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Alteration of soil carbon and pH by selected common tree species on farms in Eastern Highlands of Kenya

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Abstract: *Lack of knowledge and evidence to farmers on the benefits of the tree and soil interactions which may halt land degradation on farms often results in the removal of the trees that grow on farms as scattered parklands. An on-farm study was carried out at four sites in Central highlands of Kenya to investigate the effects of selected common tree species on soil organic carbon and pH. Sampling of the top soil was done under the canopies of selected common tree species and from control plots (away from trees). Results revealed that Croton macrostachyus Hochst. Ex Delile plots had a significantly higher (P < 0.01) total organic carbon mean of 2.85% compared to 2.04% obtained in plots under Grevillea robusta A. Cunn. at Kyeni site. Senna spectabilis (DC.) H.S. Irwin & Barneby also had significantly higher (p < 0.05) total organic carbon mean of 2.89% compared to 2.33% obtained in control plots at Kanwaa site. In soil pH, control plots had significantly lower (P < 0.01) mean soil pH values than the plots under selected the trees at all the sites. Among the tree species only G. robusta revealed significantly lower (P < 0.01) soil pH than the C. macrostachyus, Cordia africana and control plots at Kyeni site. The study suggested that S. Specatabilis helps in increasing soil carbon and consequently soil fertility. S. specatabilis, C. africana, C. macrostachyus and Erythrina abyssinicca also showed some positive influence in reducing soil acidification on farms. It is recommended that an increase in the number of trees on farms may improve soil fertility and reduce land degradation.*

Key words: *Agroforestry, Land degradation, Soil acidification, Soil fertility.*

Abbreviations: *AEZ= Agro Ecological Zones; DBH= Diameter at Breast Height; LH= Lower Highlands; MASL=Meters above Sea Level; SOC= Soil Organic Carbon; TOC= Total Organic carbon.*

I. Introduction

A significant increase in land degradation on farms in the Central 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). Land degradation refers to lowering of the land productive capacity through processes such as soil erosion, loss of soil fertility, soil salinity and acidification (Young, 1997). 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). Low soil fertility and poor crop husbandry among others have led to declining yields in Kenya (Murithi *et al*., 1994). The land degradation situation in Kenya has been exacerbated by the recent increase in human populations and consequent demand for farmland and wood products (Sekubyu and Mosango, 2012). The use of farm inputs like inorganic fertilizers and lime by smallholder farmers to replenish soil fertility is severely constrained by prohibitive costs associated with such solutions (Akinnifesi *et al*., 2007). Thus assessment and adoption of low-cost and sustainable technologies to address problems associated with land degradation is very crucial.

Conservation agriculture complemented with agroforestry is now emerging as the promising land use option to sustain agricultural productivity and livelihoods of farmers (Syampunani *et al*., 2010). The integration of trees in farming systems provides environmental services and off-farm products that are either traded or used to confer multiple livelihood benefits; this can alleviate malnutrition, hunger and poverty in resource poor smallholder farmers (Leakey, 2010). One benefit of increasing trees on farms is an increase in soil organic carbon (SOC) pools which is a good indication of soil fertility (Konare *et al*., 2010). Increase in soil organic matter (SOM) and subsequently, SOC has the potential to improve several soil properties like structure, water retention capacity, nutrient availability, pH and microbial activity (Rashidi and Seilsepour, 2009; Jangra *et al.*, 2010; Ch'ng *et al*, 2011; Sebukyu and Mosango, 2012). With such a rich soil status, cropping period can be prolonged; intensive cropping and higher crop yields are possible (Mosango, 1999; Palm *et al*., 2001; Sileshi, 2009; ICRAF, 2009).

Research in agroforestry has typically focused on fast-growing tree species planted at high density which capture most of the available resources neglecting slow growing indigenous and probably adapted tree species that grow on farms (Ong and Leakey, 1999). Worldwide, much research has been focused on soil status under tree canopies in forests or natural ecosystems (Jangra *et al.*, 2010; Ch'ng *et al.*, 2011; Li *et al.*, 2012). Lack of knowledge and evidence on the benefits of the tree, soil and crop interactions to farmers motivates the removal of the trees scattered on their cropping area as traditional parkland systems (Ong *et al*., 2002; Sileshi *et al*., 2007. Farmers plant fast growing timber tree species and maintain a few specific tree species on croplands whose role in maintaining soil fertility has not been investigated. Empirical evidence on soil benefits through science will lead to increased planting of trees in farms. This study ought to understand the interaction of selected tree species with the soil on farms thereby closing the existing research gap. The purpose of this study was to investigate the effects of selected trees species growing on farms in Central highlands of Kenya on soil carbon and pH.

II. Materials And Methods

2.1. Study sites

The research study on the effect of common tree species on soil carbon and pH was carried out at four sites selected from three counties in Central highlands of Kenya, one site, Kyeni South a sub-location in Embu. 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 in Lower highlands (LH5), Agro-ecological Zone (AEZ) and 2070 meters above sea level (Masl) 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. This study was carried out during the long rainy season in 2012 that stretched from March to June in 2012. The average annual rainfall is estimated at 1206 mm. The county has a diverse agro-ecology with very fertile soils influenced by Mt Kenya.

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 masl at the peak of Mount Kenya to 600 masl 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 deep red loam 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 masl. 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. 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.

2.2. Study design and Sampling procedure

This was an on-farm research survey that followed a complete randomized design (CRD) with one factor (type of tree species) at three levels in each site. The sampling units were the plots marked under the selected trees and control plots (no trees) replicated three times for soil sampling. Field sampling was conducted on farms selected from the four study sites.

This study was part of the International Centre for Agroforestry Research (ICRAF) and International Maize and Wheat improvement Centre (CIMMYT) collaborative project entitled "Enhancing total farm productivity in smallholder conservation based systems in Eastern Africa" and was conducted in project sites. The sites were selected by the project in order to build on another project called Sustainable intensification of maize-legume cropping systems (SIMLESA) which focused on conservation agriculture for maize and legume productivity and worked with one farmer group in each site. In this study a two stage purposive sampling was used. First a list of farmers in each of the groups that worked with the SIMLESA project at the four sites was acquired and ten farmers were selected randomly. This constituted more than half of the group members in each group. The selected farms were visited and an inventory of all the tree species growing on farms was conducted. This was done to identify the most common tree species growing especially within the cropping area and thereafter purposive sampling of farms with high numbers of the identified common tree species was done. Four farms were selected in each site and the study was carried out on three common tree species that were selected in each site.

The most prevalent tree species that were selected in each site were; *Grevillea robusta* A.Cunn.ex R.Br., *Cordia africana* Lam., *Croton macrostachyus* Hochst.ex Delile at Kyeni, *Grevillea robusta*, *Senna* *spectabilis* (DC) H.S. Irwin & Barneby and *Vitex payos* (Lour.) Merr at Kanwaa, *G. robusta*, *C. africana* and *Erythrina abyssinica* Lam. at Mweru and *Grevillea robusta*, *Cordia africana* and *Senna spectabilis* at Mworoga. *G. robusta* was selected in all the four sites, *C. africana* in three sites and *S. spectabilis* in two sites Mworoga and Kanwaa. In total six tree species were selected. The selection of the four farms was based on the availability of the selected tree species and their positioning on farms. Farms with at least three individual trees of the identified species growing within the cropping area and isolated at least 10 meters away from any other tree were selected from each site. The selection of the trees was also based on the size in diameter at breast height (DBH), farms with the trees to be compared that showed less variability in size were selected (Table 1). The plots for soil sampling measuring 8m x 8m were marked under the trees in each farm leaving the tree centrally located in each plot. In addition three plots measuring 8m x 8m were also selected at least 10 meters away from any tree in each farm as control plots. In total 16 farms were selected for soil sampling (Table 1).

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.

Site	Sampling plots under the trees	Number of replicates	Min DBH (cm)	Max DBH (cm)	Mean DBH (cm)	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	2.10
	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	5.90
	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				

2.3. Soil sampling and analysis for soil fertility status

Soil sampling was done once before planting at the beginning of the long rainy season of March 2012. Soil samples were collected under the canopies of each selected tree at each farm in all the sites (Table 1). Soil samples were collected from a total of 12 sampling points to make one composite sample. Two sampling points were marked systematically in each direction of the four cardinal points from the tree base. The first sample at 1m and the second one at 4meters from the tree base in each direction. In addition four more samples were randomly collected around the base of the tree. At each control plot 8 soil samples were collected at random. At each sampling point 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 (Table 1). A GPS gadget (Garmin, USA) was used to record the points of all the trees and control plots were soil sampling was done. Laboratory soil analysis was carried out on the samples to determine total organic carbon (TOC) using the Walkley- Black titration method (1934) and soil pH using the pH meter (Hanna HI 831K, Romania).

2.4. **Data analyses**

Data obtained from the laboratory analysis were statistically analyzed using Genstat 13th edition. One-way Analysis of Variance (ANOVA) was used to detect significant differences in soil total carbon and soil pH sampled under the canopies of different tree species. Where there were significant differences at alpha level of 0.05 means were separated using the least square differences. Prior to analysis the data was first subjected to normality tests using the Shapiro-Wilk test and homogeneity of variance using the Bartlett’s test. The data which did not violate the assumptions of ANOVA were not transformations. Data from each site was analyzed separately.

III. RESULTS

3.1. Total organic carbon

At Kyeni and Kanwaa sites, the results from ANOVA revealed significant differences ($P < 0.05$) in the total organic carbon (TOC) in soils sampled under the canopies of different tree species. At Kyeni the soils sampled under *C. macrostachyus* canopies revealed the highest value of 2.85 % TOC (Fig. 1a) whichwas significantly different($N = 48$; $P < 0.01$) with the *G. robusta* plots that had the lowest mean of 2.04% TOC. However, the species (*C. macrostachyus*) was not significantly different from the plots under *C. africana* and the control plots. Significant differences were also revealed when the plots under *G. robusta* were compared to the control plots but not with *C. africana* at that site.

At Kanwaa, a significantly higher amount of TOC in soils sampled under the *S. spectabilis* compared to the control plots was observed ($N = 48$; $P < 0.05$). Soils sampled under *S. spectabilis* had the highest mean value of 2.89% compared to 2.04% for the control plots which had the lowest TOC at that site (Fig. 1b). At the other two study sites namely Mweru and Mworoga no significant differences ($P > 0.05$) were shown between the tree species (Figures 1c and 1d).

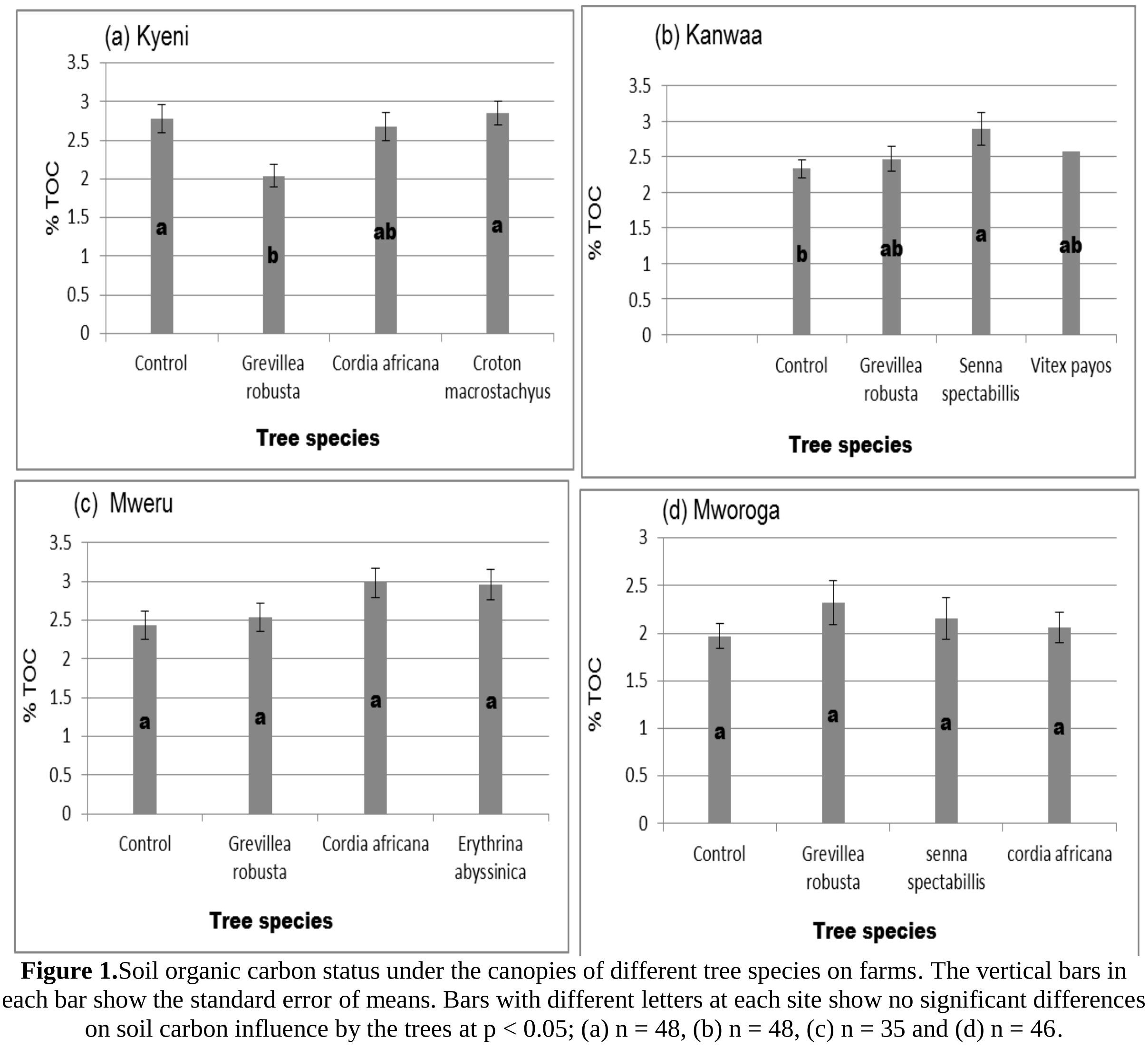

Figure 1. Soil organic carbon status under the canopies of different tree species on farms. The vertical bars in each bar show the standard error of means. Bars with different letters at each site show no significant differences on soil carbon influence by the trees at $p < 0.05$; (a) $n = 48$, (b) $n = 48$, (c) $n = 35$ and (d) $n = 46$.

3.2. Soil pH

Tree species influenced soil pH differently at different study sites with some showing a significant positive influence (Figure 2). At Kyeni the control plots were not significantly different from the *C. africana* and *C. macrostachyus* plots in soil pH but the soils under these two tree species were significantly different from those of *G. robusta* plots($N = 48$; $P < 0.01$). The soils sampled under the canopies of *G. robusta* tree species showed the lowest soil pH value of 5.99 while those from the *C. macrostachyus* had the highest of 6.44 (Fig. 2a).

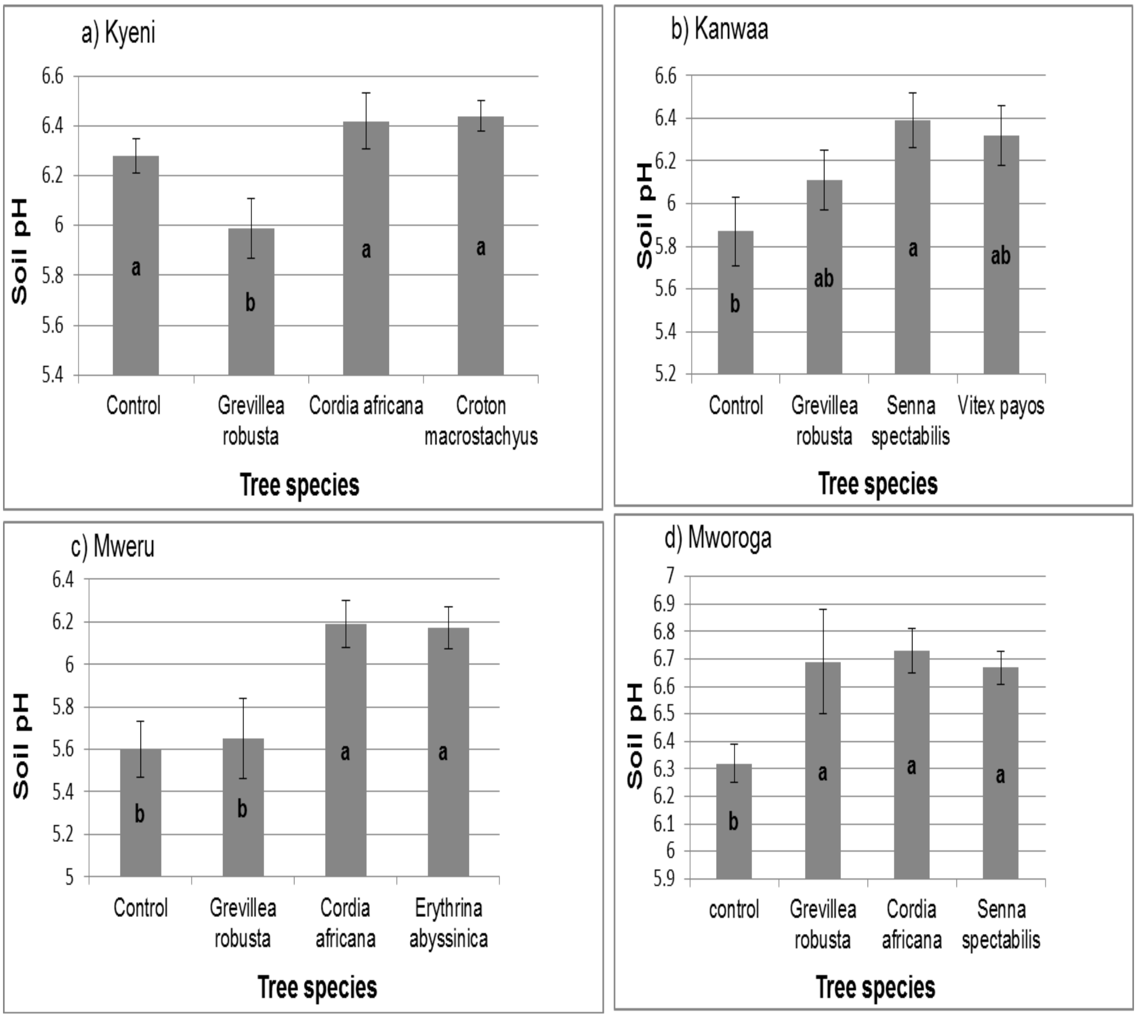

Figure 2. The influence of different tree species on Soil pH on farms.

The vertical bars in each bar shows the standard error of means. Bars with the different letters at each site show no significant differences in soil pH influenced by the compared tree species at $p < 0.05$; (a) n = 48, (b) n = 48, (c) n = 35 and (d) n = 46.

At Kanwaa site, plots under *G. robusta* did not show any significant differences on soil pH with those under *V. payos* and *S. spectabilis* as well as the control plots. However, the *S. spectabilis* plots showed significant differences (N = 48; P = 0.01) with the control plots (Fig. 2b). At Mweru the third study site, the soil pH in plots under *C. africana* was not significantly different with those under *E. abyssinica* but were significantly different with those under *G. Robusta* and the control (N = 35; P < 0.01). The control plots revealed the lowest mean pH value of 5.60 though not significantly different from *G. robusta* plots at that site (Fig. 2c). At Mworoga the control plots had significantly lower pH (N = 46; P < 0.01) than the plots under the three tree species namely; *G. robusta*, *S. spectabilis* and *C. africana* (Fig. 2d). The control plots showed the lowest soil pH value of 6.32.

IV. Discussion

The high levels of soil organic carbon revealed in soils sampled under the canopies of *C. macrostachyus* at Kyeni site may be explained by fast decomposition of its litter. While the relatively lower soil organic carbon under *G. robusta* tree species at the same site may be attributed to slow decomposition of its leaf litter despite the heavy leaf fall as observed under its canopies. The litter quality controls the rates of decomposition and mineralization (Mafongoya *et al*., 2000). In order to maintain the nutrient replenishing cycle from the leaf litter 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).

Lower soil carbon in soils sampled beneath the canopies of the *G. robusta* tree species obtained in this study, may be related to low soil pH as observed (Fig. 2a). 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). The highly significant soil carbon levels under the *S. spectabilis* tree species observed at Kanwaa site can be related to low soil acidification (Figure 2b). Organic litters that decompose faster tend to releases more carbon and other secondary compounds like nitrogen that reduces the accumulation of organic acids (Chesson, 1997; Mafogonya *et al*., 1998).The differences in soil carbon may also 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. Soil carbon content is also variable depending on soil type, climate, management practices and initial soil status (Nsabimana *et al*., 2008). However, on average, total organic carbon of the soils sampled under all the trees canopies at all the sites was greater than 2% which is considered to be productive or good in African soils (Okalebo *et al.*, 1993).

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 (Finzi *et al*., 1998). 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 Constantides and Fownes, 1993; Handanyato *et al*., 1995 and 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, Nsabimana (2008) reported that *Grevillea robusta* tree species how less soil acidification.

The low soil pH observed in control plots at three sites Kanwaa, Mweru and Mworoga 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 in Mweru and Mworoga sites which are dominated by steep slopes. The control treatments were selected away from trees and therefore the soils could have been subjected to higher rates of soil erosion and leaching.

V. Conclusions

The *C. macrostachyus* and *S. spectabilis* tree species showed some potential as soil improving tree species in agroforestry, based on their influence on soil carbon and pH. Only one tree species *G. robusta* showed less influence on soil carbon and some signs of soil acidification on two sites. Trees can therefore play a great role in soil conservation especially in places characterized by steep slopes and farmers can benefit from trees on off-farm uses.

Despite a number of negative influences on the soil shown by *G. robusta* tree species on farms it is still a potential agroforestry tree given its popularity and multi-purpose uses but farmers might need to reconsider niches for growing it and replace it in the cropping area with species that have more potential to improve soil fertility. A study on the phenolic composition of the leaves and roots of the studied trees is recommended.

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