IMPACT OF TREE SPECIES ON MAIZE PRODUCTIVITY BY SMALLHOLDER FARMERS IN EASTERN KENYA

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Impact of tree species on maize productivity by smallholder farmers in Eastern Kenya

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DECLARATION BY THE CANDIDATE

This dissertation is my original work and to my knowledge has not been presented for the award of a degree in any other University.

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DEDICATION

To all the farmers in Meru and Embu who allowed me to conduct my research work in their farms.

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Provider, Friend, Supervisor, Parent and Guardian the ALMIGHTY GOD; Forever I shall praise him.

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LIST OF ACRONYMS

AEZ	Agro-ecological Zones
ARS	Agricultural Research Stations
ANOVA	Analysis of Variance
CA	Conservation Agriculture
CEC	Cation Exchange Capacity.
CIMMYT	International Maize and Wheat improvement Centre
DBH	Diameter at breast height
GDP	Gross Domestic Product
GPS	Global Positioning System
GFCL	Global Forest Cover loss
ICRAF	International Centre for Research in Agroforestry
IPAR	Intercepted photo synthetically active radiation
KARI	Kenya Agricultural Research Institute
LH	Lower Highlands
MASL	Meters above Sea Level
NEWS	North, East, West and South.
NGO	Non-Government Organizations
OFR	On Farm Research
TOT	Transfer of Technology
SAS	Statistical Analysis System
SLM	Soil Land Management
SPSS	Statistical package for Social sciences
SOC	Soil Organic Carbon

SSA	Sub Saharan Africa
WACE	Weeks after crop emergence

ABSTRACT

Low maize productivity due to declining soil fertility is a major problem faced by smallholder farmers in Eastern Highlands of Kenya. Adoption of agroforestry which has a huge potential to halt land degradation on farms is however, very low due to lack of documented evidence on the effects of the woody perennial tree species on the soil, growth and yield of maize. An on-farm survey was therefore carried out to identify common tree species in four study sites in Eastern Kenya. The main objective was to investigate the effects of the identified common tree species on soil organic carbon, pH, maize growth and yield.

A baseline survey was conducted in 50 farms chosen at random from the existing farmers' groups from the four sites to identify the common tree species growing on farms. Four farms were selected in each site to make a total of 16 farms for the study. Three most prevalent tree species growing within the cropping area on farms were selected in each site. Plots were marked under the canopies of selected individual trees and control plots (at least 10 meters away from any tree). A survey was carried out on soil, crop growth and yield during the long cropping season of 2012 that stretched from March to June. Soil sampling was done at the beginning of the cropping season under the canopies of the selected trees and in control plots to determine the influence of the tree species on total organic carbon (TOC) and pH in the soil on farms. The influence of the trees on maize growth was also examined on plants; selected in plots under the trees and control. The height, basal diameter and SPAD readings (related to the amount of chlorophyll) were examined. Grain yield was determined at the end of the season only at one site (Kyeni) due to seasonal crop failure at the other three sites.

Results on soil carbon revealed that at Kyeni *Croton macrostachyus* Hochst. Ex Delile significantly increased soil carbon than *Grevillea robusta* A. Cunn. Ex R. Br. Soils sampled under *C. macrostachyus* had the highest mean (% TOC) of 2.78 compared to 2.04 for *G. robusta* plots, however *C. macrostachyus* plots were not significantly different from the *Cordia africana* Lam. and the control plots. *Senna spectabilis* (D.C.) H.S. Irwin & Barneby also had a significantly higher soil carbon value of 2.89 % compared to the control plots that had the lowest value of 2.33 % at Kanwaa. However, no significant differences were found between *Senna spectabillis*, *G. robusta* and *Vitex payos* (Lour.) Merr plots. No significant differences were observed between the tree species at Mweru and Mworoga on their influence on soil carbon.

In soil pH analysis, the results revealed that the control plots had a significantly lower pH value than the plots under the trees at all the sites ($p < 0.001$). Except for the soils sampled under the *Grevillea robusta* tree species at Kyeni, that revealed significantly lower ($p < 0.001$) soil pH value of 5.99 compared to *Cordia africana* (6.42), *Croton macrostachyus* (6.44) and the control (6.28). At Mweru site *G. robusta* plots also had significantly lower mean pH value of 5.65 compared to 6.17 for *Erythrina abysinnica* Lam. and 6.19 for *Cordia africana* plots ($p < 0.001$) but was not significantly different from the control plots (5.6). No significant differences were observed between the tree species in influencing soil pH at Kanwaa and Mworoga sites.

Tree species and time interactions had a significant influence on plant growth. The trees species at all the sites showed a significant suppression of plant height and basal diameter only at 6 weeks after crop emergence (WACE), ($p < 0.05$) but not at 2 WACE. At Kyeni the plants in *G. robusta* plots had the lowest mean basal diameter of 1.67 cm at 6 WACE and 1.96 cm at 9 WACE. A similar trend was observed at Mweru site where the plants in *G. robusta* plots had the lowest mean basal diameter of 1.77 cm at 6 WACE but not significantly different from the *Erythrina abysinnica* plots which had a mean of 1.83 cm. No significant differences were observed between the tree species in influencing plant basal diameter at Kanwaa and Mworoga.

At Mweru site the lowest mean plant height of 108.8 cm was observed in *G.robusta* plots compared to 119.4 cm and 156.2 cm for the *Erythrina abysinnica* and control plots respectively at 6 WACE. At Mworoga site the *G. robusta* and *Senna spectabillis* plots showed significantly lower mean plant heights of 143.3 cm and 148.8 cm respectively, when compared to *Cordia africana* plots which had a mean of 162.2 cm at 6 WACE. No significant differences were observed in plant height in plots under different tree species at Kanwaa and Kyeni.

Significant suppression of chlorophyll development (indicated by SPAD readings) was observed in all the tree species at 6 WACE ($p < 0.01$) at all the sites. No significant differences were observed between the plots under different plant species at Kyeni and Kanwaa. At Mweru site the *G. robusta* plots had the lowest mean SPAD value of 33.6 % which was significantly different from of *C. africana* (38.05 %) and *Erythrina abysinnica* plots (40.87 %). Tree species and distance interactions were found to be significant in influencing SPAD readings in *Grevillea robusta* plots at Mweru site ($p = 0.02$) and *Senna spectabilis* at Mworoga ($p = 0.002$).

On grain yield, only determined in four farms at Kyeni the *G. robusta* plots had significantly lower maize grain yield of 1.57 t ha^{-1} compared to the control plots that had the highest mean yield of 2.21 t ha^{-1}. No significant differences were observed between the tree species but planting distance had a significant effect in *Cordia africana* plots. Higher mean grain yield of 2.08 t ha^{-1} was obtained from the crops that were planted at 3.25 m (fourth row from the tree) compared to 1.44 t ha^{-1} that was obtained in crops planted at 1 m (first row from the tree) in *Cordia africana* plots.

Grevillea robusta was found to be the most prevalent tree species on farms in three sites except in Mworoga were *Senna spectabilis* was dominant. Low soil carbon and pH under the *G. robusta* interacted in suppressing plant growth in basal diameter and grain yield in maize at Kyeni site. Only *Croton macrostachyus* was found to increase soil carbon more than *Grevillea robusta* at Kyeni but no significant differences were observed between trees at other sites. A similar trend was observed on soil pH, *Croton macrostachyus* and *Cordia african*a were found to increase soil pH more than G. *robusta* at Kyeni. At Mweru site soil acidification was observed in *G. robusta* plots compared to *Cordia africana* and *Erythrina abysinnica. Grevillea robust*a suppressed growth in plant diameter than other tree species at Kyeni. *Cordia africana* showed less suppression on plant diameter at Mweru site. *G. robusta* suppressed plant height more than *Erythrina abysinnica* at 6 WACE at Mweru site and *Cordia africana* showed less suppression on plant height than *G. robusta* and *Senna spectabilis* at 6 WACE at Mworoga site. *G. robusta* suppressed chlorophyll development more than the other tree species at Mweru site while *Cordia africana* showed less suppression at Mworoga site.

As shown by the study, trees tend to suppress chlorophyll development, growth in height and basal diameter of the maize crop which can be attributed to both above and below ground competition for resources by the trees. However, trees showed a positive role in increasing soil pH and increased soil carbon on farms. Increasing the number of trees on farms with proper management of crowns and roots by pruning to reduce both above and below ground competition is necessary. *Grevillea robusta* which showed negative effects especially in reduced soil pH and carbon can be grown on farm boundaries. *Croton macrostachyus, Cordia africana* and *Senna spectabilis* are recommended as potential candidates for agroforestry for purposes of increasing soil carbon and productivity on farms coupled with proper crown management.

CHAPTER ONE

1.0 INTRODUCTION

1.1. Background

Agriculture is the mainstay of the Kenyan economy directly contributing 26 % of the GDP annually, and another 25 % indirectly; it accounts for 65 % of Kenya's total exports and provides more than 70 % of informal employment in the rural areas (Republic of Kenya, 2010a). In addition, the sector provides food security and livelihood for over 80% of the Kenyan population. Therefore, the agricultural sector is not only the driver of Kenya's economy but also the means of livelihood for the majority of Kenyan people (Republic of Kenya, 2010b). Thus, strengthening of the agricultural sector is a prerequisite for maintaining economic recovery and growth.

Over the years, population pressure and lack of growth in other economic sectors in Kenya has increased pressure on land resources, resulting in declining soil fertility, productivity and general environmental degradation (Mati, 2005). Land degradation is the lowering of the land productive capacity through processes such as soil erosion, loss of soil fertility and soil salinity (Young, 1997a). Soil fertility which is the capacity of the soils to provide essential elements for plant growth is one of the major limiting factors in crop production (Foth and Ellis, 1997). Soil organic carbon is one of the major factors influencing fertility and productivity of soils (Kucharik *et al*., 2001; USDA, 2002). A significant decline in soil carbon on farms in Eastern highlands of Kenya due to continuous cultivation and low soil fertility replenishment has been widely reported (Woomer *et al*., 1994; Sanchez *et al*., 1997; Gitari and Friesen, 2001; Solomon *et al*., 2007; Rosen, 2009). Low soil fertility, poor crop husbandry and use of unimproved seeds among others have led to declining yields (Murithi *et al*., 1994). Population pressure in the Eastern highlands of Kenya has increased demand on food production forcing smallholder farmers to practice poor methods of farming such as limited crop rotation and clearing large areas of natural forests (Micheni *et al*., 2002; Shisanya, 2003). Recently, uncertainties associated with poor seasonal rainfall distribution have often made water availability a major limiting factor in maize production (Lobell *et al*., 2009).

In Eastern Africa (EA), maize occupies 21% of the arable land. It accounts for 41% of the total cereal area in the sub-region, albeit varying from 19% in Ethiopia to 81% in Kenya (FAO, 2010), but maize yields in Eastern highlands of Kenya still average less than 2 t ha^{-1} (Gitari *et al*., 1996; Hassan *et al*., 1998). Despite the declining soil fertility in most Kenyan regions, aggressive soil conservation measures to enhance and maintain soil fertility have not been widely employed. The situation warrants the need for appropriate use of farm inputs like inorganic fertilizers especially for nitrogen and phosphorus, liming and certified high yielding seed varieties. In as much as adoption of improved maize seeds is now estimated at 40% of maize area in Eastern and Southern Africa, however, the use of fertilizer and proper crop management practices remains relatively low and inefficient (Smale *et al*., 2011). The use of farm inputs like inorganic fertilizers and lime by smallholder farmers is severely constrained by inadequate supply due to delivery problems and prohibitive costs (Akinnifesi *et al*., 2007). Low farm productivity by smallholder farmers has remained a major contributing factor to the deepening poverty cycle and Kenya is not an exception to these problems. Low-cost and sustainable technologies to address problems associated with declining soil fertility, drought and land degradation are very crucial in Kenya and the sub-Saharan region at large and are needed on a scale wide enough to improve the livelihood of these farmers. Adoption of new approaches to agriculture and rural development will be required (Pretty, 1995).

Conservation Agriculture (CA) technology is the most promising affordable option for promoting soil fertility, water management and farm productivity in smallholder farmers (Mazvimavi *et al*., 2010). Conservation Agriculture (CA) systems are defined by three key principles, namely: no or minimal mechanical soil disturbance, permanent organic soil cover especially by crop residues and cover crops, and diversified crop rotations (Kassam and Friedrich, 2010). The major challenge has been on the use of crop residues for mulching or soil cover since farmers also depend on the crop residues as feed for their livestock, thus the need to integrate conservation agriculture with agroforestry technologies. Crop residues used by farmers have also been reported to be of poor organic quality not sufficient enough for soil fertility replenishment (Kilongozi, 1992). Conservation agriculture with trees is now emerging as the promising land use option to sustain agricultural productivity and livelihoods of farmers (Syampunani *et al*., 2010). It is noteworthy that after several decades of soil and water conservation in Africa, conservation agriculture with trees has been recognized as the missing link between biological methods of agriculture (Mati, 2005). A study done in the coffee belts around Mt. Kenya concluded that tree abundance was generally low among smallholder farmers and suggested the need for increased tree abundance in order to support higher nutrient requirements (ICRAF, 2010). Adoption of new soil replenishment technologies like conservation agriculture with trees in this region has been hampered by many factors amongst them farm management practices and farmers perceptions on the influence of trees on soil fertility, crop growth and yield (Gitari and Friesen, 2001). It is undisputable that negative effects of trees on crop growth are existent but more benefits have been reported. The major goal of conservation agriculture with trees is to stimulate biological activity and improve soil structure. Adoption of agroforestry therefore has the potential to halt land degradation, improve soil fertility, prolong cropping period and increase fodder. The integration of trees in farming systems provides environmental services and off-farm products that are either traded or used domestically to confer multiple livelihood benefits, which can alleviate malnutrition, hunger and poverty in resource poor smallholder farmers (Leakey, 2010). One benefit of increasing trees on farms would be an increase in soil organic carbon (SOC) pools which is a good indication of soil fertility (Konare *et al*., 2010).

Regional evidence has been provided on the nitrogen fixing abilities and reverse leaf phenology of the *Faidherbia albida* tree which has potential benefits in terms of enhancing soil fertility and improving crop yields (ICRAF, 2009). In Eastern and Western Kenya, the use of *Tithonia diversifolia*, *Senna spectabilis*, *Sesbania sesban* and *Calliandra calothyrus* tree species planted as farm boundaries, woodlots and fodder banks has proven to be beneficial as a source of soil nutrients for improving maize production (Palm *et al*., 2001). A study by Gachengo (1996) found that the use of *Tithonia spp* green biomass grown outside fields and transferred into the fields was quite effective in supplying N, P and K to maize equivalent to the amounts of recommended commercial inorganic NPK fertilizer. However, biomass transfer technologies require a lot of labor for managing and incorporating a leafy biomass, if used for the production of a low value crop like maize. It is more profitable in high value crops like vegetables (ICRAF, 1997), unlike the generally positive influence of trees scattered in cropping area (Ong and Leakey, 1999). In Malawi, maize yields were increased up to 280% under the tree canopy zones (Saka *et al*., 1994). Thus the importance of maintaining trees scattered within the cropping area for soil improvement and growth of important and widely grown crops like maize. Young (1997b) stated that the need for agroforestry systems is particularly great in densely populated sloping humid and sub humid tropics, a typical case in Eastern highlands of Kenya. Soils in these areas are often degraded by soil erosion; typically the forest cover has been cleared extensively for timber, charcoal, and agriculture.

The World Agroforestry Centre (ICRAF) and partners have been testing and developing agroforestry technologies for sustainable soil fertility replenishment. Since the late 1990s, ICRAF's research has increasingly emphasized on-farm testing, adaptation and country-wide scaling up and scaling out of proven technologies with increasing partners and farmer involvement decreasing direct researcher involvement (Akinnifesi *et al*., 2009). On-farm research is a problem-oriented approach to agricultural research that begins by diagnosis of conditions, practices, and problems experienced by particular groups of farmers (Tripp and Woolley, 1989). Researchers tend to have poor understanding of farmers' farm management strategies, lack basic technical information about agroforestry systems and lack locally validated technologies (Scherr, 1991). This on-farm study intends to facilitate close interactions between scientists and farmers.

The effects of trees on field soil carbon, pH, maize growth and yields were explored in this study.

1.2. The limitations of the study

The study was not an experimental intervention but an assessment of the situation on the ground. It was therefore difficult to control factors in real situation like the effects of neighboring trees, the differences in the size of trees and soil types. The study was also conducted in one season due to time and resource limitations.

1.3. Statement of the problem

Farmers are concerned about the adverse effects of the trees that are scattered within the cropping area and grow with the crops on farms (Bhatt *et al*., 1993). As such, most farmers are not willing to grow trees together with crops within their cropping area which is limited for growing only food crops like maize and legumes. Potential benefits of trees on farms have been proven in Southern Africa like Zambia, Malawi and Zimbabwe where the intervention has been adopted (Sileshi *et al*., 2009). Besides these efforts, fewer benefits have been documented in Kenya, although some aspects of conservation agriculture with trees have been practiced by these farming communities for a long time. There is inadequate awareness about its potential benefits to the millions that still live in poverty (Garrity, 2006). Lack of knowledge and evidence on the benefits of tree-crop interactions to farmers motivates the removal of the trees scattered on their fields as traditional parklands systems. As such agricultural losses are being experienced by many smallholder farmers.

The Government extension services' and NGOs' attempts to increase farm productivity and ultimately livelihoods of people in these areas have been focused more on conservation farming and proven fertilizer trees. Ong and Leakey (1999) noted that agroforestry research has typically focused on fast-growing tree species planted at high density which capture most of the available resources neglecting the woody multi-purpose and probably adapted tree species. Besides maize-legume tree intercropping systems an alternative nutrient source from nitrogen fixing tree legumes (fertilizer tree systems) have been researched in the last two decades (Kwesiga *et al*., 2003). However, the adoption of the proven soil improving agroforestry tree species has remained low due to low survival rates on farm tree nurseries, and unavailability of cheap planting materials (Kung'u *et al.,* 2008).

Though on-farm research is quickly becoming popular in agroforestry research to address the above mentioned problems, major challenges are still existent in the implementation. Riley and Alexander (1997), recommended that less material was available with regard to the designs and analysis of on-farm and participatory agroforestry research. Since then much work has been focused on statistical methodology that offer advice on design and data analysis in agroforestry on-station research. After reviewing much literature, Franzel (2003) also provided recommendations for researchers on designing and implementation of on-farm trials. However, researchers still face some challenges in implementation of on-farm research due to confounding factors which are dynamic. At times the research process has to address both the interest of researchers and that of the farmers and in some cases for the funding organization. Less documentation is available on the challenges of the entire research process to substantiate advice and proper recommendations for the researchers to cope.

1.4. Justification of the study

Agroforestry involves the cultivation and use of trees in farming systems and is a practical and low-cost means of implementing many forms of integrated land management, especially for small-scale producers (Leakey, 2010). Farmers have always practiced some of the aspects of conservation agriculture like maintaining a few tree species on small portions of their farms. In fact trees on farms have increased especially on farm boundaries in densely populated areas with limited land like the Eastern highlands of Kenya (FAO, 2005). However, most farmers are not willing to expand on this technology due to lack of knowledge on its benefits especially on crop productivity. This study aims to provide future researchers with results on the effects of tree species that are potential candidates for agroforestry but subject to further experimental investigation. The results are useful to farmers and other stakeholders as short term communication to give insight on the effects of identified common trees species on soil fertility, growth and yield of maize in their farms. This should stir up more research on the interactions of different tree species with the soil and the maize crop which will enable the farmers to make informed decisions on the selection of the trees to grow in their farms. In this way adoption of the technology is expected to increase and consequently improve the livelihoods of farmers in Eastern Kenya in the long run. Major interventions in agroforestry have been focused on the effects of fertilizer trees on maize productivity. In view of the limited research on the common woody trees species growing on farms, this study sought to assess the effects of common tree species in Eastern Kenya on soil fertility, pH, growth and yield of maize. The results of the survey will also provide answers to farmers on effects of different tree species especially on light interception which is a major concern for farmers in their resistance to include trees on farms.

1.5. Objectives

1.5.1. The general objective

To identify the prevalent tree species growing on farms, investigate their effects on soil carbon and growth and yield of maize in Eastern Kenya.

1.5.2. Specific objectives

1. To determine the prevalent tree species growing on farms and their common uses in Eastern Kenya.
2. To assess the effects of identified tree species on soil organic carbon content and pH in farms in four sites.
3. To investigate the effect of the identified common tree species on growth and yield of maize.

1.5.3. Research questions

The above objectives of the study are based on the following research questions:

1. Which type of tree species are commonly growing on farms in Eastern Kenya?
2. Does the soil carbon content and pH in farms differ significantly with the type of tree species?
3. Do the common tree species growing on farms have an effect on the growth and yield of maize?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Challenges faced by smallholder farmers

The ever increasing population in Africa has resulted in increased demand for food and other resources. Since 1970, the population of Sub Saharan Africa (SSA) has more than doubled (ICRAF, 2009). Africa remains the only region in the world where per capita food production has declined by 13% over the last 35 years. Declining soil fertility is ranked a major constraint in crop production (IIRR and ACT, 2005). The smallholder farmers have responded by clearing forests in order to increase their agricultural land. Vast forest areas have been cleared by smallholder farmers in a bid to increase agricultural land and improve food security. Global Forest Cover Loss (GFCL) was estimated to be 1,011,000 km^2 from 2000 to 2005, representing 3.1% loss per year (Hansen *et al*., 2010). Africa has suffered the second largest net loss of forest with 4.0 million hectares cleared annually, with Nigeria and Sudan being the two largest losers of natural forest due to subsistence activities during 2004-2005 periods (Butler, 2005).

The continuing population growth will see more land being converted to agricultural lands further exacerbating the problem of land degradation. The Eastern highlands of Kenya which have a high agriculture potential due to good rains and fertile soils cannot be an exception to this regional problem. Young, (1997b) stated that the need for agroforestry systems is particularly great in densely populated sloping regions in the humid and sub humid regions. Land degradation on hilly areas and reducing soil fertility is of major concern. Three major biophysical constraints to improved maize production by smallholder farmers in Eastern Kenya are reducing soil fertility, prevalence of maize streak virus and weeds (Seward, 2005). Conservation farming with trees may be a possible sustainable solution to these challenges.

2.2. Importance of agroforestry in crop production and livelihood of smallholder farmers

2.2.1. Benefits of agroforestry

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, bamboos etc.) are deliberately grown on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (Keppel and Wickens, 2007). The major benefit is its role of enhancing the most important properties of soil that are the biological activities, aeration, nutrient status and structure and moisture retention. As highlighted by ICRAF (2009), one of the major goals of conservation agriculture with trees is to stimulate biological activity and soil structure. Overall this is aimed at conserving the soil and improving the crop yields of smallholder farmers.

In Western Kenya, the use of *Tithonia diversifolia, Senna spectabilis, Sesbania sesban* and *Caliandra calothyrus* species planted as farm boundaries, woodlots and fodder banks has proven to be beneficial as a source of soil nutrients and improving maize production (Palm *et al*., 2001). Research with *Faidherbia albida* in Zambia over several years showed that mature trees can sustain maize yields of 4.1 tonnes per hectare compared to 1.3 tonnes per hectare beyond the canopy of the tree. Unlike other trees, *Faidherbia albida* sheds its nitrogen-rich leaves during the rainy season so it does not compete with the crop for light, nutrients and water. The leaves then re-grow during the dry season and provide land cover and shade for crops (ICRAF, 2009). Trees may provide mulch when their leaves, fruits, and branches drop and decompose. This results in an increase of organic matter and recycling of nutrients from deep zones of the soil and leguminous trees fix nitrogen that can benefit food crops (Sanchez, 1995).

Grevillia robusta is considered by farmers in the highlands of East Africa to be an outstanding agroforestry tree. It is thought to be deep rooted and to possess few lateral roots, which suggests good potential for below-ground complementarity (Lott *et al*., 1996; Howard *et al*., 1997). Agroforestry contributes to soil conservation in several ways, Mercer and Pattanayak (2003) reported that intercropped trees (contour hedgerows) successfully mitigate soil erosion by forming natural terraces in a sloping land and replenish soil fertility with prunings from the trees. Kiepe, (1995) used a slow growing tree, *Senna siamea*, to form contour hedgerows in Machakos, Kenya. The trees reduced soil erosion from 5.8 to 1.4 t ha^{-1} over 3 years and did not reduce crop yield. In semi-arid Kenya, farmers have recently developed an intensive parkland system using the fast-growing indigenous species *Melia volkensii* (Meliaceae) which is reputed to be highly compatible with crops and can provide high value timber in 5-10 years (Stewart and Blomley, 1994; Tedd, 1997). Trees can conserve the soil in many ways such as cushioning the impact of raindrops on the soil and reduce the amount of rain-splash erosion. More so, their roots bind or stabilize the soil. Planted along contours, they can interrupt the flow of water running off the surface. They can also act as windbreaks protecting the soil against wind erosion (Infonet-biovision, 2010). Agroforestry has the potential to help mitigate effects of climate change since trees take up and store carbon at a faster rate than crops. Trees control the water table, sequester carbon and mitigate floods (Sileshi *et al*., 2007). In addition to soil conservation and enhancing soil fertility, trees on farms are also a source of livelihood diversification for smallholder farmers through provision of ecosystem services such as food, fodder, firewood and timber (Leakey *et al*., 2005; Rice 2008). The major on-site (on-farm) benefits of soil land management (SLM) practices include: higher and sustainable crop yields; cut-and-carry systems in which trees, shrubs, grass and leguminous vegetation are cut and fed to animals; fencing and windbreaks; and diversification of production (Pagiola *et al*., 2007; FAO, 2007).

2.2.2. Limitations of agroforestry systems

Adapting agroforestry to farming systems is a major challenge to food production considering the complex tree-crop interactions. For better use of trees in agroforestry systems, it is important to understand the biophysical adaptability of the commonly grown multipurpose woody trees and/or shrubs (Bationo *et al.*, 2008). One of the most cited challenges is light competition between the crops and trees. Kater *et al*., (1992) stated that differences in yields under crowns of varying sizes and shapes indicate an effect of light competition between crops and trees. If competition is to be minimized, tree planting must be combined with appropriate management practices such as crown and root-pruning. The possibility of increasing crop yields by increasing their exposure to sunlight is a strong argument for pruning. Experiments on *Cordyla pinnata* in Senegal (Samba, 1997) and *Azadirachta indica* in Burkina Faso (Zoungrana *et al*., 1993) indicate that crop yields under pruned trees are generally higher than under un-pruned trees. However, soils under mature parkland tree canopies are generally more fertile than those in the open due to limited availability of leaf litter (Boffa, 2000). Cannell *et al*., (1996) argued that agroforestry may increase productivity provided the trees capture resources which are under-utilized by crops. Competition for below ground resources between trees and food crops can mask or suppress many of the advantages that trees may provide for long term sustainability of agroforestry systems (Van Noordwisk and Purnomoshidi, 1995). Therefore, there is need to select trees with desirable root and shoot architecture that will be compatible with food crops under different agroforestry systems (Bationo *et al*., 2008).

Harborne (1977) proved that some higher plants (tree crops) release some phytotoxins into the soil, which adversely affect the germination and yield of crops. In agroforestry the importance of multi-purpose tree species cannot be overlooked as they provide food, fodder, fuel wood and social security to growers. Some species improve the soil but at the same time some species may cause adverse effect on long-term basis (Gill, 1992; Mughal, 2000).

2.3. Importance of Maize in Kenya

Maize is major food crop in Kenya and dominates all food security considerations in the country. In Kenya, maize is a major staple and the main source of income and employment for many households. Smallholder farmers contribute more than 70% of the country's maize production (Ouma *et al*., 2002). The Eastern highlands are amongst the major agro-ecological zones with great potential in crop production due to high rainfalls and fertile soils. Maize is one of the most important annual staple food crops grown in the region (ICRAF, 2010). Maize production in Embu and Kirinyaga is well below potential, despite their potential in agricultural productivity. Maize varieties with a yield potential of 5-10 tha^{-1} are available on the market but yields in these Counties are in the range of 0.5 tha^{-1}-1.0 tha^{-1} (Seward, 2005).

2.4. Challenges in the research process of on-farm studies in Agroforestry

2.4.1. Importance of on-farm studies in Agroforestry

On-farm research (OFR) is a set of procedures for adaptive research whose purpose is to develop recommendations for representative groups of farmers (Tripp and Woolley, 1989). There are three types of on-farm trials; Type 1: these are on-station trials transferred to farmers' fields, designed and managed by researcher. They are useful for evaluating biophysical performance under farmers' conditions and for obtaining accurate information about the interaction between the biophysical environment and crop management (Franzel *et al*., 1995). These trials require the same design rigor as on-station research with regard to treatment and control choice, plot size, replication and statistical design. At the design stage, however, the researcher has to consult with the farmer on the site's homogeneity and history. Type 2: the experiments are planned and designed by the researcher but managed by the farmer and take into account the interests and preferences of the farmer. The objective is to get reliable data over a broad range of farm types and circumstances. Other data that may be reliably gathered are: cost and return analysis; quantity of inputs (e.g., labor) and outputs (e.g., crop yield). Type 2 trials are useful for assessing farmers' assessments of a specific practice and their suitability to their circumstances (Coe, 2002). Type 3: This is an on-farm work planned and activated by farmer such that the researcher merely observes (Riley and Alexander, 1997). Researchers and farmers together monitor the farmers' experiments, focusing on the assessment of the new practice and on any innovation done. This enables farmers to learn from each other and increases the adoption of the technology. In the 1950s and 1960s; the Agricultural Research Stations (ARS) and Universities of many countries were using the transfer of technology (TOT) model as the standard in disseminating agricultural information. The model calls for delivery of research findings, after conducting on-station experiments, from scientists to the extension agents, who will, in turn, package the information for the farmers (Stroul *et al*., 2009). This means that researchers regard themselves as superior to the resource-poor farmers (Reij and Waters-Bayer, 2001). If the system was not adopted, the blame was on the farmer's resistance to change (Collinson, 2000; Blann *et al*., 2002), rather than the inappropriateness of the technology. It is this major weakness of on-station research that led to the emergence of on-farm research.

Most agroforestry research in the 1980s followed a linear model that tested species, interactions, and prototypes for new technologies first done on-station, then later evaluated and refined on-farm (Rocheleau, 1999). Participatory research methods hold the greatest potential for integrating farmers into the process of designing agroforestry systems. Attempts to bridge the gap between laboratory research and practical farming is often through on-farm research. On-farm is where the ecological, social and economic influences that determine that viability and adoption of agroforestry technologies meet and integrate their findings (Haggar *et al*., 2001). This ensures increased farmer participation in technology development and adaptation limiting rejection of new innovations. A study in Malawi showed that a good proportion of the farmers who planted the agroforestry trees under trials increased the area that they initially planted from 48% in Zambia to 64% in Malawi (Phiri and Akinnifesi, 2001; Ajayi *et al*., 2007). In addition, a study in Zambia found that 75% of farmers that tested improved fallows have continued to practice the system (Keil *et al*., 2005). The higher adoption rates of improved fallow by farmers in Zambia were associated with proper and effective diagnosis of farmers' problems, their participation in programs and encouragement to innovate (Franzel *et al*., 2001).

Researchers in Rwanda reported major advances in potato and bean varietal breeding research through survey of farm knowledge (Haugerud, 1986) and involvement of farmers' experts in on-station research (Sperling, 1994). Although on-station experiments are associated with high scientific rigor, they have low relevance with regard to how the information is used in reality (Crookston, 1994). Conducting experiments or surveys on farmers' fields provides an opportunity to verify research station results and examine the dynamically broader range of agronomic components whilst determining changes to productivity and the resource base at the same time. It also enables researchers to gather detailed data or complex systems over time, within an experimental framework that embraces variability. Such multidisciplinary studies appear complex and do not fit in the standard and documented designs Riley, 2000). Experimentation on farmers' fields poses problems not encountered on experimental stations and despite the increasing literature on the subject little data seem to be available (Riley and Alexander, 1997). Much of the agroforestry participatory research and experience by researchers has not been documented (Rocheleau, 1999). Numerous researchers continue to face challenges in conducting isolated, undocumented research within agroforestry programs. Despite the advantages associated with on-farm studies, there are several challenges researchers encounter when conducting on-farm research. The following sections discuss the stages of research process that are critical and face challenges that may jeopardize the research work in on-farm studies.

2.4.2. Setting objectives in an agroforestry research study

Objectives are very important in every study as they determine the type of study, what is to be measured and the general research process. Identification of priorities of the farming community at any stage will influence the objectives of both on-farm and on station studies and information gained from each of these studies should influence the direction of the study type. As with any scientific investigation, it is crucial to specify the objectives of the study clearly prior to embarking on the research. Time must be allowed for this phase and the objectives need to be re-assessed during the planning of the trial, to see whether there is need to be revised. This is particularly challenging in on-farm trials, where researchers and farmers are now working together, often with extension staff and NGOs. It is important that the objectives are clearly identified from all perspectives (Franzel and Coe, 2002). Farmers' perceptions and understanding of their socio-cultural environment and of the farming system is used to determine a common goal (Savory, 1991). Specific approaches to design relating to the objective must be chosen (Riley and Alexander, 1997). One major objective in agroforestry is to evaluate biophysical performance of a practice under a wider range of conditions than is or available on-station. Many researchers start from interviews with a broad base of representative community group, to determine what is called the "common knowledge" (Rocheleau *et al*., 1989). Despite extensive on-farm experience of many research programs, researchers still do not fully understand or take into account farmers priorities when setting their objectives. In ICRAF's first on-farm trials, researchers tended to dismiss farmer-identified problems as unimportant such as "lack of shade trees" or "lack of fruit-trees" because, at the time, they did not see these as posing many interesting research questions. Of greater importance to the researchers was the diagnosis of long-term decline in soil fertility; this affected the productivity of the whole land-use system and, not insignificantly, offered the researchers greater scope for interesting research (Raintree, 1987).

2.4.3. Selection of the study site

The design of long term agroforestry experiments to incorporate multidisciplinary systems to achieve research impact in communities is complicated (Riley, 2000). The most difficult decision in such studies is the selection of the study site and study units. Participatory research has been criticized for lack of rigor, accuracy, for being subjective, and for bias in favor of specific local groups or individuals (Pretty, 1995). This is because of many sources of variation, interactions and interests. In selection of farmers there is involvement of some other interested parties like local institutions, a scientific technique of sampling can conflict with the participatory approach (Hagmann, 1993). The selection of farms must be closely related to the objectives of the research, and in turn to the recommendation domain for which results are intended. The large variation that generally exists between farms means they must be selected with care to ensure that conclusions will apply to the appropriate group of farmers (Coe, 2002). The process is highly dependent on the objectives as well. It is highly recommended that on-farm trials be conducted at representative, well characterized sites so that the results can be extrapolated to recommendation domains. The researcher needs to understand the purpose of the study, otherwise if the purpose, compositions or community context of a participatory group is misunderstood, it can bias the research results and distort the quality and dissemination of participation within the community (Rocheleau, 1999).

On-farm trials should provide important diagnostic information about farmers' problem (Coe, 2002). Researchers may choose a group at random or select groups systematically to represent a range of characteristics present in the community. Forming new groups may often be an advantage in quantitative research designs like researcher managed trials (Norman *et al*., 1988) but not desirable in local innovation, research and information exchange. Pre-existing groups can apply their own leadership and participation trends to research activities. However, this may be contrary to the objectives of the research, though they have advantages of familiarity, local control and credibility (Fernandez and Salvatierra, 1989).

2.4.4. Designing on-farm studies

The choice of the study type will also depend on the type of research questions, the variability of social, economic and ecological conditions in the region and the time, space, and precision required to produce useful answers to the research questions (Rochleau, 1999). Farmer and researcher preferences for different research designs may differ substantially. Design features vary according to the aims of an experiment and the environment in which it is done. Typically researcher designed and managed on-farm experiments will have design structures not very similar from those done on research station. Variation caused by existing environmental features and the influence of farm management patterns will cause major differences in design and analysis requirements. Enough replication is needed in within levels of the identified major source of variability (Riley, 2000).

According to Riley and Fielding (2001), some on-farm studies generate data that can be analyzed statistically although their multidisciplinary structure, inherent data variability and, often small sample sizes make them complex to design, analyze and interpret. In most cases, designs and locations of the study sites are poorly planned and, replication and randomization of treatments is absent, which later causes confounding of results. Treatment effects are also masked by covariates such as slope and variability in soil type, vegetation type, climatic patterns (Collins *et al*., 2001) that therefore, should be considered in the designs. Experiments are usually designed by scientists, trained in a quantitative approach but with limited knowledge about qualitative methods. They may experience many challenges and frustrations when conducting experiments under the conditions of the farmers. The farmers may not have enough of the required resource (e.g. land area, livestock heads, and live trees) for a conventional experiment (Sutherland, 1998).

2.4.5. Data collection in agroforestry research studies

Consistency in data collection is important, for plot experiments documented sampling procedures may be useful (Dyke, 1988). Choosing suitable sample size from which to measure the response is another important aspect related to this. However, the sample sizes, type of measurements are ultimately determined by the objectives, level of precision required and the availability of resources. A trial design where each site acts as a replicate is one approach that allows many environments to be sampled (Matsaers *et al*., 1997). The size of the sampling unit e.g. plots depends on many factors like the objectives, type of measurements to be made, the expected duration of the study, ultimate size of the trees, the requirement for extra space to avoid interference between plots (Keppel and Wickens, 2007). According to Roger and Rao (1990) larger plots (50-200m^2) are needed for experiments designed to test species for a particular agroforestry technology or to study the effects of management practices. Important decisions about research design and data quality are influenced by the large amounts of data that are usually collected during problem diagnosis and experimentation in natural resources research (Sutherland, 1998). Inclusion of a biometrician from the beginning of the experiment (Johnston *et al*., 2003), coupled with collection of quality data, is essential if meaningful results are to be obtained and computed easily.

2.4.6. Handling data analysis

On-farm studies are at a greater risk of generating data which cannot provide precise and consistent estimates of change. Precise data cannot be guaranteed from short term on-farm studies where variability is large and its sources are at times not known (Riley, 2000). Any set of data comprising of multiple observations that are not all identical will require some sort of statistical analysis to summarize common patterns. Choice of analysis depends on objectives, design and type of measurements taken. It is worthwhile to mention here that several types of analysis of data resulting from agroforestry experiments can now be performed easily because of sophisticated and flexible statistical computer software packages like SAS and SPSS (Keppel and Wickens, 2007).

2.4.7. Sources of variations in on-farm study

Farmer managed on-farm trials are likely to be subject to less control of variation. Shepherd and Roger (1991) examined the importance of different sources of variability in on-farm agroforestry trials and showed that genetic, environment and management factors were considered separately. The patterns in variability caused by trees, plots, experimental blocks, farms and regional locations differed relative to each other. In addition to the basic principles of experimental designs there are other factors that need to be checked while planning agroforestry experiments. Several characteristics of trees like the growth rate, long term effects on their surroundings, longevity, size, age, the area coverage which the influence of trees extends can complicate designs and bring about some variation (Keppel and Wickens, 2007).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Study site description

The survey was carried out at four sites selected from three counties in Central highlands of Kenya, one site at Kyeni South a sub-location in Embu County, Mariani sub-location in Tharaka Nithi County and two sites in Meru County (Mweru and Mworoga sub-locations). The study was carried out at the beginning of the long rains season in 2012 that stretched from March to June.

Embu County is located in the Central highlands of Kenya between 0º.00' N and 38º.00' E. Situated about 120 KM North-east of Nairobi, towards Mt. Kenya. It lies between 760 (MASL) in Agro-ecological Zone (AEZ) Lower highlands (LH5) to 2070 meters above sea level in LH1. The average annual temperatures range between 9ºC and 31ºC. The area receives bimodal rainfall with the long rainy season from March to June and the short rain season from October to December. The average annual rainfall is estimated at 1206 mm. The county has a diverse agro-ecology with very fertile soils influenced by Mt Kenya. The dominant soils in Central highlands of Kenya are Rhodic Nitisols and humic Nitilsols that are characterized by red to reddish brown deep clay soils of more than 35% clay content. The soil pH is generally low (< 5.5) due to leaching of soluble bases (Gachene and Kimaru, 2003).

Tharaka Nithi County is situated between longitudes 37 º.18' and 37 º.28' East and latitudes 0º.07' and 0 º.26' South. It borders Meru Central to the North, Embu to the

South, Mbeere to the East, Kirinyaga and Nyeri to the west. The altitude ranges from 5200 meters above sea level at the peak of Mount Kenya to 600 meters in the low lying areas. The area has a bimodal rainfall pattern with the long rain season stretching from March to June and the more reliable short season stretches from October to December. The rainfall ranges from 200mm to 800mm and annual temperatures range between 14 ºC and 27 ºC. Characterized by Nitilsols that are deep red clay soils the area has fairly fertile soils though with declining fertility due to continuous cultivation.

Meru County lies to the North and North-east of the slopes of Mt. Kenya. Located between 0º.05' N and 37 º.65' E. It lies between 300 and 5199 meters above sea level in altitude. The average annual temperatures range between 16 º C and 21 ºC. The rainfall pattern is bimodal with long periods of rains occurring from mid-March to May and short period occurring from October to December. The mean annual rainfall is about 1300 mm, ranging from 380 mm in lowland areas to 2500 mm on the slopes of Mount Kenya. The county is characterized by valleys, hills and plains with ten major rivers emanating from Mt Kenya and constitutes a large area stretching northward to the volcanic Nyambene Hills. The wide range of altitude creates a variety of ecological zones ranging from extremely fertile, well-watered agricultural areas to low-lying semi-arid lands.

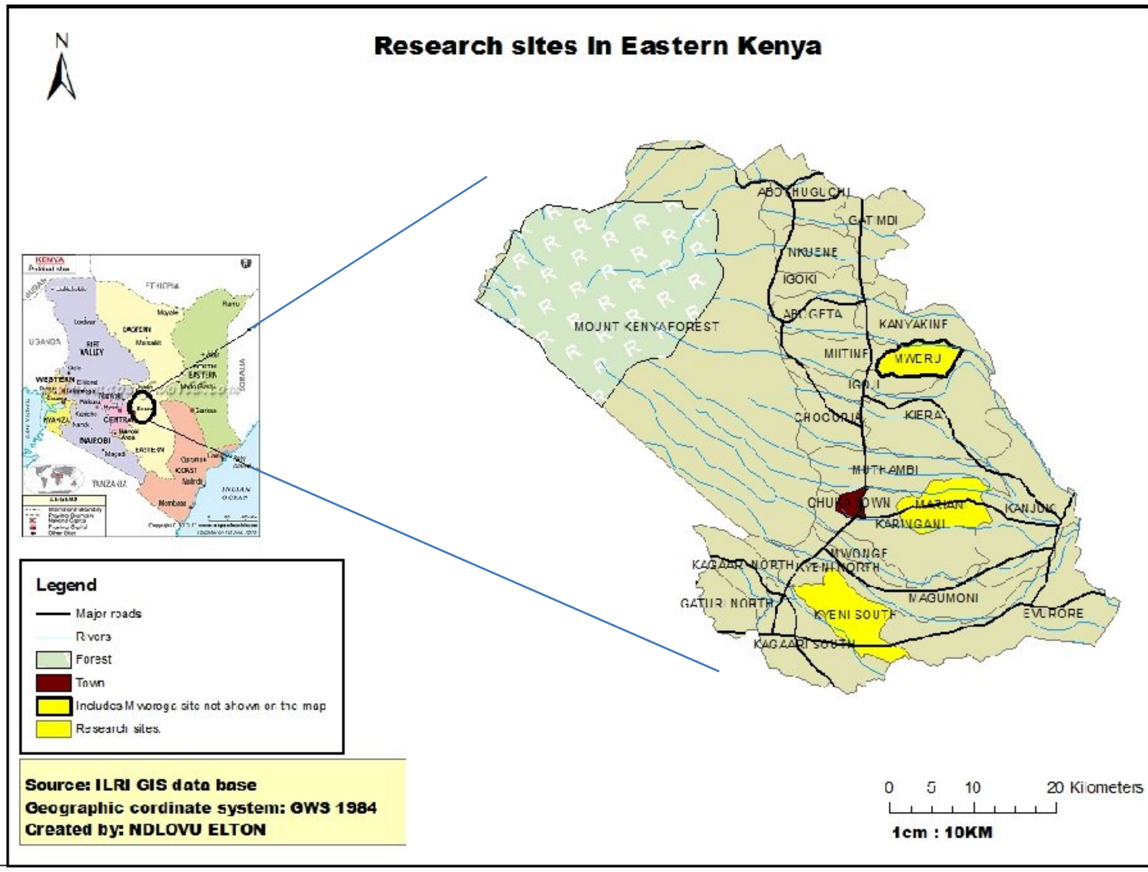

Figure 1. Location of the study sites in Eastern Kenya

3.2. Sampling procedure

The four study sites were chosen as representatives of the major maize growing areas in the three counties by CIMMYT in a project called "Enhancing total farm productivity in smallholder conservation based systems in Eastern Africa". The study was therefore superimposed on a project that was already ongoing led by CIMMYT in partnership with ICRAF. A Baseline survey to determine common tree species growing on farms was carried out in a total of 50 farms; at least 10 farms were selected at random from a list of farmers' group members in each site. Thereafter, purposive sampling was done using the results of the baseline survey to select farms where the study was conducted. Three most prevalent tree species in each site were selected for the study. The selected tree species in each site were; *Grevillea robusta, Cordia africana, Croton macrostachyus* in Kyeni, *Grevillea robusta, Senna spectabilis* and *Vitex payos* in Kanwaa, *Grevillea robusta, Cordia africana* and *Erythrina abyssinica* in Mweru and *Grevillea robusta, Cordia africana* and *Senna spectabilis* in Mworoga. Only *Grevillea robusta* was selected in all the four sites and *Cordia africana* in three sites. *Croton macrostachyus* was only selected in Kyeni, *Vitex payos* in Kanwaa, *Erythrina abyssinica* in Mweru andd *Senna spectabilis* in two sites Mworoga and Kanwaa. In total 6 species were selected.

Four farms were selected in each site based on the availability of the selected trees species and their location on the farms. Farms with at least three individual trees of the identified species growing within the cropping area and positioned at least 10 meters away from any other tree were selected from each site. The selection of farms was also based on the size of trees in diameter at breast height (DBH) (Table1); farms with the trees that showed less variability in size were selected. Therefore, this was a multistage sampling since at least ten farmers were selected for the baseline survey on trees from each farmers group in each site, and from the selected farmers, four farms and plots were selected in each farm for soil and crop survey. In total 16 farms were selected for the crop and soil survey.

3.3. Study design

This was an on-farm survey that followed a complete randomized design (CRD) with one factor as type of tree species at three levels for the soil study. For the study on maize growth a 3 x 2 x 2 factorial in a complete randomized design was used. The three factors investigated on growth of maize were the type of tree species (3 types), planting distance from the tree at two levels (first row and fourth row) and time or stage of plant growth at two levels (2 and 6 WACE) in each site. The type of trees (3 types) and planting distance (2 levels) applied to the maize yield study. The study units were maize plants selected in plots marked under the selected tree species in each farm and control plots marked 10 meters away from any tree. The plots for each of the three selected tree species and the controls were replicated three times in each farm except in two sites. The size of trees in diameter (DBH) and number of selected plots per each trees species in each site are shown on (Table 1).

Four replicates of maize plants were selected under the tree canopy at 1 meter away (first planting row) from the tree bases, one plant on each side of the tree. Four other plants were selected on the fourth planting row (3.25m) away from the tree bases. Three control plots were chosen at random in each farm at least 10 meters from any tree or boundary, with four maize plants selected at random in each control plot (Figure 2). Precaution was taken in selecting the trees so that they were at least 10 meters away from the canopy edge of the nearest tree to avoid effects of the neighboring trees. In Mweru, the desired number of plots for the *Erythrina abyssinica* tree species was not possible because of the relatively bigger size of the trees that did not match with the other two tree species for comparison. Therefore only one tree, *Erythrina abyssinica,* of almost the same size with the other tree species was selected per farm. *Grevillea robusta* trees also had less plots in other farms in Mweru because of their smaller sizes which could not match that of *Erythrina abyssinica* in order to reduce variability. In Mworoga only two farms had two replicates for *Cordia africana* tree species. Thus the design was balanced in two sites and unbalanced in the other two sites, Mweru and Mworoga, as not all the tree species investigated had the same number of replicates. However, the data from each site was analyzed separately due to variability in agro-ecological conditions.

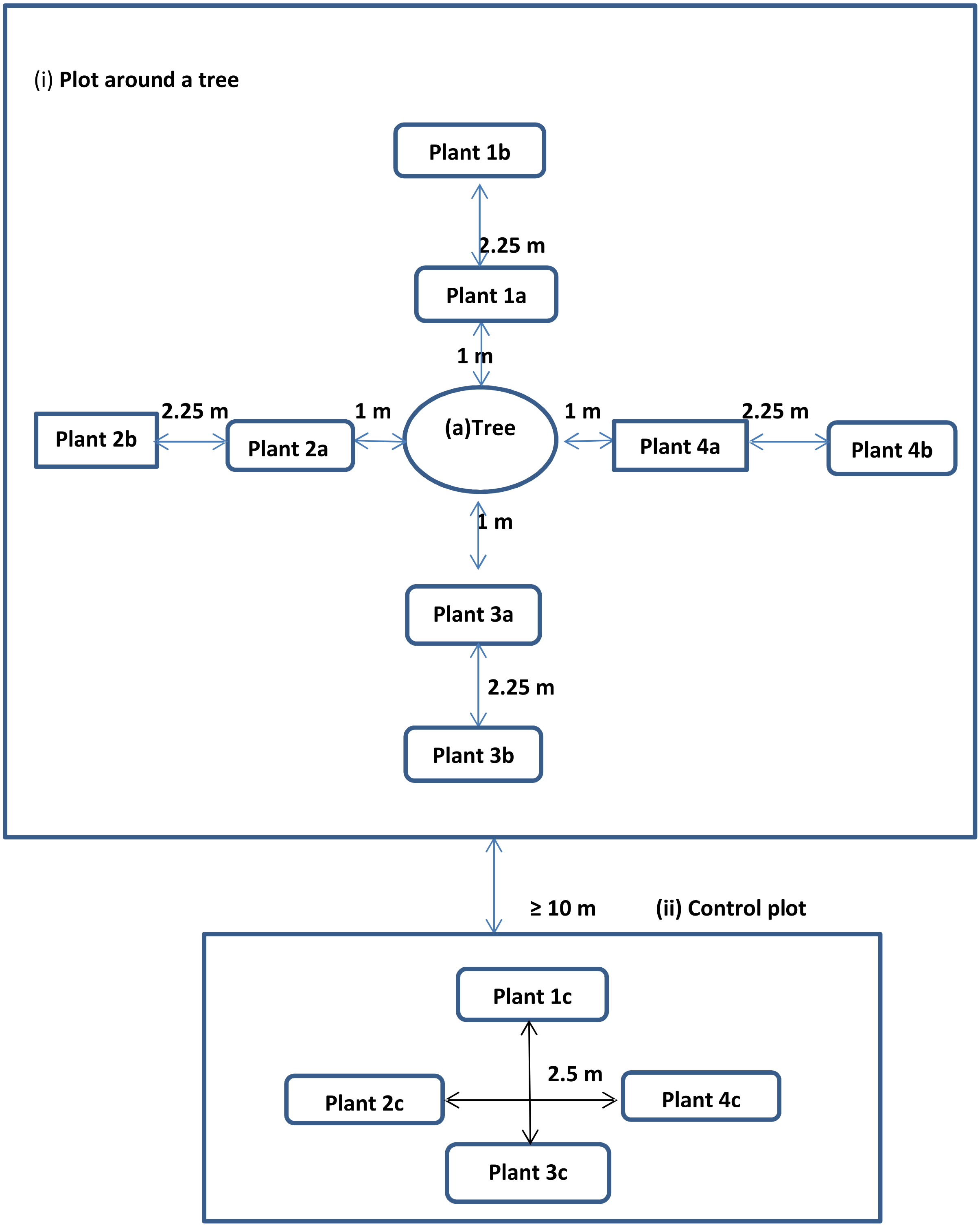

Figure 2. An illustration of the selected of plots and maize plants for measurements on farms (i) around the selected tree species (a) at 1m and (b) 3.25 m or 4 planting rows from the tree base (ii) In control plots (at least 10 m away from trees)

3.4. Management of plots

Land preparation was done manually by farmers and planting was done at the same time in the first two weeks of March. The farmers planted the same maize variety DK 8031 in the selected plots for the survey. The plant spacing used was 75cm x 50 cm to give a plant population of approximately 27 000 per hectare. The farmers used the compound fertilizer (NPK 23:23:0) at an application rate of 10 g per planting station with two seeds. Farmers also used some cattle manure. Weeding was done by farmers as per their usual practice but at the same time to reduce variability and they were requested not to prune the trees during the cropping season of study. The plots were managed by the farmers.

3.5. Site characterization

3.5.1. Survey on tree species

The number of trees within the cropping area and on the farm boundaries were counted and recorded per tree species in each farm. Three common tree species in each site were identified using that data. The data was used to select the farms for the survey on soils and crop growth and yield. The diameter at breast height (1.3m) of each selected tree was measured using a tape measure and recorded. The GPS points for each tree selected was also taken and recorded. The survey on effects of trees on soil and crops was conducted on those whose DBH matching.

Table 1. Minimum, maximum and mean values for trunk diameter at breast height (DBH; cm) and standard errors of the mean for the selected trees in farms for the study in Eastern Kenya in February 2012

Sites	**Trees species plots**	**Number of replicates**	**Min DBH (cm)**	**Max**	**Mean**	**SE**
Kyeni	*Grevillea robusta*	12	15.3	31.9	19.06	1.28
	Cordia africana	12	16.2	39.8	24.89	2.04
	Croton macrostachyus	12	16.6	39.8	22.40	2.1
	Control (no trees)	12				
Kanwaa	*Grevillea robusta*	12	15.9	38.2	22.77	1.85
	Senna spectabilis	12	15.9	31.9	22.08	1.49
	Vitex payos	12	15.3	46.2	22.48	2.72
	Control (no trees)	12				
Mweru	*Grevillea robusta*	7	24.3	48.4	37.67	0.24
	Cordia africana	12	24.1	52.9	37.58	2.07
	Erythrina abysinnica	4	39.9	61.8	44.20	5.9
	Control (no trees)	12				
Mworoga	*Grevillea robusta*	12	18.9	41.4	27.39	2.71
	Cordia africana	10	15.9	41.4	31.98	2.98
	Senna spectabilis	12	15.3	35	22.96	0.25
	Control (no trees)	12				

3.5.2. Rainfall data collection

Rainfall data for the long rain season when the study was carried out was obtained from the main weather stations in Embu and Meru. Monthly rainfall totals and mean temperature were used to study and characterize the rainfall pattern during the season of the study (Figure 3).

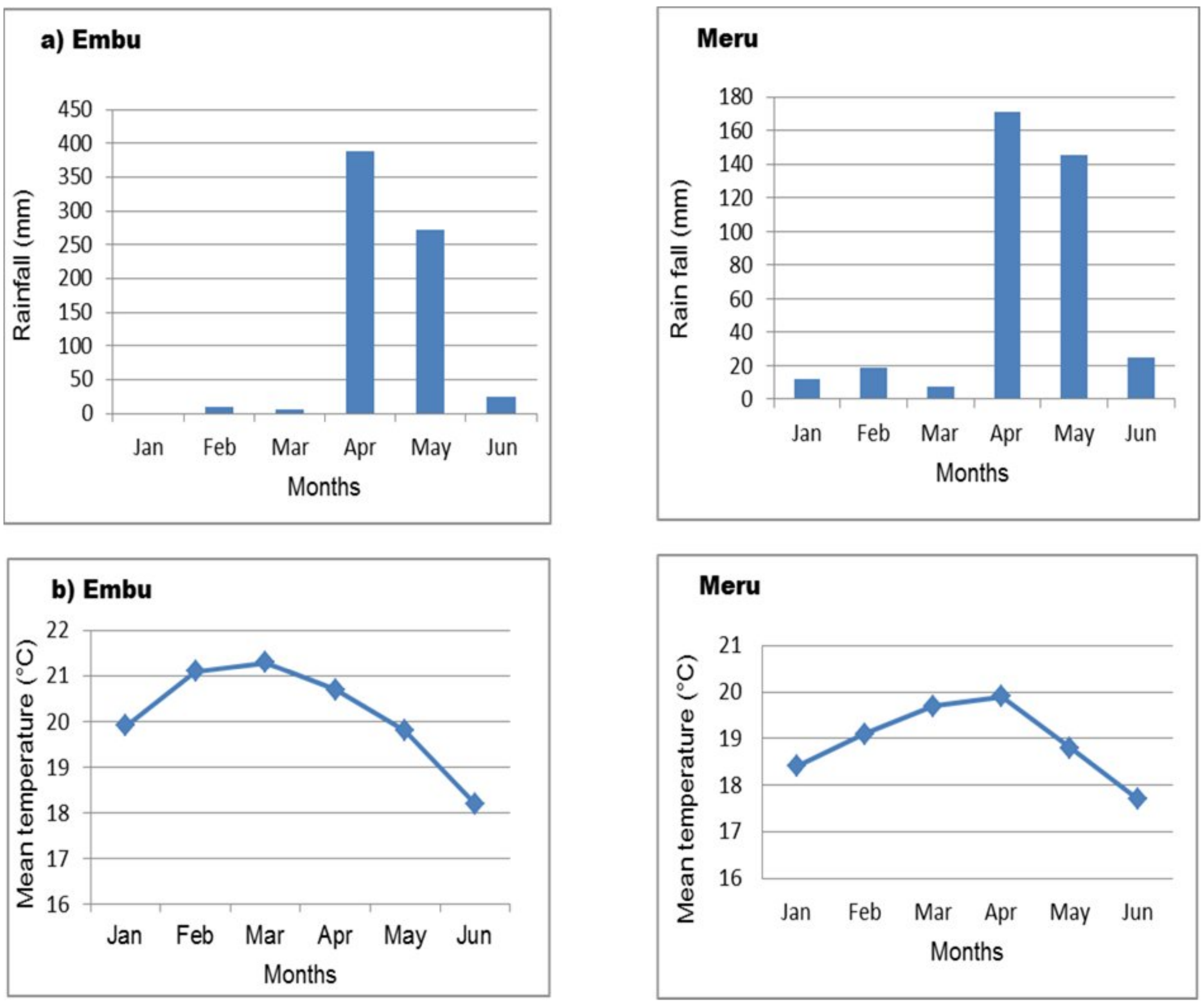

Figure 3. (a) Total monthly rainfall and (b) mean monthly temperatures in Embu and Meru during the long cropping season of 2012

3.6. Soil measurements

3.6.1. Soil sampling

Soil sampling was done once before planting at the beginning of the long rainy season of 2012. Soil samples were collected under the canopies of each selected tree in each farm at all the sites (Table 1). Eight (8) sampling points were marked systematically, one meter and four meters away from the tree bases in each direction of the cardinal points (N, E, W and S). Four (4) more samples were randomly collected around the base of the tree. At each sampling location top soil (0-30cm) samples were collected using a soil auger and mixed in order to produce a composite sample. In total 177 soil samples were collected.

Plate 1. Soil sampling under tree canopies at the beginning of the cropping season

3.6.2. Walkley and Black titration method for determination of soil organic carbon

Soil analysis was carried out on the samples to determine soil carbon content using the Walkley Black method (1934). 0.5g was mixed with 15 millimeters of Potassium dichromate. The solution was placed in an oven for 2 hours at 105° C. There after 15 millimeters of concentrated sulphuric acid was added and the conical flask was allowed to stand for 30 minutes. Then 150 millimeters of distilled water and 5 millimeters of orthophosphoric acid (85%) were added. The contents were then titrated with 0.5 N Ferrous ammonium sulphate till the colour changed from blue to green. A blank without soil was run simultaneously. The calculations to determine the total organic carbon (% TOC) were as follows:

% TOC = (b-a) x 0.3 x 10/ BW x 1.33

Where %TOC = Total organic carbon to be estimated

B= blank reading

A= Titration reading

W= weight of the sample in g

1.33 is a constant used to multiply the organic carbon obtained based on the assumption that there is 77 percent recovery

10 = millimeters of potassium dichromate used

0.3 = a is a constant

3.6.3. The pH (water) meter method

The principle is that a glass surface in contact with hydrogen ions of the solution under test, acquires an electrical potential which depends on the concentration of H^+ ions. A measure of the electrical potential (emf) therefore, gives H^+ ion concentration or pH of the solution. The pH of the soil solution was determined by pH meter method in a ratio of 1: 2:5 soils to water 20g of the soil sample, air dried and passed through a 2mm sieve, weighed, placed in 250 conical flasks, then 50mls of distilled water was added and stoppered well. The contents were then shaken in reciprocal shaker machine for at least 30 minutes, removed to settle for 10 minutes. The pH meter (Hanna HI 831K, Romania) was first calibrated using the buffers 7 and buffer 4 respectively. There after the electrodes were placed in the soil solution and readings taken after the meter readings had stabilized.

Source: Gupta P.K. 1999, Soil, plant, water and fertilizer analysis, Agro Botanica, New Delhi.

3.7. Quantitative traits of maize

3.7.1. Vegetative growth data on non-destructive measurements (height, diameter)

Non-destructive measurements were taken at 2 and 6 weeks after crop emergence (WACE) at three sites and additional measurements at 9 WACE at Kyeni. Seasonal rain failure from 6 WACE was the main reason that led to abandoning of plant height and basal diameter measurements at the other three sites. One maize plant at the first row (1m) and fourth row from the trees (3.25m) in each direction (N, E, W and S) were labeled with tape to facilitate repeated measurements, thereby providing a total of 4 plants at each distance around each tree for non-destructive analysis. Four maize plants were selected randomly in control plots (Figure 2). Parameters measured included basal stem diameters, and plant height (measured from the soil surface to the tip of the top youngest leaf flag using a tape measure).

3.7.2. Chlorophyll content determination in maize

A possible source of inter-specific variation in photosynthetic activity may be differences in the constitution of the photosynthetic apparatus, particularly chlorophyll content. It was therefore assessed using a Soil and plant analyzer development (SPAD-502 meter Minolta, Japan). The instrument uses measurements of transmitted radiation in the red and near infra-red wavelengths to provide numerical values related to chlorophyll content (Lawson *et al*., 2001). SPAD readings were taken at four positions along the third youngest leaf of each marked plant and an average was recorded. This was to give an indication on the effect of shading by trees on chlorophyll content in maize.

Plate 2. Taking height measurements and SPAD readings using a SPAD meter

3.7.3. Grain yield at maturity

The yield of maize was assessed at the end of the cropping season. After attainment of physiological maturity, the cobs from the marked plants were harvested manually. Husk covers that cover and protect the corn grain were removed, placed in separate labeled bags and the ears were oven dried at (70 ^{o}C) for one week to 12.5% moisture content. Each cob was shelled separately and an average weight of grains without the husks from the four cobs was recorded. Then mean grain yield in (t ha $^{-1}$) was determined.

Plate 3. Preparation of samples to determine grain yield.

3.8. Data analysis

3.8.1. Tree data

The data on the trees was be subjected to some exploratory data analysis to explain the patterns. Pivot tables, frequency tables and histograms in excel were used to show the frequencies in determining common trees in the four areas.

3.8.2. Soil parameters

The data on soil organic carbon and pH was subjected to the Analysis Of Variance (ANOVA) using Genstat 13. The F-test to compare means at 95% level of significance was used and where there were significant differences at alpha level of 0.05 means were separated using the least square differences. The data was first subjected to normality tests using the Shapiro-Wilk test and homogeneity of variance using the Bartlett's test before the ANOVA. The data did not violate the assumptions of ANOVA and no transformations were done. Data from each site was analyzed separately.

3.8.3. Maize growth and yield

For height and basal diameter, ANOVA for repeated measures in Genstat 13 was used to compare mean differences in SPAD values, height and basal diameter at 95% level of significance. The yield data obtained only at Kyeni were also subjected to ANOVA in Genstat 13. Where significant there were significant differences at alpha level of 0.05 the means were separated using the least square differences. All the data was first tested for normality and homogeneity to ensure the assumptions of the ANOVA were not violated and all the data was normal and no transformations were done. Sites were analyzed separately as well.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1. The prevalence and distribution of the tree species growing in farms in Eastern Kenya in the long cropping season of 2012

Grevillea robusta tree species was found to be the most prevalent on farms at the three sites except Mworoga where *Senna spectabilis* was found to be the most prevalent. Nevertheless, *G. robusta* was still the second most common tree species at Mworoga after *Senna spectabilis.* The highest average number for *G. robusta* trees species was recorded at Mweru and the lowest at Mworoga (Figure 4). Similar results on the popularity of *Grevillea robusta* in farms were reported by Ong *et a*l., (2000) in Machakos and Muthuri *et al*., (2005) in Central highlands of Kenya. *Cordia africana* was the second most prevalent tree species at Kyeni and Mweru, while *Senna spectabilis* was favored as the second best at Kanwaa. *Croton macrostachyu*s was the third most common tree at Kyeni, *Vitex payos* at Kanwaa, *Erythrina abyssinica* at Mweru and *Cordia africana* at Mworoga (Figure 4).

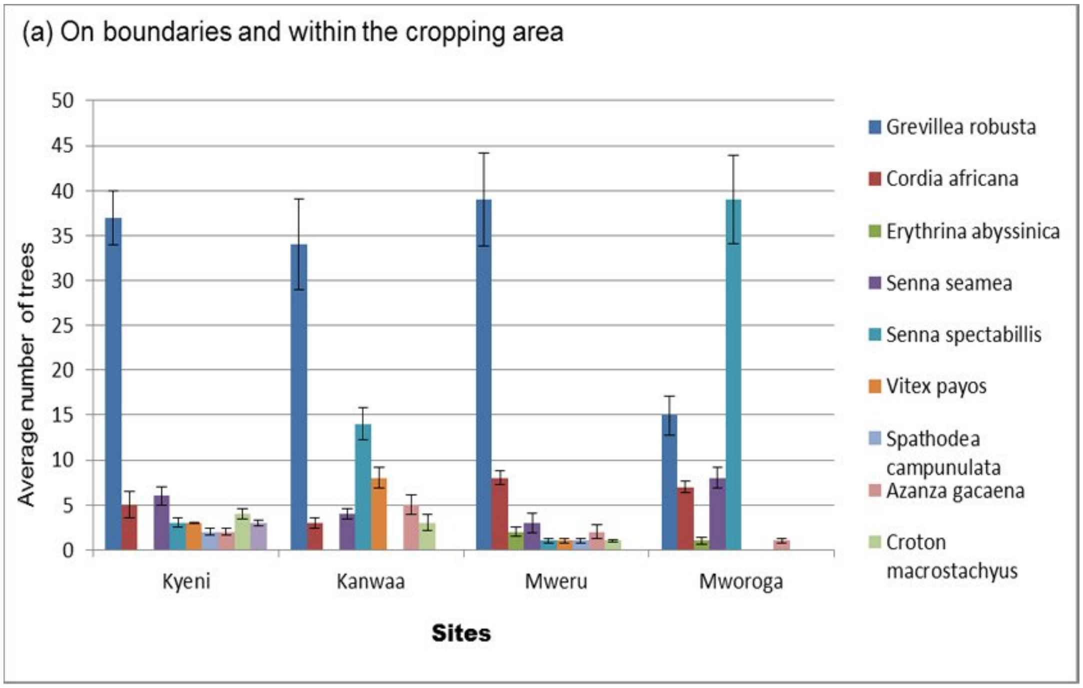

Figure 4. The average number of trees growing on boundaries and within the cropping area. The vertical bars in each bar show the standard errors for the means

At the three sites *G. robusta* was found to be the most common tree growing on the cropping area on farms. The *Cordia africana* was found to be the second most common tree species in the cropping area at Kyeni and Mweru while the *Vitex payos* was the second most dominating tree growing on cropping area in farms at Kanwaa (Figure 5). Three sites namely Kyeni, Kanwaa and Mweru had the highest number of *G. robusta* growing on the farm boundaries except for Mworoga where *Senna spectabilis* dominated on the farm boundaries (Fig. 6 and plate 4).

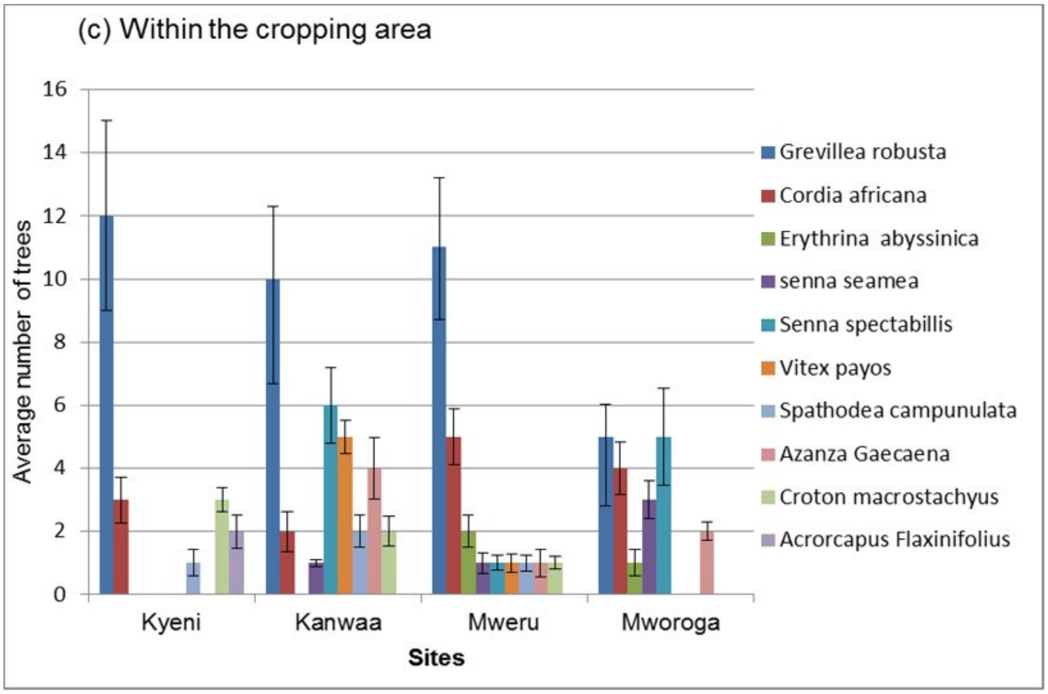

Figure 5. Common tree species that grow within the cropping area on farms. The vertical bars in each bar show the standard error for of the mean

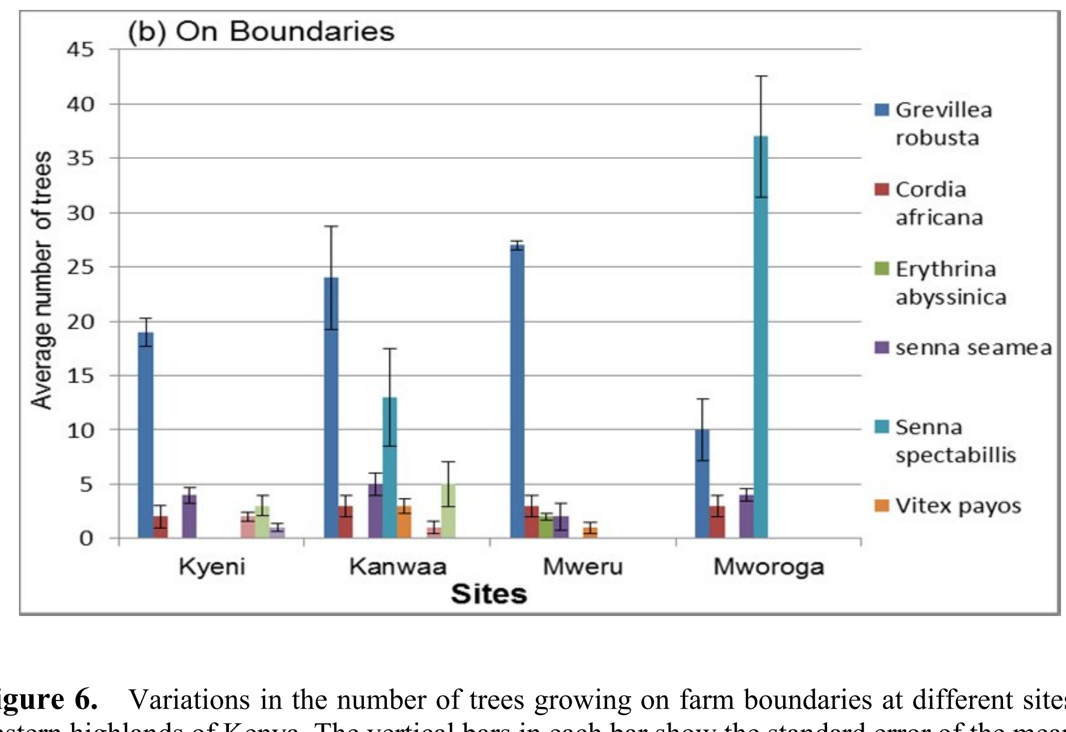

Figure 6. Variations in the number of trees growing on farm boundaries at different sites in Eastern highlands of Kenya. The vertical bars in each bar show the standard error of the mean.

It is note-worthy that the average number of trees that were found growing on farm boundaries outnumbered those found within the cropping areas for all the trees species except for *Erythrina abyssinica* which is grown mostly on farms at Mweru despite its relatively huge size (Figures 5 and 6).

Plate 4. The orientation of trees on farms (a*) Senna spectabilis* trees growing on farm boundaries, (b) *Senna spectabilis* trees growing within the cropping area on farms

The results indicated that farmers in Meru and Embu used a wide variety of agroforestry trees and limited agroforestry systems. The preference of trees is likely to be affected by the agro-ecological conditions and tree phenology, *Grevillea robusta* is widely preferred by farmers because of its fast growing, adaptability to a wider range of soils and as a multi-purpose tree used for timber, fuel wood and its flowers are suitable for honey production (Harwood and Getahun, 1990). Muthuri (2004) also outlined use of forage for bees and leaves and twigs of *G. robusta* as mulch in coffee plantations as a substitute for manure due to its heavy leaf fall. Large woody indigenous tree species grown with crops in agroforestry are preferred due to their advantages such as restoration of soil fertility through nutrient cycling, provide mulch and fodder for livestock, and reduce soil erosion (Kebebew and Urgessa, 2011), their ecological adaptability and economic importance (Nair *et al*., 1984; Sebukyu and Mosango, 2012). This is shown in the results on the prevalence of *Cordia africana*, *Erythrina abyssinica* and *Vitex payos* which are indigenous woody species. On the other hand the high prevalence of exotic species like *G. robusta* may be attributed to the availability of the planting material on the local seedling markets and ease in growing.

The high prevalence of the tree species on farm boundaries as shown on (Figure 6) gives an insight on farmers' perceptions on the negative effects of trees on crops. Limited size of land owned by farmers in the densely populated Eastern highlands of Kenya can be also be mentioned as a possible reason as farmers reserve land mainly for growing crops which is their major source of food and livelihood. This was postulated by Heineman *et al.*, (1997), that subsistence farming systems in the highlands of Kenya occur in areas of high population density (100-1000 people per km^2), resulting in small farms of an average of 0.l-1.0 ha. The influence of agro-ecological conditions on the choice of trees was observed at Kanwaa and Mworoga sites which are relatively dry. The *Senna* species were the most prevalent due to their adaptability to dry conditions which is in agreement with results on trials conducted by Kinama *et al*., (2005) in similar semi-arid sites in Machakos, Kenya. Interestingly, results showed that farmers maintain the *Senna spp* on farm boundaries most probably due to their proven competitive ability for underground resources like water which is a limiting factor on the same study. Their hard small leaves that are difficult to decompose make them ideal for long lasting mulching purposes as noted by Kinama *et al*., (2005). *Croton macrostachyus* and *Acrocarpus spp* were only prevalent at Kyeni (Embu) where agro-climatic conditions were semi humid to humid (Maundu and Temgnas, 2005). However, *Cordia africana* and *G. robusta* were found to be prevalent in all the sites except for Kanwaa which shows that they are adapted to a wider range of climatic conditions. Despite the big size of the *Erythrina abyssinica* farmers at Mweru still maintain it on the cropping field. This may be attributed to its sparsely leafed canopy that minimizes light interception. *Grevillea robusta* were found to be among the smallest trees found on farms because it is a multi-purpose tree, hence farmers cut it more often but maintain its numbers by planting more (Table 2).

Table 2. **Summary of the most prevalent trees and their common uses by farmers in Embu and Meru**

Plant species	**Local name/ English name**	**Relative Prevalence (%)**	**Uses by farmers**
Cordia africana	Moringa	12.94	Fuel wood, soil fertility, bee keeping, soil conservation, fodder
Croton macrostachyus	Mutundu	4.31	Fodder, soil fertility, soil conservation, medicinal
Erythrina abyssinica	Muh ti	1.96	Soil fertility, shade, bee keeping, fuel wood
Grevillea robusta	Mukima	44.71	Fuel wood, building material, timber, commercial purposes/trade, soil fertility, farm boundaries, mulching, coffee shade
Senna spectabilis	Mucassia	14.9	Medicinal, fuel wood, shade, farm boundaries, building material
Senna seamea	Mucassia	7.05	Fuel wood. Building material, farm boundaries. Fodder
Spathodea campunulata	Nandi frame	1.96	Timber, aesthetic value
Azanza gacaena	Muut	5.88	Fruits, farm boundaries, fuel wood ,building material
Acrocarpus fraxinifolius Arn	-	1.18	Fuel wood, shade aesthetic value, farm boundaries
Vitex payos	Muuru /Meru oak	5.1	Fuel wood, timber, soil fertility, fruits ,building material, timber

4.2. The influence of different tree species on organic soil carbon in farms in the four study sites at the beginning of the long cropping season of 2012 in Eastern Kenya

At Kyeni and Kanwaa sites, the results from ANOVA revealed significant differences in the total amount of carbon in soils sampled in plots under the canopies of different tree species ($p < 0.05$), at 0.05 level of significance. At Kyeni, the *Grevillea robusta*, *Croton macrostachyus* and *Cordia africana* tree species were studied and compared to the control plots (no trees). The soils sampled under *Croton macrostachyus* canopies revealed the highest total organic content in soil (2.85%). This was found to be significantly different ($p = 0.006$) from the *Grevillea robusta* plots which had the lowest mean of 2.04%, However, *Croton macrostachyus* was not significantly different from the *Cordia africana* and the control plots, Significant differences were also revealed when the *Grevillea robusta* plots were compared to the control plots but not with *Cordia africana* at that site. At Kanwaa, a significantly higher amount of total organic carbon in soils under the trees relative to the control plots was shown in the *Senna spectabilis* plots ($p = 0.03$). The plots had the highest value of 2.89% compared to 2.04% (TOC) (Fig. 7.b) for the control plots which had the lowest at that site. No significant differences were found between the *Senna spectabillis* plots and the other two tree species investigated at that site i.e. *Vitex payos* and *Grevillea robusta.* Much variation was shown at Kanwaa with the highest standard error for the means of soil carbon under the *Vitex payos* tree species. At the other two study sites studied namely Mweru and Mworoga no significant differences ($p > 0.05$) were shown between the tree species, and even when compared to the control (Figures 7.c and 7.d).

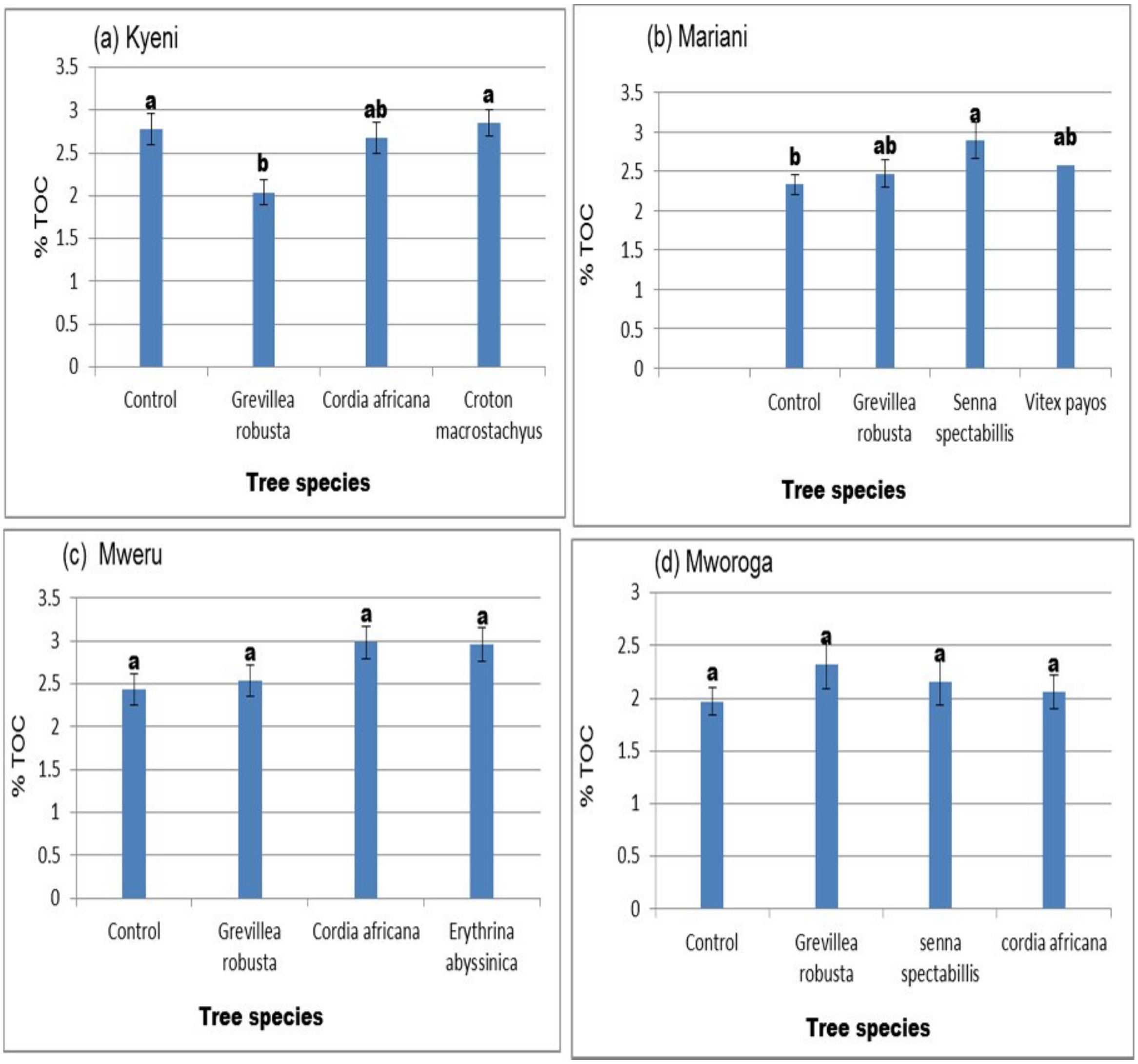

Figure 7. Soil organic carbon status under the canopies of different tree species on farms. The vertical bars in each bar show the standard error of the mean. Bars with the same letter in each site show no significant differences on soil carbon influence by the trees

The high levels of soil organic carbon revealed in *Croton macrostachyus* plots at Kyeni study site and in *Senna spectabilis* at Kanwaa may be attributed to root exudates following the explanation by Nsabimana *et al*., (2008), that soil carbon content is modified by plant uptake, wood harvest and increased by litter fall and root exudates, thus soil carbon content may differ from one tree species to the other. The relatively lower soil organic carbon under *Grevillea robusta* tree species at Kyeni may be attributed to lower rates of decomposition of its leaf litter despite the heavy leaf fall as observed under the trees shown on (Plate 5) below. The litter quality controls the rates of decomposition and mineralization (Mafongoya, *et al*., 2000). Lower soil pH in soils sampled beneath the canopies of the *Grevillea robusta* tree species at Kyeni observed in this study (Fig. 8a) may be related to low soil carbon. Low soil pH has been reported as a contributing factor to low mineralization and unavailability of soil carbon (Ahmed *et al*., 2010; Ch'ng *et al*., 2011; Xu *et al*., 2007, 2011).

Plate 5. *Comretum spp* showing faster decomposition of leaf litter than *Grevillea robusta*

In order to maintain the nutrient replenishing cycle from the crop residues or leaf litter or any organic matter the rates of decomposition must be equal to the rates of addition of organic matter (Bot and Benites, 2005). This is the reason why more recently, techniques have been developed to fractionate carbon on the basis of lability (ease of oxidation), recognizing that these sub pools of carbon may have greater effects on soil physical stability and be more sensitive indicators than total values of carbon dynamics in agricultural systems (Lefroy *et al*., 1993; Blair *et al*., 1995; Blair and Crocker, 2000). Soil carbon content is also variable depending on soil type, climate, management practices and initial soil status (Nsabimana *et al*., 2008). The results might also have been affected by the method used for soil analysis. The Walkley-Black (1934) method only estimates a fraction of the soil carbon pools, and incomplete oxidation of organic carbon often results in erroneous values (Heanes, 1984) compared to dry combustion which is regarded as accurate (McCarty *et al*, 2002), but the cost of the latter was a deterring factor considering the large number of samples that were to be analyzed. At Kanwaa the *Senna spectabilis* species revealed a significant influence on the soil carbon, however this may not be a true reflection as statistical significant variations in farms were observed at this site. Therefore this may be due to some influence of farmers' practices.

4.3. The influence of different tree species on soil pH on farms in the four study sites at the beginning of the long cropping season of 2012 in Eastern Kenya

Tree species influenced soil pH differently in different sites with some showing a significant positive influence (Figure 8). In general the ANOVA results revealed that in all the sites the control plots were significantly different from the plots of some of the tree species that were compared ($P < 0.05$). At Kyeni the control plots were not significantly different from the *Cordia africana* and *Croton macrostachyus* plots but all the above mentioned were significantly different from the *Grevillea robusta* plots ($p < 0.001$) at 5% level of significance. The soils sampled under the canopies of *Grevillea robusta* trees showed the lowest soil pH value of 5.99 while those from the *Croton macrostachyus* had the highest of 6.44 (Fig. 8.a).

At Kanwaa, *G. robusta* plots did not show any significant differences on soil pH with the *Vitex payos*, *Senna spectabillis* and the control plots. However, the *Senna spectabilis* plots showed significant differences ($p = 0.01$) with the control plots (Fig. 8.b). At Mweru the third study site which is near Mworoga, the *Cordia africana* plots were not significantly different from those of *Erythrina abyssinica* but were significantly different from those for *Grevillea robusta* and the control ($p < 0.001$). The control revealed the lowest pH mean value of 5.60 though not significantly different from *Grevillea robusta* plots in that site (Fig. 8.c).

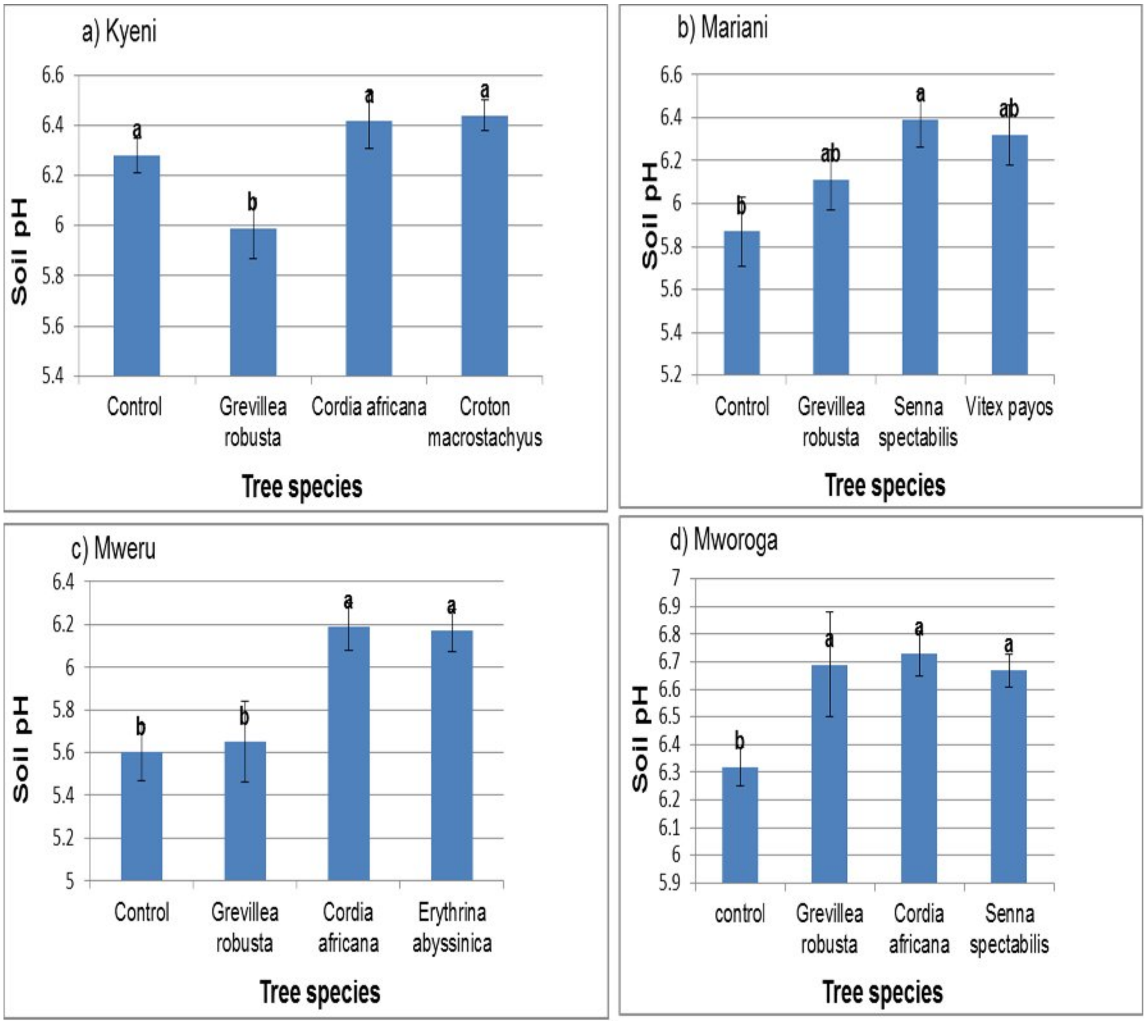

Figure 8. The influence of different tree species on Soil pH on farms.

The vertical bars in each bar show the standard error of the mean. Bars with the same letters in each site show no significant differences in soil pH influenced by the compared tree species

The interspecific differences may be explained by the production of organic acids from the decomposing litter (Finzi *et al*., 1998). At Mworoga the control plots were significantly different (p = 0.003) from those of the three tree species namely; *Grevillea robusta, Senna spectabilis* and *Cordia africana* which were compared at that site (Fig. 8d). The control plots showed the lowest soil pH value of 6.32 at that site. This may be attributed to the inherently acidic soils in this region as reported by FAO (1986). Increased soil erosion and leaching of basic cations in cases of high rainfall (Bai *et al*., 2002; Rieuwerts, 2007) may also be factor especially when coupled to the results obtained at Mweru which is dominated by steep slopes. The control treatments were away from any trees which can help reduce soil erosion and leaching.

The significantly low soil pH value beneath the canopies of the *Grevillea robusta* tree species observed at Kyeni and Mweru when compared to other tree species may be attributed to the organic acids produced by the decomposing litter. This is more pronounced in organic litter that proves to be slow to decompose as observed under the canopies of the *Grevillea robusta* in almost all the sites. This can be explained in terms of the presence of high lignin and tannin contents in such litter (Millen, 1995; White, 1991) also reported by the following researchers (Constantides and Fownes, 1993; Handanyato *et al*., 1995; Lehmann *et al*., 1995). This tree species is also reported to be a relatively higher consumer of water (Ong *et al.*, 2000; Kimatu, 2011) hence this may increase the solute concentrations in the soil resulting in reduced soil pH. However, Nsimabamana (2008) reported that *Grevillea robusta* tree species show less soil acidification.

4.4. The influence of trees species and distance from the tree on maize height and basal diameter at different stages of growth in the long cropping season of 2012 in the four study sites

At the three sites, Kanwaa, Mweru and Mworoga height and basal diameter was only measured at 2 and 6 WACE due the seasonal rainfall shortage that was experienced from 6WACE thus planned measurements at 9 WACE were abandoned, however, at Kyeni measurements were also taken at 9 WACE as planned. The ANOVA results revealed significant tree species x time interactions on basal diameter, ($p < 0.001$) at the three sites and ($p = 0.03$) at Mworoga. However, diameter showed much variation in tree species x time interactions in the four sites. At Kyeni the *G. robusta* plots were significantly different from the control plots, showing a notable suppression in maize diameter at 2 WACE, though not significantly different from the plots of the other two tree species. *G. robusta* continued to show significantly lower basal diameter in maize at 6 and 9 WACE (Fig. 9.a).

At Kanwaa no significant differences were noted in maize basal diameter between all the tree species and the control plots at 2 WACE while at 6 WACE the tree species differed significantly from the control plots (Fig. 9.b). The highest mean basal diameter of 2.51cm was observed in the control plots at Kanwaa at 6 WACE. At Mweru site no significant differences were shown between the control and the *Cordia africana* plots at 2 WACE but significant differences were noted between the *Erythrina abyssinica* which recorded the lowest value and *G. robusta* plots. No significant differences were noted between the *G. robusta* and *Erythrina abyssinica* plots. At Mworoga the control plots differed significantly when compared to the *G. robusta* and *Senna spectabilis* but not with *Cordia africana* plots at 2 WACE (Fig. 9.d). At 6 WACE no significant differences were noted between the plots under the tree canopies but only with the control plots.

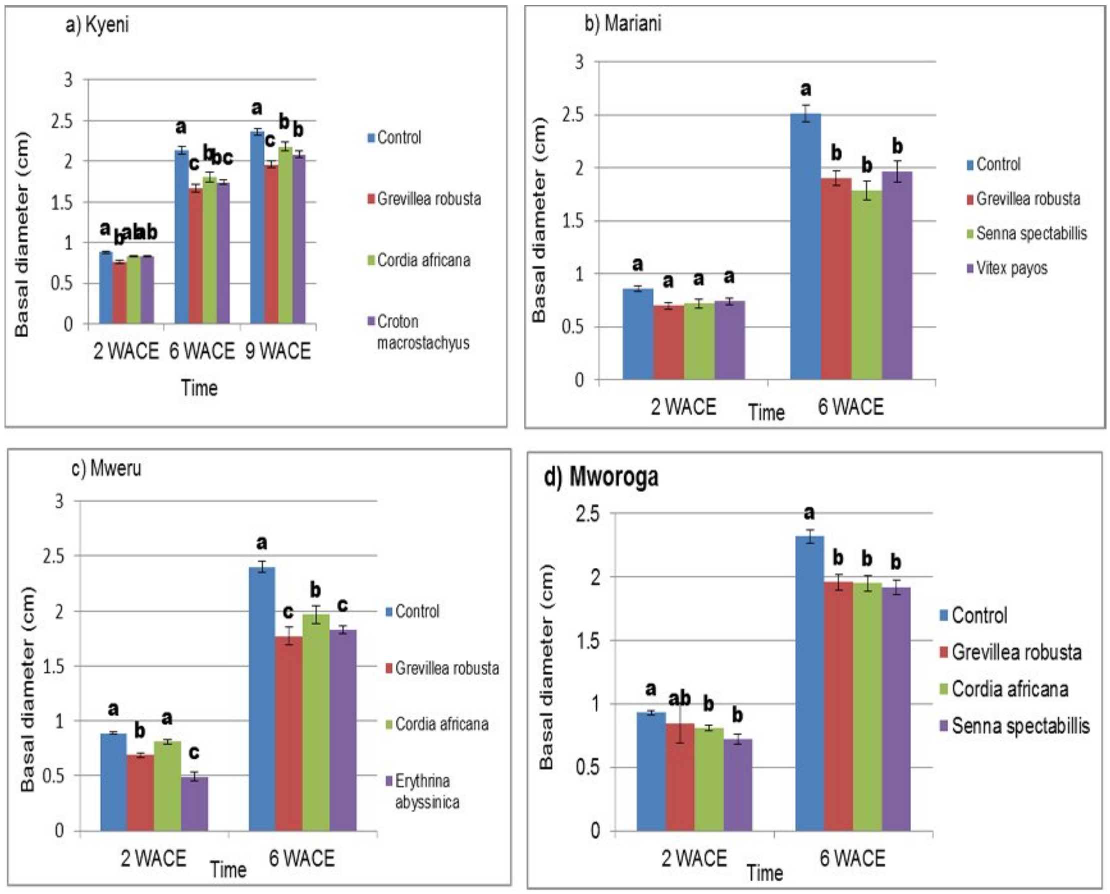

Figure 9. The influence of different tree species on maize plant basal diameter at 2, 6 and 9 WACE.

The vertical bars on each bar show the standard error of the mean and the bars with the same letter at each time point in each site show no significant differences in plants basal diameter in relation to the influence of tree species.

The ANOVA results revealed significant time x tree species interaction on maize height ($p < 0.001$) at all the four sites. At 2 WACE significant differences were observed neither between the trees species nor with the control (no trees) at all the sites (Fig. 10), were significant differences only noted at 6 and 9 WACE at Kyeni. This may be due to low light competition between the crop and trees at the early stages of maize growth. At all the sites suppression of maize growth in height was significant ($p < 0.001$) at the control plots compared to the tree species at 6 WACE and at 9 WACE (only measured at Kyeni). This may be attributed to the shading effect by trees on the crops; reduced growth due to intercepted photo synthetically active radiation (IPAR) has been reported by Sinclair and Muchow (1999); and Liu *et al*., (2012).

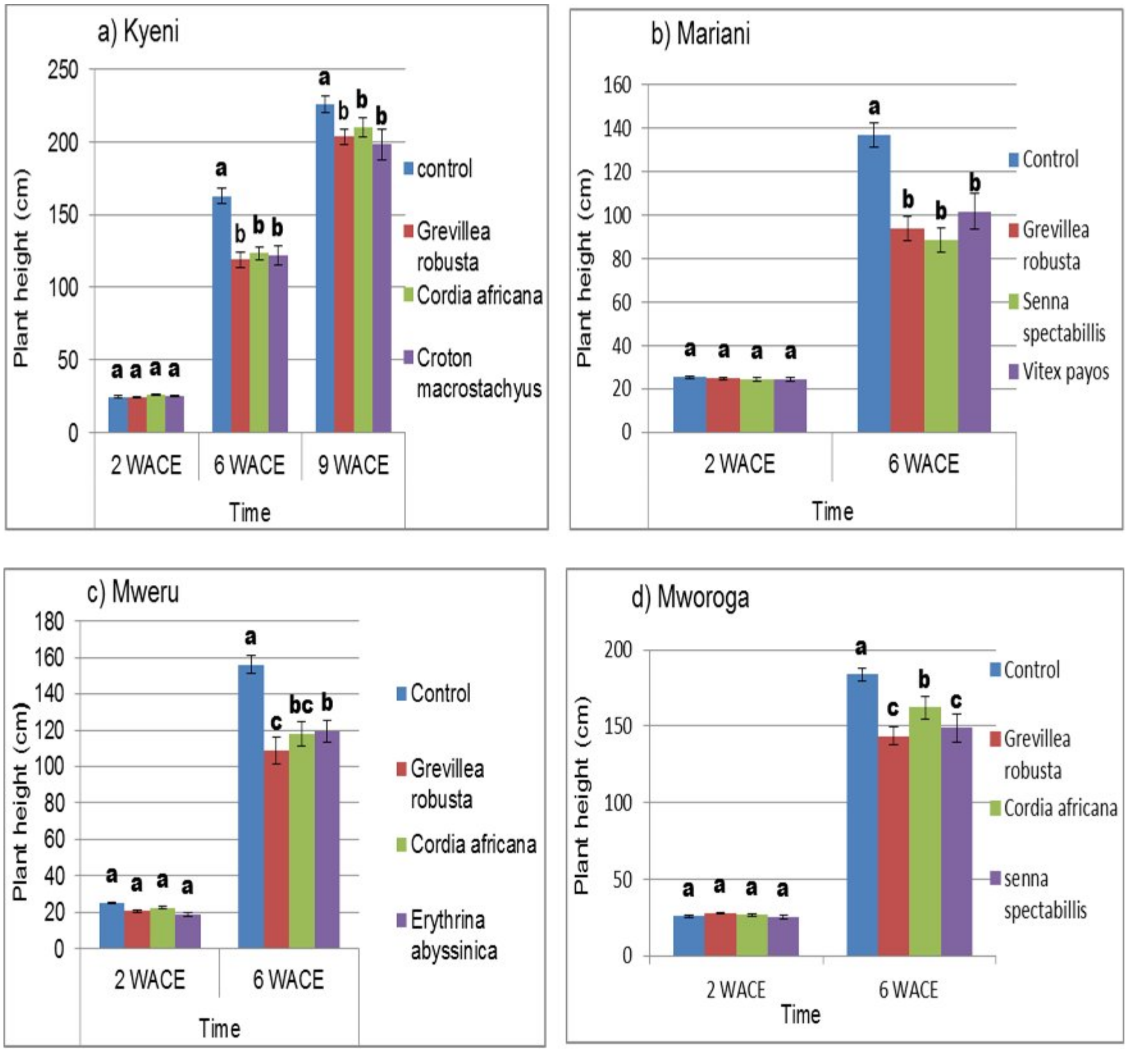

Figure 10. Height for maize planted under the canopies of different tree species

The vertical bars on each bar show the standard error of the mean and the bars with the same letter at each time point in each site show no significant differences in plants height in relation to the influence of tree species

At Kyeni no significant differences where observed between the tree species on the growth of maize at 6 and 9 WACE. The only significant differences were in relation to the control which maintained a relatively higher maize height. Similar results were observed at Kanwaa at 6 WACE (Fig.10.b). At Mweru differences within the tree species were observed with *Grevillea robusta* plots which revealed significantly lower maize height values when compared to the *Erythrina abyssinica* and the control plots (Fig. 10.c), but it was not with the *Cordia africana* plots at 6 WACE. At Mworoga the control plots showed significantly higher mean height compared to all the tree species (Fig. 10.d). Furthermore *Cordia africana* plots showed significantly higher mean height when compared to the plots of the other two species, *G. robusta* and *Senna spectabilis*, but the latter were not significantly different (Fig. 10.d). Overall no significant tree x distance and tree x time x distance interactions were observed on the influence of maize growth in height.

4.5. Variation of SPAD values with tree species and distance from the tree in maize plants at 6 WACE in the long cropping season of 2012 in the four study sites

The control plots had significantly higher SPAD values when compared to all the plots under the canopies of the tree species ($p < 0.001$) at all the sites except at Mworoga where the control and *Cordia africana* plots were not significantly different.

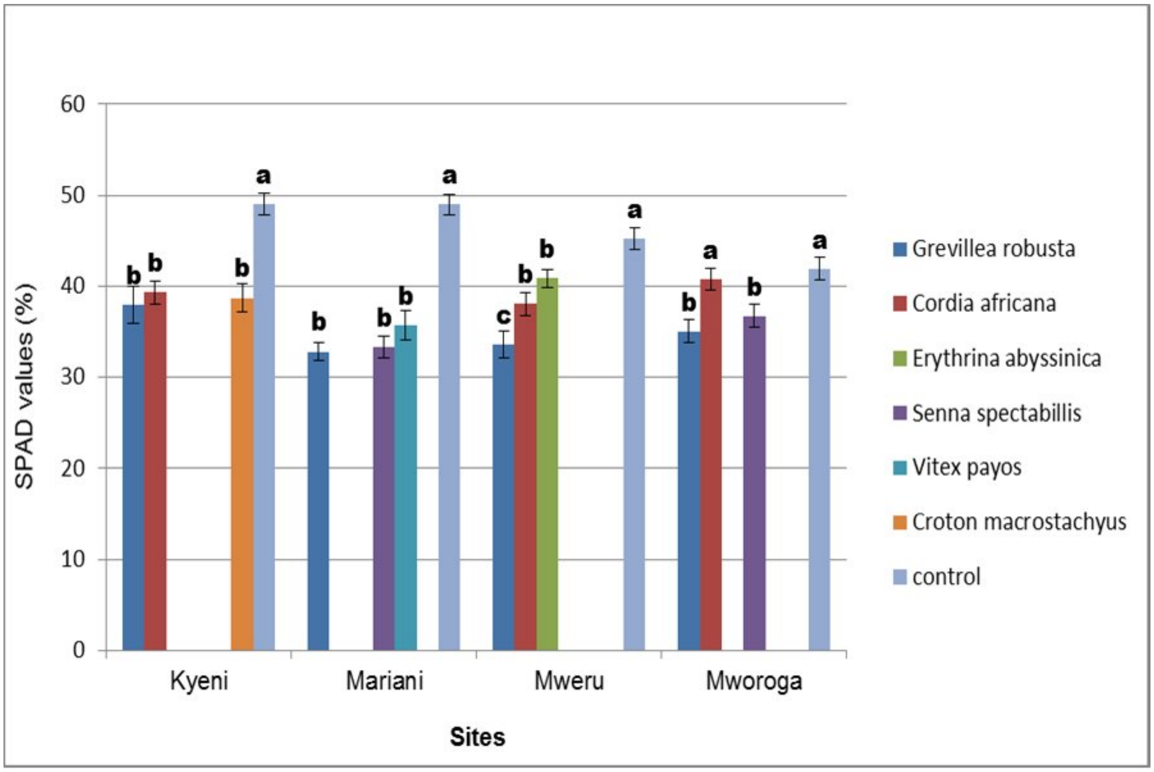

Figure 11. The influence of different tree species on SPAD readings on maize plant leaves at 6 WACE

The vertical bars on each bar show the standard error of the mean and the bars with the different letters show significant differences in plant SPAD values in relation to the influence of the tree species studied in that site

This is an indication of significant influence of trees in suppressing the chlorophyll development on maize plants. This may be attributed to light interception, decreased chlorophyll concentrations due to shading has been reported by Hashermi and Herbert

(1992). The reduction depends on the leaf area and layers of canopy at different times (Ong *et al*., 1996). The shading effect can be also related to the amount of nutrients absorbed by plants from the soil which has been found to have an influence on the chlorophyll concentrations in plants (Follet *et al*., 1981; Yadava, 1986; Kacar and Katkat, 2007; Hawkins *et al*., 2009; Celik *et al*., 2010).

Nutrient uptake is increased by transpiration pull; hence shading by the trees which consequently reduce the rate of transpiration may have contributed to reduced nutrient uptake by the plants. This could have consequently hindered some physiological processes like protein formation resulting in low chlorophyll concentrations in maize plants planted under the trees. The rate of leaf senescence is increased under soil mineral deficiencies which can be affected by trees' uptake at a local level (Valadabidi and Farahani, 2010). The exceptional scenario observed with *Cordia africana* which is normally densely foliated but showed less suppression on SPAD values on maize at Mworoga site which was not significantly different from the control (Figure 11). At Kyeni and Kanwaa no significant differences were observed on the SPAD values obtained from the tree species plots, the only differences were in relation to the control. Similar results were obtained on *Senna spectabilis* by (Mclntyre *et al*., 1996), and reported that the *Senna spp* showed less light interception such that it did not reduce maize growth and yield. At Mweru the *Cordia africana* and *Erythrina abyssinica* plots were not significantly different but were significantly different with that of *Grevillea robusta* which recorded the lowest SPAD value of 33.60% at that site. The ANOVA results revealed that distance had a significant effect on the SPAD values in Mweru and Mworoga sites with p-values of (0.018) and (0.012), respectively. No tree species and distance interactions were noted at both the sites thus ANOVA was done on individual tree species at all the sites and the results revealed that distance had a significant influence on the *Grevillea robusta* plots at Mweru. The SPAD values of the maize plants planted at 1m from the *Grevillea robusta* tree species in the site were reduced by an average of 6.35 % compared to those planted at 3.25m away from the trees (Fig. 12.c). At Mworoga, the analysis on the effect of planting distance from trees revealed significant differences in the *Senna spectabilis* plots ($p = 0.012$). The SPAD values for the maize planted at 1m from the trees were reduced by 5.9 % compared to those planted at four rows (3.25m) away from the trees (Fig. 12.d).

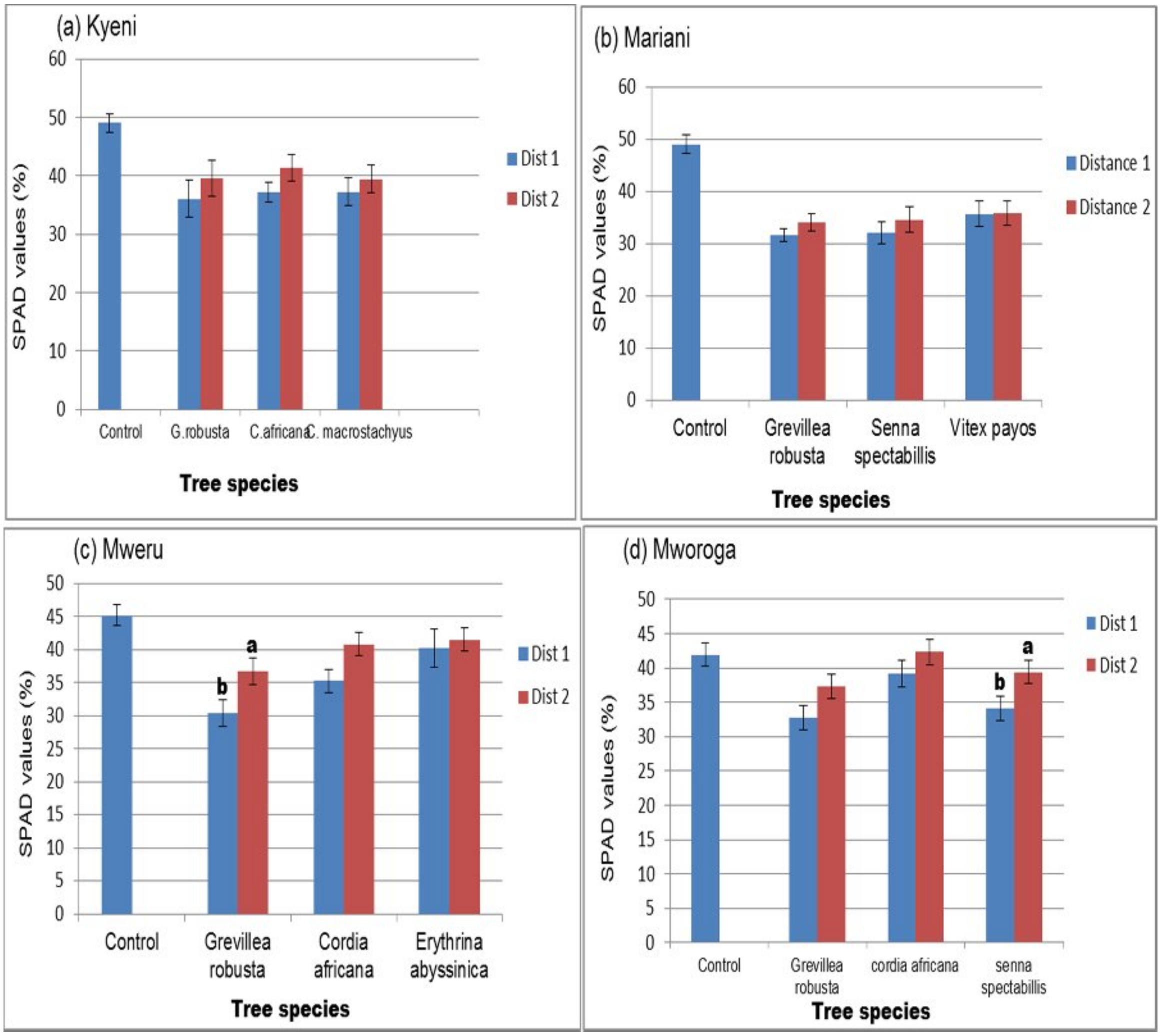

Figure 12. The variations of SPAD readings on maize plant leaves with planting distance from the different tree species. Distance 1 and 2 indicate crops planted at 1m and 3.25 m respectively from the trees. The vertical bars on each bar show the standard error of the mean and the bars for each species with the different letters show significant differences on SPAD values in relation to the influence of that tree species studied in that site

The differences on the effect of distance shown only by these two tree species at these sites may be due to differences in the width of the crowns for the trees used at these sites. Narrow but deep crowns which are typical of *Grevillea robusta* and *Senna* *spectabilis* tree species may affect only the crops that are planted closer to the tree. The plants at 3.25m may not have been exposed to shading which could suppress their chlorophyll development.

4.6. The variations of maize grain yield at physiological maturity, with tree species during the long cropping season of 2012 in Kyeni

Grain yield was only examined at Kyeni because of the crop failure experienced in other three sites due to poor rainfall that were received from the mid of the season. The control plots showed the highest grain yield of 2.21 t ha^{-1} which was significantly higher than that of *Grevillea robusta* plots (p = 0.002) but not with the *Croton macrostachyus* and *Cordia africana* plots. However, the results showed that *Grevillea robusta* plots were not significantly different from those of the other two tree species.

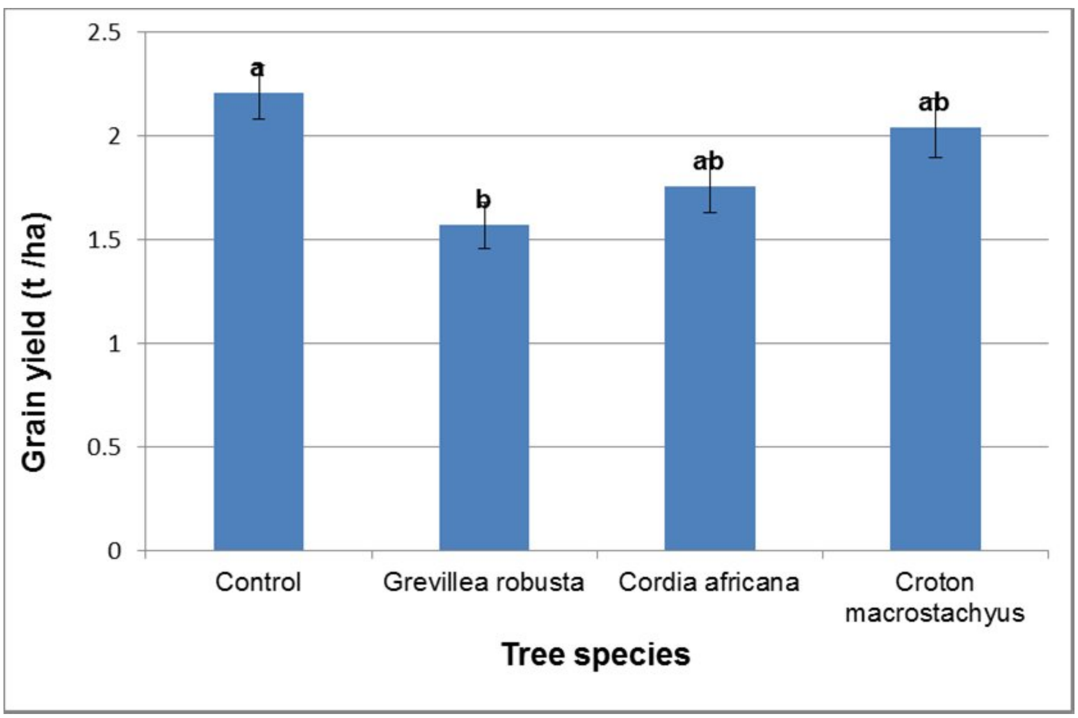

Figure 13. Grain yield of maize harvested under canopies of different tree species. The vertical bars on each bar show the standard error for the estimation of means and the bars with the different letters show significant differences in grain yield related to the influence of the tree species

The reduction in yield in plots under the canopies of *Grevillea robusta* tree species can be attributed mainly to the interaction of shading effect and low soil fertility. The *Grevillea robusta* plots revealed low organic carbon on soils beneath its canopies when compared to the *Croton macrostachyus* and the control plots (Figure 7). Furthermore, the lowest SPAD values were recorded in *Grevillea robusta* plots (Fig. 12) linked to reduced chlorophyll content. Suppressed maize growth by the *Grevillea robusta* trees was also apparent in maize basal diameter at 6 and 9 WACE at that site which were significantly lower than the control. This may explain the reduction in final grain yield in maize plants sampled under *Grevillea robusta* tree species. The effects of shading on reduced maize yield under *G. robusta* tree species was reported in a similar study by Ong *et al*., (2000) in Machakos. The effects of low soil pH on reduced maize grain yield in Kenya were reported by Mwangi *et al*., (1991). However the narrow margins of low soil pH observed in this study in *G. robusta* plots discount it from being a major contributing factor. The soil pH levels recorded were still close to the optimum requirements for maize of 6.5 to 7 (Nielsen, 2005).

The ANOVA results on the three tree species without the control, on the influence of the distance from the trees on grain yield was significantly different ($p = 0.002$). The species and distance interactions were not significant, thus the ANOVA in relation to distance was done on individual trees species. The highest significant yield difference in relation to distance from the trees was obtained on the crops harvested in *Cordia africana* plots (Fig. 14). The grain yield obtained from the plants harvested at 1m from the trees was significantly reduced by 64.8% compared to those harvested at 3.25 m away from the *Cordia africana* tree species. Since the SPAD values on crops under the canopies of *Cordia africana* showed no significant differences in relation to distance at this site, the reduction in yields can be attributed to other factors other than light.

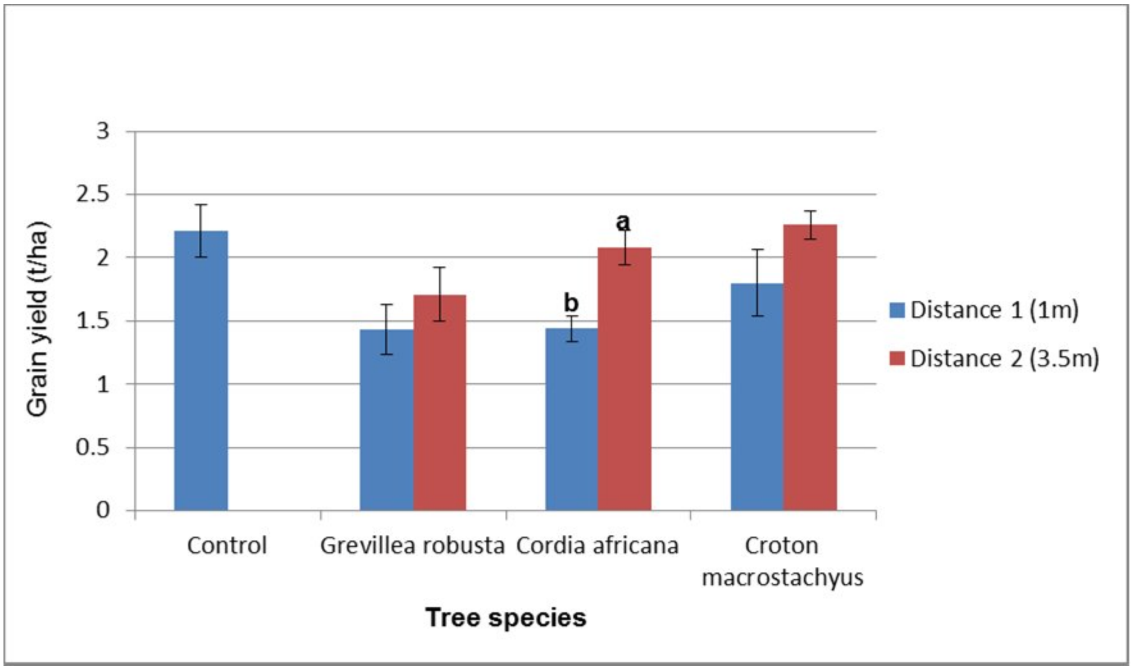

Figure 14. The influence of planting distance from the trees on maize grain yield.

The vertical bars on each bar show the standard error for the estimation of means and the bars with different letters show significant differences in grain yield relation to the distance from that tree species

4.7. Challenges in research process encountered during the study

Setting of objectives is the starting point of research and it directs the type of study and design of the work to be carried out. Challenges were encountered during this process, aligning priorities of the research and farmers interests proved challenging. Farmers wanted the study to also investigate the suitability of some maize varieties in their area which was out of scope of the study. Farmers always want to see a kind of research that will give immediate benefits like use of fertilizers, instead of agroforestry. Again some farmers had different perceptions on the effect of some tree species on soil fertility like *Grevillea robusta* some perceived it very beneficial in terms of improving soil fertility hence saw no reason to investigate its effects on soil fertility. However the effects could not only be on soil fertility but other factors like light interception. Thus it was important to explain and convince the farmers on the importance of each objective since the objectives determine the kind of data to be collected. If the farmers do not understand or approve of some objectives they may not co-operate during data collection.

For more reliable results a wider range of sites could have been selected but time and resources could not permit. Again this study was superimposed on an already going on project hence the sites were pre-selected. The selection of the sites was based on already established farmers groups to reduce time of organizing the farmers. This brings in some bias but it is easier to mobilize and work with farmers' group as they already have an idea on research projects. This was noted in a few farmers who had recently joined the groups they had some doubts on the research work and were suspicious on some aspects of data collection like soil sampling and harvesting. Some farmers did not understand the selection criteria of farms. Only four farms were selected from each site according to the availability of trees in their farms hence some farmers thought the researcher was biased in selection of farms.Most of the challenges were encountered during the designing and management of the study. Less farms than desired were selected due to lack of enough trees of interest for replication in some of the farms. It is often recommended to have more farms than replications in an on farm study. The selection of trees for study was also based on the distance from any neighboring tree and matching sizes. Farms with trees that were spaced at least 10 m were selected to avoid the confounding effects of other neighboring tree. Some farms had more trees but which were too close hence could not be used.

The significant differences in size of trees especially in Mweru where *Erythrina abyssinica* was compared *to Grevillea robusta* and *Cordia africana* led to few replications for the *Erythrina abyssinica* to reduce variability. This is one of the main challenges in designing on farm research; some factors on the ground cannot be controlled by the researcher especially when dealing with long lived study units such as trees. Farmers were advised to manage the plots the same way; but some farmers included some management practices that were not in the protocol like pruning the trees that were selected probably to please the researcher. This led to changing of the trees that were initially selected thus time consuming. This shows that on farm research may result in biased confirmation of results as farmers interfere with the treatments to force the results in a bid to please the researcher on based on their perception on the study. Some farmers did not plant maize under the trees as agreed but preferred legumes which are known to be tolerant to shading. Consistency in data collection was compromised due to the variability in the agro-climatic conditions of the sites. The crops at Mworoga site matured at a faster rate due to higher temperatures than at Kyeni. The rainfall shortages that led to water stress and even crop failure in other sites resulted in missing yield data for the other three sites.

Many parameters needed to be measured to come up with a broader explanation since many factors interact to influence the results but this called for more time, manpower and resources. Soil physical properties like texture and chemical properties like C: N ratio and CEC are linked to soil pH and carbon. Leaf length, leaf area and biomass for crops and more information was needed on the physiology of the trees like their leaf and root phenolic effects and root depth which could also not be determined in this study given limited time. The research needed more labor in order to collect data at the same time in all the sites which in some cases was not possible. In data analysis some parameters like plant height, diameter and soil pH were not normally distributed when tested as the entire data for all the sites, thus violating the assumptions of the ANOVA. However the data confirmed normality when tested separately according to sites. This shows the vast variability in sites and some confounding factors thus all the parameters were analyzed separately according to sites.

5.0. Conclusions

Grevillea robusta was found to be the most prevalent tree species on farms in three sites except in Mworoga were *Senna spectabilis* was dominant. Low soil carbon and pH under the *G. robusta* interacted in suppressing plant growth basal diameter and grain yield in maize at Kyeni site. Only *Croton macrostachyus* was found to increase soil carbon than *Grevillea robusta* at Kyeni but no significant differences were observed between trees at other sites. *Croton macrostachyus* and *Cordia african*a showed a positive effect in reducing soil acidification which was significantly different from *Grevillea robusta* at Kyeni site. At Mweru site soil acidification was observed in *G. robusta* plots compared to *Cordia africana* and *Erythrina abysinnica.* However, the average organic carbon content of the soils sampled under all the trees canopies in all the sites was greater than 2% which is considered to be productive or good in African soils (Okalebo *et al*, 1993).

*G. robust*a suppressed growth in plant diameter than other tree species at Kyeni. *Cordia africana* showed less suppression on plant diameter site while *G. robusta* suppressed plant height more than *Erythrina abysinnica* at 6 WACE at Mweru site. At Mworoga site *Cordia africana* showed less suppression on plant height than *G. robusta* and *Senna spectabilis* at 6 WACE. *G. robusta* suppressed chlorophyll development more than *Erythrina abysinnica* and *Cordia africana* at Mweru site while *Cordia africana* showed less suppression at Mworoga site. No significant influence by the trees on grain yield was observed except for *Grevillea robusta* which suppressed the grain yield than the control plots at Kyeni site.

6.0. Recommendations and way forward

- Chopping down of litter fall under *G. robusta* trees is likely to facilitate decomposition and increase the release of carbon in the soil.
- Further studies on phenolic composition of the litter from the trees may be necessary especially on C: N ratio, lignin and tannin contents and polyphenols of the leaves especially for *G. robusta* to establish the cause of acidification and low carbon content on the soil.
- *Croton macrostachyus, Cordia africana* and *Senna spectabilis* are recommended as candidates for agroforestry for purposes of increasing soil carbon and productivity on farms coupled with proper crown management.
- Similar future research should be coupled with more measurements on soil physical and chemical properties related to soil pH and carbon.
- Since much suppression on the growth and yield of crops seem to be pointing at above ground tree crop competition especially for light trees can still be incorporated into agroforestry on farms with good canopy management to reduce the above ground competition.
- Trees still play a great role in soil conservation especially in places characterized by steep slopes and farmers can benefit from trees on off farm uses. However, the study served as a short term communication and exploratory just for one season, this calls for more studies on several seasons in order to reach tangible conclusions.
- Despite a number of negative influences shown by *G. robusta* tree species on farms it is still a potential agroforestry tree given its popularity and multi- purpose use or else it can be planted more on the boundaries if its effects on crops are fully proven.

- Research should not be confined to on-station where most conditions are controlled but also expanded to on farm where real situations are experienced. After all the end users for most of the agroforestry research are farmers, however, researchers should be prepared for the challenges mentioned in this study.
- Farmers to be involved from the inception of research and a good follow up by researchers to avoid deviations in management and data collection protocol.
- More resources and time to allow more replications and measurement of many related parameters to avoid underlying factors.
- Involvement of expertise from different disciplines like crop physiology, social sciences, soil science and biometricians.

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