33 ± 0.03 ppm, those with 6-10 years practice it was 1.33 ± 0.04 ppm, then among farmers with 11-20 years of agroforestry practice it was 1.38 ± 0.04 ppm and those with over 20 years of agroforestry practice the percent was 1.36 ± 0.05 ppm. Statistical analysis indicates that there was a significant difference in manganese based on the age of agroforestry practice ($p < 0.05$).

The concentration of manganese increased with age of adoption of agroforestry, which concur with those of those of who showed a significant increase in manganese in soils associated with agroforestry (Bhatt *et al.*, 2016; da Cunha Salim *et al.*, 2018; de Freitas *et al.*, 2018; Mulyono *et al.*, 2019). It is possible that the increased manganese could be attributed to the major pool of manganese in soils originating from crustal sources. The other source of manganese from practice of agroforestry could be attributed to leachates plants and soil surface, shedding or excretion leaves, and animal excreta. Therefore, it is more likely that manganese sources during agroforestry was from wash off from plants leachate from plant tissues as well as shedding of leaves, dead plants and livestock materials.

The concentration of Copper (Cu) in the soil ranged from 8.56 to 10.70 ppm in soils without agroforestry but was 8.82 to 12.98 ppm in soil whose owners practice agroforestry. The copper in soils for farmers with 1-5 years agroforestry practice was 8.80 ± 1.40 ppm, those with 6-10 years practice copper was 8.01 ± 1.17 ppm, and 11-20 years of agroforestry practice it was 12.32 ± 3.27 ppm and those with over 20 years of agroforestry practice the percent was 12.77 ± 2.07 ppm. There was a significant difference in copper relative to the age of agroforestry practice ($p < 0.05$). The concentration of copper increased with age of adoption of agroforestry.

This study concur with those of other researchers who showed a significant increase in copper in soils associated with agroforestry (Lambert and Ozioma, 2012; Uthappa *et al.*, 2015; Sistla *et al.*, 2016; Dhaliwal *et al.*, 2019; Prasad *et al.*, 2019). Copper present as an impurity in silicate minerals or carbonates (Gautam *et al.*, 2017). In some soils, organic matter and soil pH influence copper availability where copper availability increases as organic matter in soil increases since organic matter binds copper from the free state and liberate the copper when it decomposes (Mounissamy *et al.*, 2017). Therefore, the high organic matter content can be the main source of copper in agroforestry soils.

In the soils, practicing of agroforestry elevated Iron (Fe) from 355 to 527 ppm compared to 350 to 278 ppm in soils devoid of agroforestry. The iron concentration in soils for farmers with 1-5 years agroforestry practice was 352.76 ± 98.93 ppm, those with 6-10 years practice it was 521.55 ± 105.22 ppm, then among farmers with 11-20 years of agroforestry practice it was 503.76 ± 90.44 ppm and those with over 20 years of agroforestry practice the percent was 514.73 ± 61.65 ppm. There was a significant difference in iron based on the age of agroforestry practice ($p < 0.05$). Increased iron concentration with age has been reported in other studies as well (Lorenz and Lal, 2014; Schwab *et al.*, 2015; Abreu *et al.*, 2016; Wang *et al.*, 2017; Salgado *et al.*, 2019). Most of the iron in soil is found in silicate minerals or iron oxides and hydroxides, forms that are not readily available for plant use (Pandey *et al.*, 2000; De Souza *et al.*, 2012). Iron from organic matter and degradation of the organic matter pool can be rendered available soils (Yadav *et al.*, 2011). Adding manure to soil during agroforestry may therefore increase iron content in the soils. Iron can also have been increased by spraying of the plants grown during agroforestry with supplemental iron containing fertilizers.

The Zinc (Zn) in the soils ranged from 31.4 to 33.2 ppm in soils with no form of agroforestry practice but was 33.4 to 42.6 in soil practising agroforestry. The zinc in soils for farmers with 1-5 years agroforestry practice was 33.64 ± 9.31 ppm, those with 6-10 years practice it was 51.93 ± 9.72 ppm, then among farmers with 11-20 years of agroforestry practice it was 37.09 ± 6.22 ppm and those with over 20 years of agroforestry practice the concentration was 40.58 ± 11.62 ppm (Table 4.17). There was a significant difference in zinc with soils on the age of agroforestry practice ($p < 0.05$). The concentration of zinc increased with age of adoption of agroforestry. This study concur with those of other researchers who showed a significant increase in zinc in soils associated with agroforestry (Bhatt *et al.*, 2016; da Cunha Salim *et al.*, 2018;

de Freitas *et al.*, 2018; Mulyono *et al.*, 2019; Parveen *et al.*, 2019). Zinc can be increased in the soil by application of fertilizers containing zinc, of which the most common are zinc chelates, zinc Sulphate and zinc oxide which is common in most fertilizers formulation (Meena *et al.*, 2019). It has also been reported that high levels of phosphorus found in several phosphate fertilizers (e.g. DAP) may increase the concentration of zinc in the soil by interfering with its metabolism in plants and help in the precipitation of zinc in soil (Bhaduri *et al.*, 2017; Lenci *et al.*, 2018; Sarabia *et al.*, 2020). Therefore the increase Zn with age of the agroforestry could be due to use of fertilizers during conventional agriculture.

Table 4.17: Concentrations of micro-nutrients of the soils between the adopters and non-adopters in Machakos County

Age of adoption (years)	Manganese	Copper	Iron	Zinc
0	1.32 ± 0.03 ^{a}	8.62 ± 3.93 ^{a}	350.57 ± 85.22 ^{a}	32.20 ± 5.54 ^{a}
1-5	1.33 ± 0.03 ^{b}	8.80 ± 1.40 ^{a}	352.76 ± 98.93 ^{b}	33.64 ± 9.31 ^{b}
6-10	1.33 ± 0.04 ^{c}	8.01 ± 1.17 ^{a}	521.55 ± 105.22 ^{c}	51.93 ± 9.72 ^{c}
10-20	1.38 ± 0.04 ^{d}	12.32 ± 3.27 ^{b}	503.76 ± 90.44 ^{d}	37.09 ± 6.22 ^{c}
>20	1.36 ± 0.05^{e}	12.77 ± 2.07 ^{c}	514.73 ± 61.65 ^{e}	40.58 ± 11.62 ^{d}
ANOVA				
F	7.615	6.675	6.992	4.772
df	4	4	4	4
p - Value	0.000	0.001	0.000	0.002

Values with different letters as superscript in the columns differ significantly ($p < 0.05$)

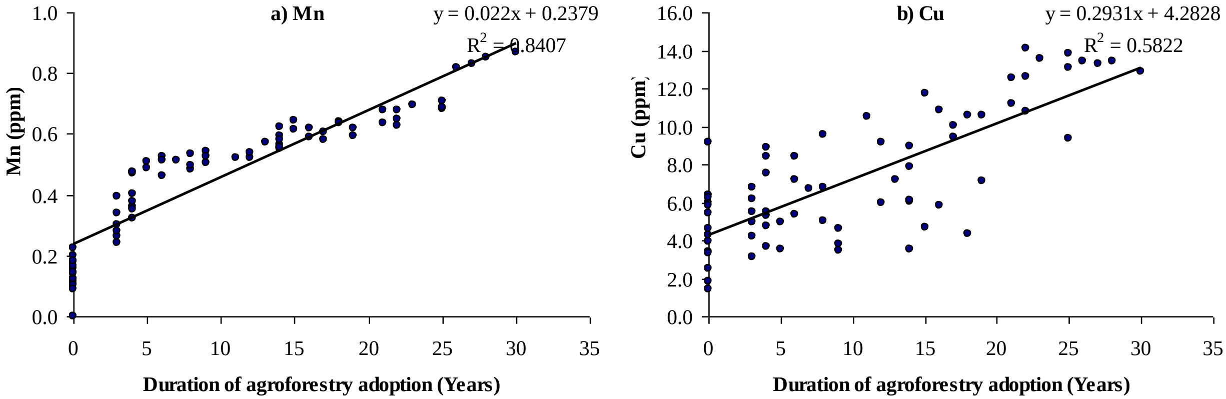

Figure 4.11: Variation in micro nutrients in the soils among farmers with different durations of agroforestry adoption.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This study determined the influence of agroforestry adoption on ecosystem services, income and livelihoods for smallholder farmers in Machakos County, Kenya. The study was guided by four objectives: To determine the influence of socio-economic and institutional factors on the adoption of agroforestry practices among smallholder farmers in Machakos County; assess the influence of agroforestry practices on ecosystem services among smallholder farmers in Machakos County; evaluate the influence of adoption of agroforestry practices on rural income and livelihoods of smallholder farmers in Machakos County and analyze the influence of agroforestry practices on soil physico-chemical parameters among smallholder farmers in Machakos County. Data were collected through household questionnaires from 248 respondents, and soil laboratory analysis.

The first objective sought to determine the influence of socio-economic and institutional factors on the adoption of agroforestry practices among smallholder farmers in Machakos County. The study determined that majority of the respondents who had adopted agroforestry were elderly aged above 36 years, mostly females, with secondary levels of education with 2-5 hectares of land. Income for majority of the adopters ranged between US$ 50 to 500. The study further established that there was 82.3% adoption of agroforestry practices. Most respondents adopted boundary tree planting (73.8%), hedgerow (69.4%) and scattered trees in rangeland (51.2%) while alley cropping was the least preferred agroforestry practice (37.1%). There was significant ($P < 0.05$) influence of age on agroforestry adoption where adoption of agroforestry increased with age of the farmers, level of education, household size where adoption of agroforestry was large in household size of 6-10 people. The study also established that access to credit facilities, access to formal agroforestry training, access to information of conservation groups and access to inputs from conservation groups significantly affected adoption of agroforestry in the study area. When socio-economic and institutional factors were combined, then a combination level of education, household size, access to credit and training significantly affected adoption. It is possible to infer that a combinations of these factors provided adopters with knowledge, manpower and technical ability to undertake agroforestry practices.

The second objective determined the influence of agroforestry practices on ecosystem services among smallholder farmers in Machakos County. The study established that ecosystem services by the smallholders farmers who adopted agroforestry practices was mainly the ecosystem supporting functions (82.5%) followed by regulatory functions (80.8%). Provisioning ecosystem service was the third most important function as perceived by the local community members (73.5%) while least was cultural functions (61.4%). Provisioning services by most of the local community members was fuelwood (84%), fruit and nuts (75%), poles (74%), timber (72%) and least for fodder. As for ecosystem regulatory services, majority of the respondents reported these to entail micro-climate regulation (85%), soil erosion control (83.5%), water infiltration (83%), flood control (51%) and least for disease and pest control (44%). Ecosystem supporting functions among the local community members was for nutrient cycling (83%) followed by soil formation (81%). Ecosystem cultural functions among the local community members was for recreation (77.5%), followed by aesthetic function (66.7%), education (54%) and least in spiritual functions (41.2%).

The third objective of the study was to evaluate the influence of adoption of agroforestry practices on rural income and livelihoods of smallholder farmers in Machakos County. The result shows that income derived from crop, livestock, tree seedlings and tree products as well as the farm and total income of the farmers were all significantly higher for the adopters. The average income derived from timber and fuel wood as well as the total income derived from wood and non-wood products was significantly higher for the adopters than non-adopters. However, the income derived from posts/poles and from fodder were similar for the adopters and non-adopters. The annual expenditure on food, clothing, education, medicine and total household expenditure on basic needs were all significantly higher for the adopters than non-adopters. The household annual expenditure on timber, poles as well as the total expenditure on wood and non-wood products was significantly higher for the non-adopters than adopters. Gross revenue for the adopters was US$ 1,237 which was higher than the non-adopters of US$ 758. The overall expenditure on variable cost by the adopters was US$ 890 which was higher than the non-adopters of US$ 664. There were higher net returns above Total Variable Costs (TVC) for the adopters (US$ 346) compared to the non-adopters (US$ 95), which resulted in positive higher net returns above Total Cost (TC) for the adopters (US$ 278) compared to the non-adopters (US$ 24). The computed margins above TVC (%) was therefore higher for the agroforestry adopters (28.02%) than the non-adopters (12.48%) and margins above the total cost for the adopters was 22.30% and 3.15% for the non-adopters.

The indicators of improved livelihoods among the adopters and non-adopters of agroforestry were also determined. The adopters of agroforestry, majority attested that indeed there was increased food supply, improved educational attendance and increased energy in the household. This study also determined the influence of adoption of agroforestry practices on rural livelihood of smallholder farmers and found that adopters of agroforestry had increased food supply, improved educational attendance and increased energy in the household. Thus agroforestry support socio-economic needs and improving the livelihoods conditions of the people in Machakos County.

The fourth objective of the study was to establish the influence of agroforestry practices on physico-chemical soil quality parameters. Adoption of agroforestry resulted to reduced sandy soil, and increased the percentage of silt in the soil but adoption did not result in any distinguishable differences in clay particles. In terms of other physical parameters, adoption of agroforestry improved the bulk density. In terms of chemical parameters (pH and concentration of TN, TP, TOC, C/N and C/P ratios) in the soils, the study established a significant increase in TN, TOC and C/P ratio but reduced the C/N ratio, and did not changes in the soil pH and TP during agroforestry adoption. As for exchangeable bases, the concentration of potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) in the soil increased with adoption duration in years of agroforestry. The possible application of organic residues during farming agricultural crops could be sources of the exchangeable bases. Among the micronutrients, the study determined that the concentration of manganese (Mn), copper (Cu), iron (Fe), and zinc (Zn) were all higher among adopters than adopters.

5.2 Conclusions

Age, level of education, household size, and non-farm income were significant socio-economic factors while access to credit facilities, access to formal agroforestry training, access to information of conservation groups and access to inputs from conservation groups were the significant institutional factors affecting adoption of agroforestry. Among 14 socio-economic and institutional factors level of education, household size, access to credit and access to agroforestry training to farmers in conservation groups were responsible for the adoption of agroforestry.

Majority of the local community members attested that they received various ecosystems supporting functions (81.5%), regulatory functions (80.8%). The highest percentage rank on the ecosystem regulatory functions among the local community members was for micro-climate regulation (85%), followed by soil erosion control (83.5%), water infiltration (83%), flood control (51%) and least for disease and pest control (44%). Also, the highest percentage rank on the ecosystem cultural functions among the smallholder farmers were for recreation (77.5%), followed by aesthetic function (66.7%), education (54%) and least in spiritual functions (41.2%).

Income derived from crops, livestock and tree resources as well as the total income of the smallholder farmers were all significantly higher for the adopters than non-adopters. The annual expenditure budget on timber and fire wood as well as the total expenditure budget on wood and non-wood products were all significantly higher for the non-adopters than adopters. However, the annual household expenditure budgets derived from posts/poles and from fodder were similar for the adopters and non-adopters. The annual household expenditure budget on food, clothing, education, medicine and total household expenditure on basic needs were all significantly higher for the adopters than non-adopters.

Analysis of gross revenue, net returns above TVC, margins above TVC (%) suggest that income was higher for the adopters resulting in profitable operational margins that render adoption as a good enterprise. There were significant contribution of agroforestry to livelihoods between the adopters and non-adopters where the adopters of agroforestry practices reported increased food supply, improved educational attendance and increased energy in the household. The scores of the indicators of household livelihoods indicated consistently higher rank scores for all the livelihoods indicators among adopters compared to the non-adopters.

Physical proportion of sand particles was higher among non-adopters compared to adopters of agroforestry practices while the proportions of silt and bulk density in the soil were higher among the adopters than non-adopters. In terms of chemical properties, the study established that TN, TOC, Ca, K, Na, Mg, Mn, Cu, Fe, Zn and C/P ratio were higher in soils where agroforestry was being practiced. However, the concentration of C/N ratio was decreasing significantly with age in years of agroforestry adoption but soil pH and total phosphorus (TP) showed similarity between soils practicing agroforestry and those without the practice. Overall physical and chemical attributes in the soil improved with increasing age duration in years of agroforestry adoption.

5.3 Recommendations

Based on the findings of this study, the following recommendations were formulated:-

1) National and County governments to support and intensify training, extension services, raise information on adoption of upcoming agroforestry technologies
2) Policy makers to encourage adoption of agroforestry to improve supply of ecosystem goods and services to smallholder farmers.
3) Farmers to adopt agroforestry for improved rural income and livelihood for value for money on investment on agroforestry. There is also a need for proper documentation of agroforestry adoption on rural incomes and expenditures, livelihoods and enterprise budget in Kenya which would help formulate strategies to intensify agroforestry technologies.
4) Promotion of agroforestry for improved soil physical and chemical parameters to increase yields and agricultural productivity to smallholder farmers.

5.4 Further Research

1) There is need for more studies on agroforestry in the entire county on the right kind of species for different agroforestry adoption practices in the different ecological zones. This should be combined with an extensive study on the level of knowledge by the different farmers regarding the different agroforestry practices and species.
2) Future study should look at the agroforestry management practices that influence soil quality parameters that were not considered in this study.
3) Ecosystem services should in future be evaluated based on monetary or economic values.

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APPENDICES

Appendix 1: Household Questionnaire for Smallholder Farmers

Topic: Influence of agroforestry adoption on ecosystem services and livelihoods for smallholder farmers in Machakos County (Kenya)

Preamble

Dear Respondent,

I am a postgraduate student in the School of Environmental Studies in Kenyatta University, carrying out research for my Ph.D. in Environmental Science. You being part of farmers in Machakos County you have been selected as a respondent. My study focus on the *"Influence of agroforestry adoption on ecosystem services and livelihoods for smallholder farmers in Machakos County (Kenya)".*These questions are for research purpose only and confidential. Your cooperation in answering these questions will be highly appreciated.

Section A: General Information

Interview Date: …………..... Interviewer No………..Interview No……………….

Sub-County…………..District…………Location: ……….Sub-location……...........

Conservation Group Name: …………………………....Adopter (1) / Non-Adopter (0)

Altitude……………………Eastings……………………….Northings…………………….

Ecological Zone (1). II…. (2). III …. (3) IV…. (4).V…….

Agro-Ecological Zone (1).LH_2 (Iveti Hills)…. (2).LH_4 (Mua Hills) …. (3) UM_3 (Kalama & Kiima Kimwe Hills).….. (4). UM_4 (Lower Kiandani)……

Section B: Socioeconomic characteristics

1. Gender: Male [ ] Female [ ]
2. Marital status: Married [ ] Single [ ]
3. Age (Years) ………..
4. What is your level of education: None [ ] Primary [ ] Secondary [ ] Tertiary [ ]
5. Occupation(s) of the head of household: Farmer [ ] Non-Farmer [ ]
6. Household size (Number): ……………………
7. How many members of your household are below 18 years …………..

8. What is the total size of your farm (in acres)?..............
9. What is average farm income per annum Ksh………………..
10. What is average non-farm income per annum Ksh……………

Section C: Institutional factors

1. Do you have access to extension services? Yes [ ] No [ ]
2. Have you benefited from extension services since you adopted hedgerow agroforestry? Yes [ ] No [ ]
3. If Yes to Question 2 above state the sources: 1. KFS 2. Agriculture 3. County Government 4. NGOs 5. Others (Specify)…………………..
4. Do you have access to credit facilities? Yes [ ] No [ ]
5. If Yes to Question 4 above, have you benefited from credit facilities to enhance your hedgerow A/F? Yes [ ] No [ ]
6. If Yes to Question 5 above, from which source 1. Banks 2. Micro-finance 3. Youth fund 4. Women fund 5. Others (Specify) ………..
7. Have you received support from NGOs on hedgerow A/F? Yes [ ] No [ ]
8. If Yes to Question 7 above, please specify the NGO………………………….
9. Have you received any formal training on hedgerow since you adopted A/F system? Yes [ ] No [ ]
10. If Yes to Question 9 above, Specify who trained you: 1. KFS 2. Agriculture 3. County Government 4. NGOs 5. Others (Specify)…………………..
11. Are you currently a member of any conservation Group? Yes [ ] No [ ]
12. If Yes to Question 11 above, specify Name of the Group………………………….
13. Have you ever participated in conservation group activities? Yes [ ] No [ ]
14. Has conservation group activities helped you as an individual? Yes [ ] No [ ]
15. What challenges do you face that hinder your participation in conservation group activities?

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

17. How often are you visited by extension staff at your farm?

(1) Not at all, (2) Rarely, (3) Yearly, (4) Once in a month, (5) Quite often

18. How often do you visit the extension officers/offices?

(1) Not at all, (2) Rarely, (3) Yearly, (4) Once after several months, (5) Often

19. Do extension officers provide seedlings Yes [ ] No [ ]

20. If no, what is the source of your tree seedlings?

From conservation group nurseries [ ]
Bought from private nurseries [ ]
Borrow from friends [ ]
Others, specify……………………………..…

Section D: Agroforestry adoption and practices

1. Have you adopted agroforestry in your farm? Yes [ ] No [ ]
2. Indicate agroforestry practices in your farm, by ticking (√) below.

Agroforestry practice	**Yes (1)**	**No (0)**
1. Hedgerow		
2. Alley cropping		
3. Woodlots		
4. Boundary tree planting		
5. Shelter belt (Windbreak)		
6. Homestead/Compound tree planting		
7. Scattered trees planting		

3. In your hedgerow agroforestry technology where do you plant trees?
    a. Along the contour [ ]
    b. Along the terrace on soil conservation structure [ ]
    c. At the hedge on cut off drains [ ]

Section E: Ecosystem services from agroforestry

1. Have you adopted any agroforestry in your farm? Yes No ☐ ☐

2. If your answer to question 1 above is Yes, please specify its benefits to your household: by putting a tick (√) in the box at the appropriate spot: KEY: 1= Strongly disagree, 2=Disagree, 3=Uncertain, 4=Agree, or 5= Strongly agree

NO.	Ecosystem Function		1	2	3	4	5
1	Provisioning	Fuelwood					
		Timber					
		Poles					

		Fodder					
		Fruits, nuts and berries					
2	Regulating	Soil Erosion control					
		Water infiltration					
		Micro-Climate influence					
		Flood control					
		Diseases and pests'					
3	Supporting	Nutrients recycling					
		Soil formation					
4	Cultural	Spiritual					
		Recreation					
		Education					
		Aesthetic					

Section E: Income and rural livelihood

1. Kindly indicate your average level of farm income (per year) from crops KSh.…….., livestock KSh……………….. and tree products KSh…………………….

   KSh. ______________

2. How much do you realize per year from the sale of trees and tree products

   Timber KSh.____________, Fuelwood KSh. ____________, Poles/Posts KSh.___________

   Fodder KSh._____________

3. Does adopting and including trees in farmlands enhanced ecosystem services and improved your livelihood for the last one year in the following contexts

No.	**Activity**	**Yes**	**No**
1	Reduced fertilizer use in the farm		
2	Increased soil fertility		
3	Reduced purchase of fuelwood		
4	Increase water infiltration and flow in farm		
5	Increased nutrient recycling / Nitrogen fixation		
6	Increase crop yields		
7	Increase income		
8	Reduced expenditure		
9	Influence of micro-climate		

4. Does crop proceeds from your farm satisfy the family food requirement Yes (1) No (0)

   If Yes, how many months are you food insecure? ……………Months

   If No, State how you supplement the family food needs.

Lease land [ ] Buy from Market [ ] Sale of timber [ ]

Sell fruits [ ] Work for neighbors to get food [ ]

Get relief food [ ] Others (specify)……………

5. Does tree proceeds from agroforestry satisfy the family fuelwood requirement?Yes [ ] No [ ]
6. What products do you get from the trees planted in the farm? (specify)

Firewood [ ] Fodder for livestock [ ] Poles / posts [ ]

Timber [ ] Others (specify) ________________________

7. Does tree proceeds from your farm satisfy the family fuelwood requirement

Yes [ ] No [ ]

If No, state how you supplement the family fuelwood needs

Buy from neighbor [ ] Buy from market [ ] Use charcoal [ ]

Use LPG gas/paraffin [ ] Others (specify)___________________________

8. State the factor(s) that significantly influence adoption of agroforestry and ecosystem services

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

9. Kindly indicate your level of expenditure on food per year:

KSh. _______

Kindly indicate your level of expenditure on non- food per year (Clothing KSh…….., Education KSh……………, Medical KSh……………...

Total KSh. ______________

10. Kindly indicate your level of spending per year on the following forest products items:

Timber KSh._______, Fuelwood KSh. ______, Poles/Posts KSh._____Fodder KSh.______

Section F: Influence of agroforestry on soil quality

1. What type of soil is in your farm?

NO.	Soil Type	Yes (1)	NO (1)
1.	Clay (Black cotton soils - local name)		
2.	Loam (Brown loam soils - local name)		
3.	Sand (Sandy soil - local name)		

2. Does agroforestry enhance soil conservation in your farm? Yes [ ] No [ ]
3. State the extent to which adoption of hedgerow agroforestry and ecosystem services has affected soil characteristics using a scale of 1=Not at all 2=To a small extent 3=To a moderate extent 4=To a large extent 5= To a very large extent

No.	Soil characteristics	1	2	3	4	5
1	Physical characteristics					
2	Chemical characteristics (Fertilizer use)					

4. If in questions 1 and 2 above, there is an effect, kindly state the specific ways in which adoption of agroforestry and ecosystem services has affected soil characteristics

Physical characteristics ______________________

____

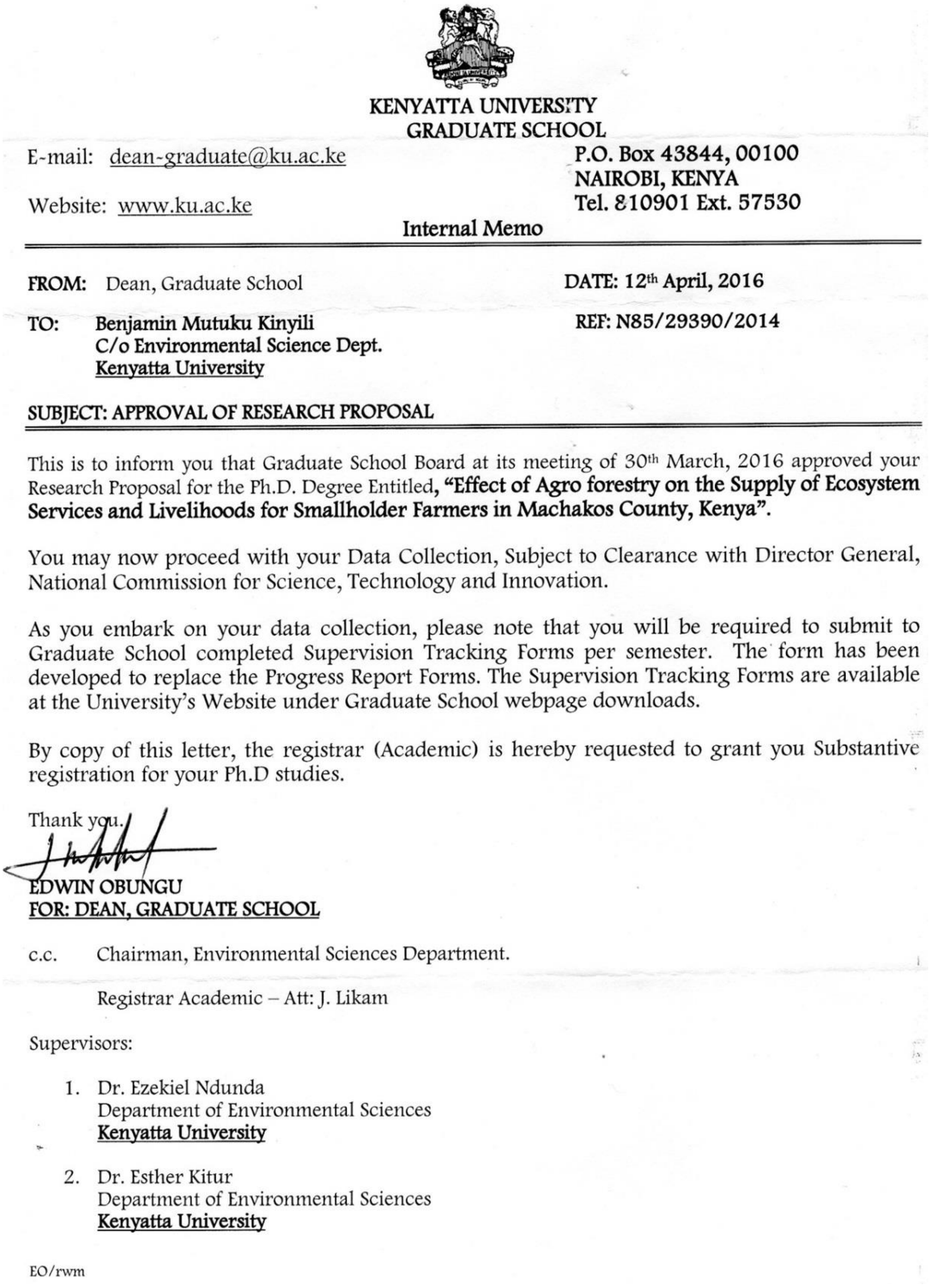
Chemical characteristics ______________________

____

Section G: Way forward

1. What suggestions would you make for improving Agroforestry in Machakos Sub-County in the following areas?
   (a) Soil Conservation……………………………………………………
   (b) Nutrient recycling and nitrogen fixation.………………………………
   (c) Shading effects……..…………………………………………………..
   (d) Provision of fuelwood, timber, fruits………………………………………
   (e) Livelihood improvement…………………………………………………

Appendix 2: Kenyatta University Research Approval



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Internal Memo

FROM: Dean, Graduate School

DATE: 12th April, 2016

TO: **Benjamin Mutuku Kinyili**
C/o Environmental Science Dept.
Kenyatta University

REF: N85/29390/2014

SUBJECT: APPROVAL OF RESEARCH PROPOSAL

This is to inform you that Graduate School Board at its meeting of 30th March, 2016 approved your Research Proposal for the Ph.D. Degree Entitled, **"Effect of Agro forestry on the Supply of Ecosystem Services and Livelihoods for Smallholder Farmers in Machakos County, Kenya".**

You may now proceed with your Data Collection, Subject to Clearance with Director General, National Commission for Science, Technology and Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking Forms per semester. The form has been developed to replace the Progress Report Forms. The Supervision Tracking Forms are available at the University's Website under Graduate School webpage downloads.

By copy of this letter, the registrar (Academic) is hereby requested to grant you Substantive registration for your Ph.D studies.

Thank you.

EDWIN OBUNGU
FOR: DEAN, GRADUATE SCHOOL

c.c. Chairman, Environmental Sciences Department.

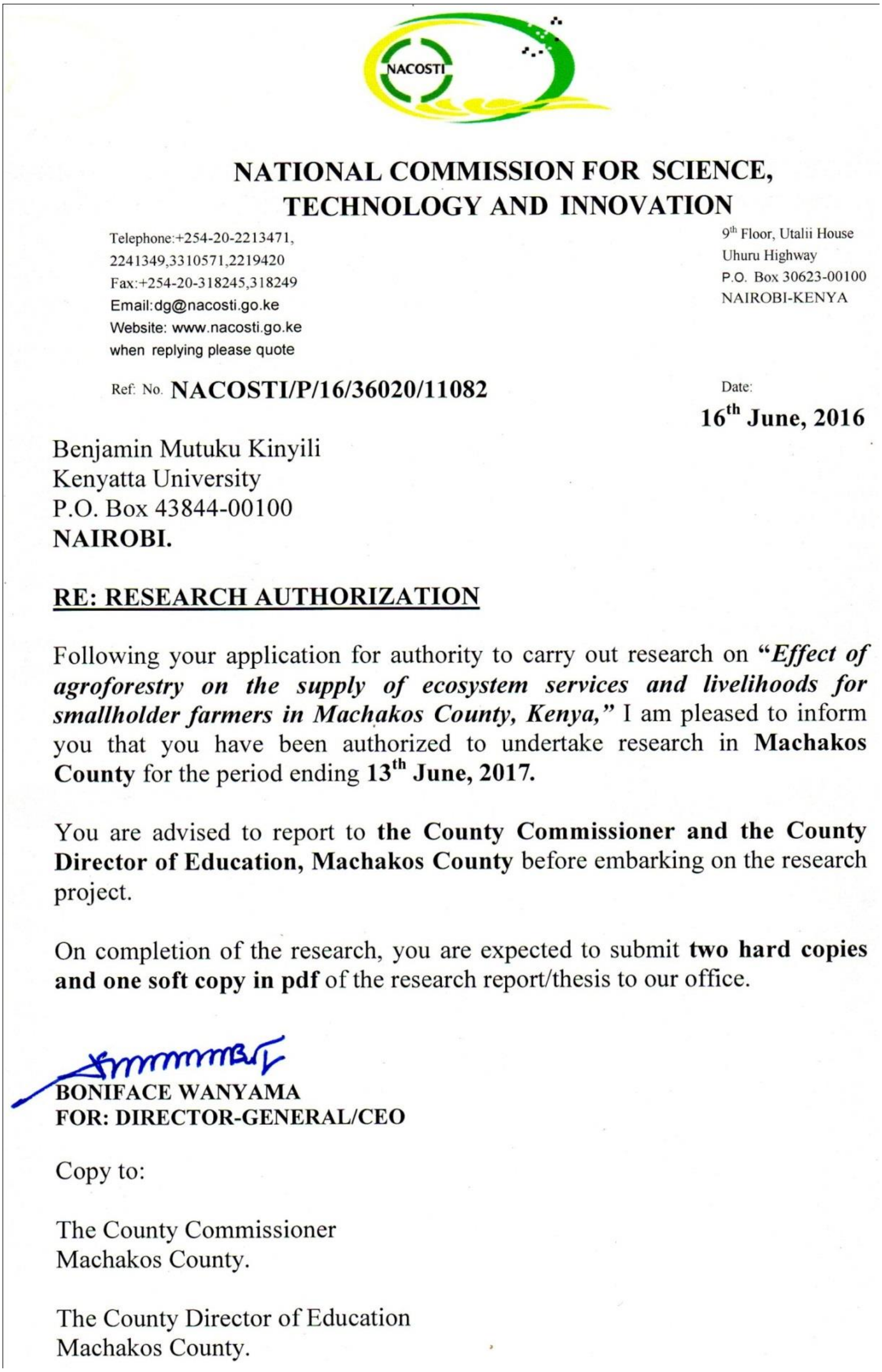
Registrar Academic – Att: J. Likam

Supervisors:

1. Dr. Ezekiel Ndunda
   Department of Environmental Sciences
   Kenyatta University
2. Dr. Esther Kitur
   Department of Environmental Sciences
   Kenyatta University

EO/rwm

Appendix 3: National Commission for Science, Technology and Innovation (NACOSTI) Research Authorization



NATIONAL COMMISSION FOR SCIENCE,
TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax:+254-20-318245,318249
Email:dg@nacosti.go.ke
Website: www.nacosti.go.ke
when replying please quote

9th Floor, Utalii House
Uhuru Highway
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/16/36020/11082**

Date:
16th June, 2016

Benjamin Mutuku Kinyili
Kenyatta University
P.O. Box 43844-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Effect of agroforestry on the supply of ecosystem services and livelihoods for smallholder farmers in Machakos County, Kenya,"*** I am pleased to inform you that you have been authorized to undertake research in **Machakos County** for the period ending **13th June, 2017.**

You are advised to report to **the County Commissioner and the County Director of Education, Machakos County** before embarking on the research project.

On completion of the research, you are expected to submit **two hard copies and one soft copy in pdf** of the research report/thesis to our office.

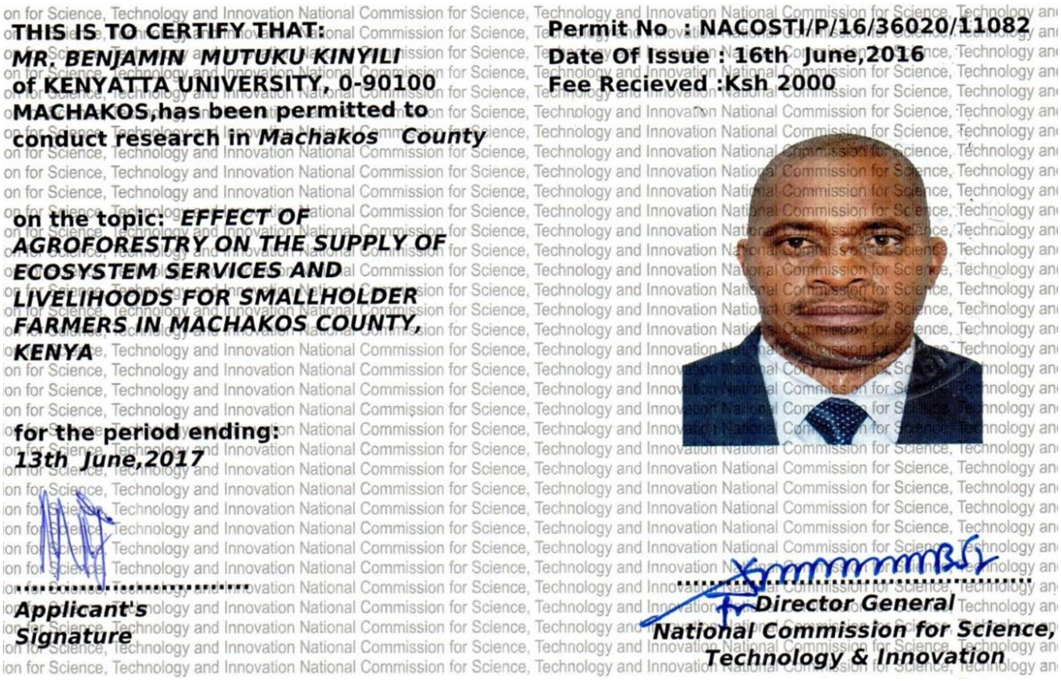
BONIFACE WANYAMA
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Machakos County.

The County Director of Education
Machakos County.

Appendix 4: National Commission for Science, Technology and Innovation (NACOSTI) Research Permit



THIS IS TO CERTIFY THAT:
MR. BENJAMIN MUTUKU KINYILI
of KENYATTA UNIVERSITY, 0-90100
MACHAKOS,has been permitted to
conduct research in *Machakos County*

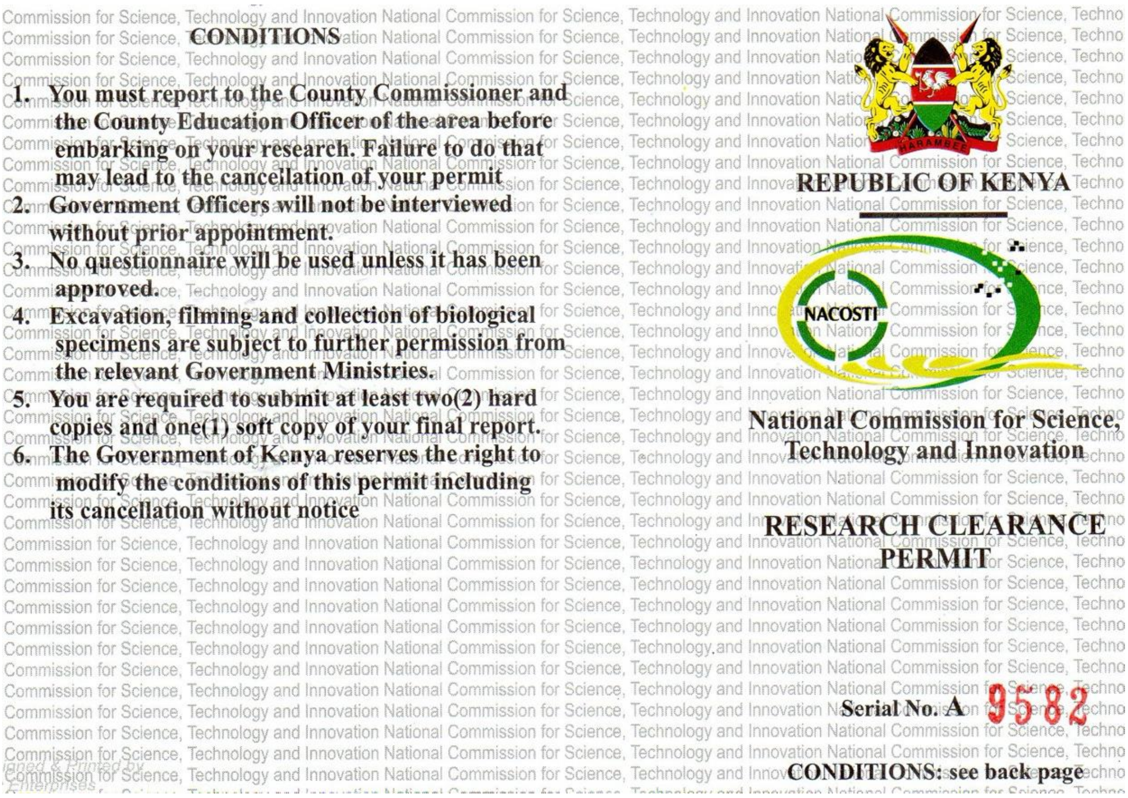
on the topic: *EFFECT OF AGROFORESTRY ON THE SUPPLY OF ECOSYSTEM SERVICES AND LIVELIHOODS FOR SMALLHOLDER FARMERS IN MACHAKOS COUNTY, KENYA*

for the period ending:
13th June,2017

Permit No : NACOSTI/P/16/36020/11082
Date Of Issue : 16th June,2016
Fee Recieved :Ksh 2000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation



CONDITIONS

1. **You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit**
2. **Government Officers will not be interviewed without prior appointment.**
3. **No questionnaire will be used unless it has been approved.**
4. **Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.**
5. **You are required to submit at least two(2) hard copies and one(1) soft copy of your final report.**
6. **The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice**

REPUBLIC OF KENYA

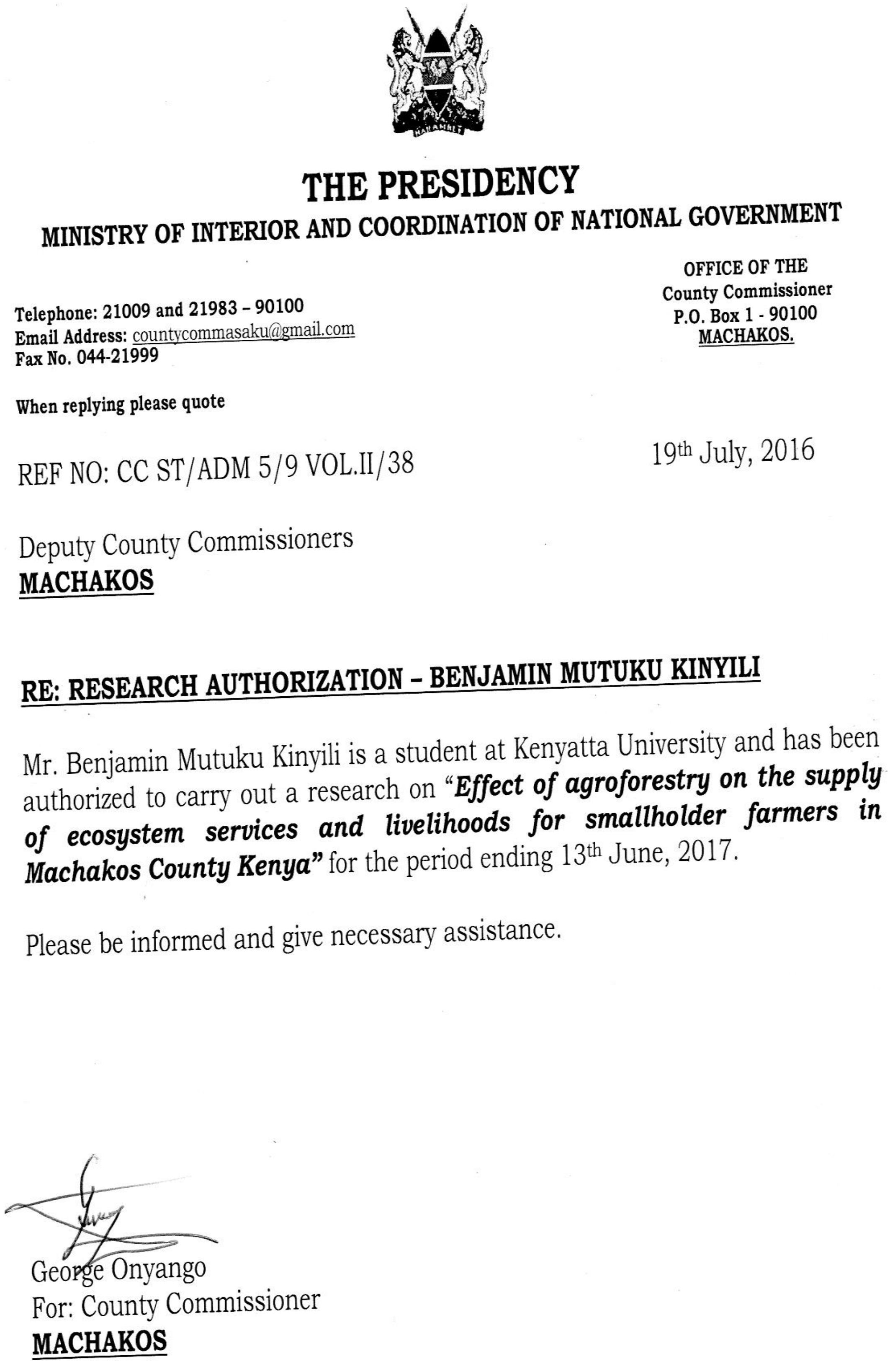
National Commission for Science, Technology and Innovation

RESEARCH CLEARANCE PERMIT

Serial No. A 9582

CONDITIONS: see back page

Appendix 5: Machakos County Commissioner Research Authorization



THE PRESIDENCY

MINISTRY OF INTERIOR AND COORDINATION OF NATIONAL GOVERNMENT

OFFICE OF THE
County Commissioner
P.O. Box 1 - 90100
MACHAKOS.

Telephone: 21009 and 21983 – 90100
Email Address: countycommasaku@gmail.com
Fax No. 044-21999

When replying please quote

REF NO: CC ST/ADM 5/9 VOL.II/38

19th July, 2016

Deputy County Commissioners
MACHAKOS

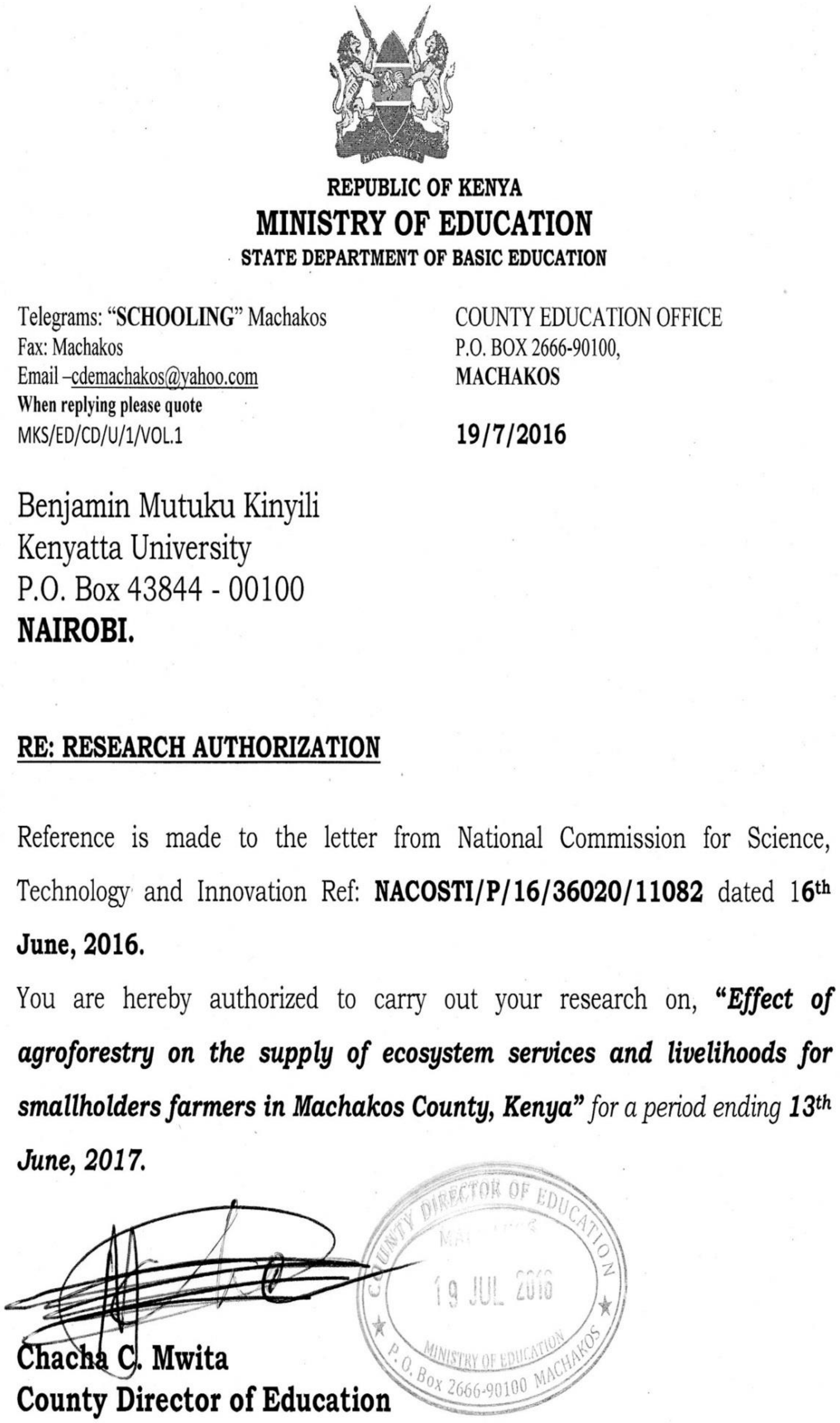
RE: RESEARCH AUTHORIZATION – BENJAMIN MUTUKU KINYILI

Mr. Benjamin Mutuku Kinyili is a student at Kenyatta University and has been authorized to carry out a research on "***Effect of agroforestry on the supply of ecosystem services and livelihoods for smallholder farmers in Machakos County Kenya***" for the period ending 13th June, 2017.

Please be informed and give necessary assistance.

George Onyango
For: County Commissioner
MACHAKOS

Appendix 6: Machakos County Director of Education Research Authorization



REPUBLIC OF KENYA
MINISTRY OF EDUCATION
STATE DEPARTMENT OF BASIC EDUCATION

Telegrams: "**SCHOOLING**" Machakos
Fax: Machakos
Email –cdemachakos@yahoo.com
When replying please quote
MKS/ED/CD/U/1/VOL.1

COUNTY EDUCATION OFFICE
P.O. BOX 2666-90100,
MACHAKOS

19/7/2016

Benjamin Mutuku Kinyili
Kenyatta University
P.O. Box 43844 - 00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Reference is made to the letter from National Commission for Science, Technology and Innovation Ref: **NACOSTI/P/16/36020/11082** dated 1**6th June, 2016.**

You are hereby authorized to carry out your research on, ***"Effect of agroforestry on the supply of ecosystem services and livelihoods for smallholders farmers in Machakos County, Kenya"*** *for a period ending* ***13th June, 2017.***

19 JUL 2016

Chacha C. Mwita
County Director of Education