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ASSESSMENT OF SOIL CARBON AND PH UNDER FOREST STANDS AND ADJACENT FARMLANDS IN A MICRO-TROPICAL FOREST IN MACHAKOS COUNTY

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ABSTRACT

This study evaluated the soil total organic carbon (TOC) and pH within Iveti forest, Machakos Kenya and the adjacent farmlands to determine variability among forest stands and adjacent agricultural fields. A total of 39 sampling points was established in the farmlands and in the forest along a line transect and at intervals of 200 meters and soil pH and carbon determined for each point. Forest soil had higher soil TOC and pH than the adjacent farmlands at 18.8 - 5.1 mg C/ha and 7.78-1.51 mg C/ha respectively. An increased TOC from the northern upper part of the forestto a peak in sampling points near the middle of the forest was observed while pH in soils at the inner parts of the forest was higher than that at the forest edges. Within the forest ecosystem, Pinus patula stands had significantly (P < 0.05) high soil TOC while Cupressus lusitanica stands contained the highest pH. The open forest canopy soils contained significantly higher TOC and pH.In farmlands, soil total organic carbon and pH varied depending on crops or types of trees planted. The Grevillea robusta stands had the highest soil TOC and pH followed by Eucalyptus trees stand, coffee farms and vegetable fields. Introduction of exotic tree species in plantation forests also invariably affected the soil organic carbon and pH. There is a need to foster management of soils both within the micro-forests and in the adjacent farmlands to decrease soil degradation and enhance soil quality.

Keywords: Adjacent Forest ecosystem; Human activities; Forest stand; Iveti Forest, Soil organic carbon

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INTRODUCTION

Human settlement and activities adjacent to forestland is ubiquitous. These human activities stem from conversion of forest land to agricultural land and include modification of vegetation at the ecotones (Sakamaki and Richardson, 2017), nutrient additions from domestic sources and agricultural practices (Guillaume *et al.*, 2015), aquaculture (dos Santos Rosa *et al.*, 2013), and watershed scale development. Land-use activities adjacent to the forest may affect the dynamics of soil properties and thus influence vegetation growth and distribution (Murty *et al.*, 2002; Lemenih, *et al.*, 2005). There are varying consequences for land use changes but the most common is the loss of nutrients when the soil profile is disturbed leading to overall reduced quality and productivity (Islam and Weil, 2010; Celik, 2011). Soil quality combines the chemical, physical and biological properties and hence confer soils the ability to carry out ecological functions such as to support plant growth. When roots, plant residues and soil organisms decompose, they increase soil organic matter (SOM). The quality of SOM is by far the most important soil quality parameter that contributes to ecosystem production and is key to maintenance or improvement of soil chemistry, physical properties, bulk density and infiltration capacity (Vesterdal *et al.,* 2002) A lot of research has been directed towards understanding the soil organic matter, with an aim of developing strategies to augment the soil C storage (e.g., Izaurralde *et al.,* 2001; Solomon *et al.,* 2007; Wang *et al.,* 2001). Meanwhile, changes in land use will profoundly affect the quantity and dynamics of SOM as well as soil properties and soil functional properties (Murty *et al.,* 2002; Kong *et al.,*2005). Release of carbon by oxidation of SOM by microbial respiration is balanced by inputs of carbon from plant residues Deuchars *et al.,* 1999; Davidson and Ackerman, 1993). However, cultivation of forest soils tends to diminish SOM within a few years of initial conversion (Corbeels *et al.,* 2006; Vesterdal *et al.,* 2002).

In the past decades, tropical areas in Africa was affected largely by increasing land use practicesdue to burgeoning population and increased demand for food, energy and water obtained from the forest (Giertz *et al.,* 2005; Bruijnzeel, 1990). Tropical regions in Africa have recorded the highest
loss rate and trends of their forest (estimated at two thirds) during the 1980s, through diverse human activities (Chapman *et al.,* 2006). Therefore, only about 30% of the original Afromontane forests have remained, the rest being transformed human settlement. Variable outcomes on the SOM have indeed been observed when forests are converted to human settlement areas. In some instances, an improvement in quality of SOM has been reported (Eshetu *et al.,* 2004; Paul *et al.,* 2012), but also decreased SOM quality has been noted (Guggenberger and Kaiser 2003). However, there is dearth of research in the African continent on the effects of human activities on SOM and fertility and hence affecting sustainability of forest soil (Malo *et al.,* 2005). Soils adjacent the forest areas in Kenya are used for agriculture, pasture lands, water towers, and for industrial purposes (Maitima *et al.,* 2009). However, unsustainable land use due and human activities, and their drivers,pose threats to the quality of soils in these systems (Matano *et al.,* 2015). Many studies report low carbon due to poor land use, lack of inputs and poor soil tillage regimen (Mganga *et al.,* 2011).

Human activities responsible for degradation of the soil quality and thus influence the SOM in Kenya include industrial activities, deforestation, hydro- modification, agricultural activities, urban runoff, and discharge of untreated waters (Mganga *et al.,* 2011; Matano *et al.,* 2015; Mganga *et al.,* 2016). The intensity of human activities may invariably affect the SOM but this degree and distribution of the effects rely on the size of the catchment (Pabst *et al.,* 2013) and therefore studies on soil quality mainly the dynamic of carbon and other soil quality parameters in a single region may not be applicable to other regions. The soil resource cannot be well managed and/or sustained unless its quality is ascertained (Guggenberger and Kaiser, 2003; Blanco-Canqui and Lal, 2008; Matano *et al.,* 2015). Information on the soil carbon and SOM and other soil quality parameters in Iveti forest area not sufficient and therefore how the human activities within the region affect the soil quality parameters remains largely unknown. Through measurement of several indicators ofsoil properties it is possible to assess the dynamic of soil quality (Solomon *et al.,* 2007). The properties selected to determine the soil quality must be: sensitive to changes in agriculturalpractices, conform to a range of soil processes, and simple to quantify. Within the tropics, there is lack of standardized minimum dataset for soil quality determination (Bastida *et al.,* 2008). However, measurement of SOM has been established to be the first point in the measurement of soil quality indicators (Bationo *et al.,* 2011; Ngoze *et al.,* 2008). This study investigated soil carbonand pH content between the forested areas with minimal human activities and those of adjacent agro-ecosystems with intense human activities in Iveti forest and their implication on the quality of soil and productivity.

MATERIALS AND METHODS

Study area

The study area was carried out between April and August 2015 in Iveti forest Machakos County (Figure 1). Machakos County is located in Eastern region of Kenya stretching from latitudes 0°45’ to 1°31’ South and longitudes 36°45’ to 37°45’ East. The county has an estimated area of 6208km^2,most of which is classified as arid and semi-arid area (ASAL) (Jaetzold et al., 2006). By the year 2019, the county had a population of about 1,421898 (population density is 229 persons/km^2) with 264,500 households (KNBS, 2019). The local climate within the county is basically semi-arid with hilly terrain with an altitude of 1000−2100 m asl. The county experiences bimodal rainfall pattern with long rains occurring between March and June while the short rains occurs from October to December. Average rainfall ranges from 500 mm to 1300 mm, for short rains and long rains seasons respectively with the driest months being February and September. The mean annual temperature ranges from 17°C to 24°C with the coolest months being from June to August while the hottest months are January to March, (Jaetzold et al., 2006) (Figure 2).

Iveti Forest covers an area of 347.2 ha and is currently a gazetted forest (Forestry Master Plan Machakos District, 2002) The vegetation in the forest comprises both planted tree species and naturally growing vegetation. Planted indigenous trees include *Juniperus procera*, *Vitex keniensis*, and *Brachylaena hutchinsii*. Naturally growing trees include *Croton megalocarpus*, *Albizia gummifera* and various shrubs.

The study site has a micro climate along the Iveti hills surrounded by small scale farms mainly dominated by coffee. Agroforestry is mainly dominated by woody species of Eucalyptus (Eucalyptus saligna), Wattle (*Acacia mearnsii*), Grevillea (*Grevillea robusta*), and Avocado (*Persea americana*) fruit trees and mulberry for silk production. The soils are crusting sandy clay loams and are classified as Chromic Luvisols and Vertisols with low organic matter content, generally acid and low nutrient content (Jaetzold et al., 2006).

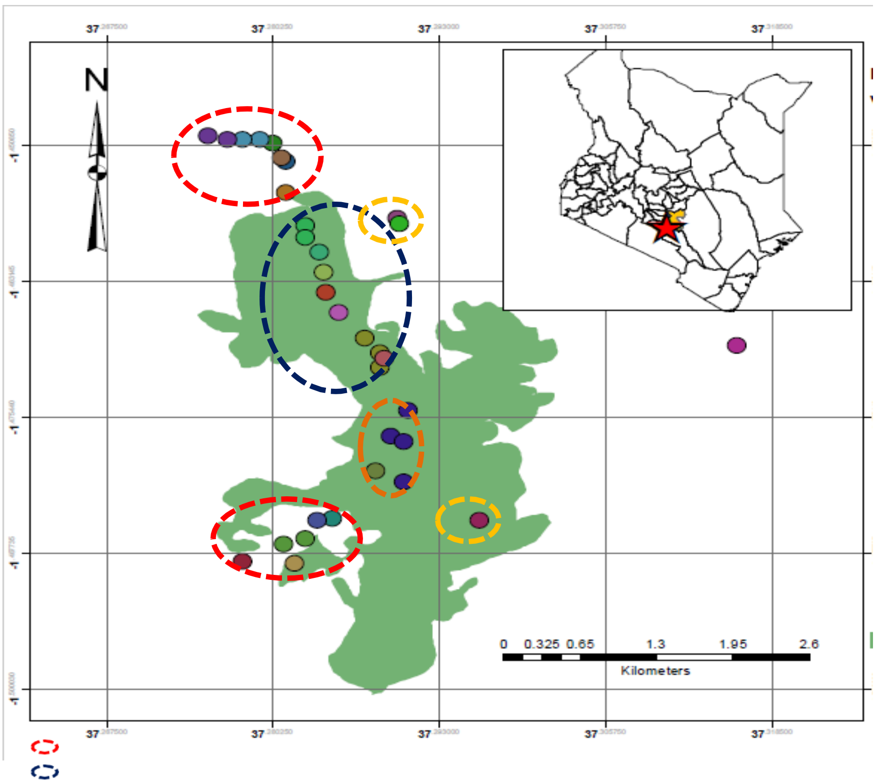
Sampling and data collection methods

The current study used a spatial analogue approach whereby soil parameters were compared among sampling plots located in different forest stands (mainly woodland comprising of indigenous forest, planted forest, open canopy with undergrowth alongside reference fields of farm land. The forest plots comprised of undisturbed forested area mainly at the core of the forest that had not been used for cultivation or any other intensive use (such as grazing or logging) for >25 years and were in the pristine status covered by indigenous forest species of *Juniperus procera* and planted forests mainly with *Pinus patula* and *Cuppresus lustanica*. Fields that had never been used for cultivation but were highly disturbed, through logging and were composed of mainly forest undergrowth or coppiced trees were classified as open canopy.

Sampling plots were categorized as agricultural if they had previously been in forest state but had been cleared and used for cultivation at least or within the last 3 years preceding the study. These plots included areas under Maize (*Zea maize*), legumes, vegetables, or under agroforestry trees comprising of coffee, Eucalyptus species, *Acacia mearnsii* or *Grevillea robusta*. The last category included fields dominated by grass and which had been extensively grazed. Detailed descriptions of the sampling plots are shown in Table 1.

Selection and characterization of sampling points

The sampling units comprised of selected forest stands and the adjacent farmlands. Sampling points were selected randomly along established transects based on the position in the forest or on the farmland and occurred in different vegetation cover types which included indigenous forest areas, planted forest areas, grazed land and cropped fields. A total of thirty-nine (39) sampling points were established in the current study as shown in Figure 2. Eight sampling points designated as *S1* to *S8* were selected within the farmlands from the edge of the northern upper part of the forest while 16 sampling point designated *S9* to *S25* were selected within the forest. Additional nine sampling points designated as *S26* to *S36* were selected in the southern lower part of the forest. The description and position of the sampling points at Iveti Forest are provided in Table 1.



S1-S8- sampling points within agricultural land along the transect
S9-S24- sampling points within forest area along the transect
S25-S32- sampling points within agricultural area in the forest
S33-S39- random sampling points within agricultural or forest land

Figure 1: Map of Kenya showing Iveti forest and the soil sampling transect within the forest andon either side of the farmlands

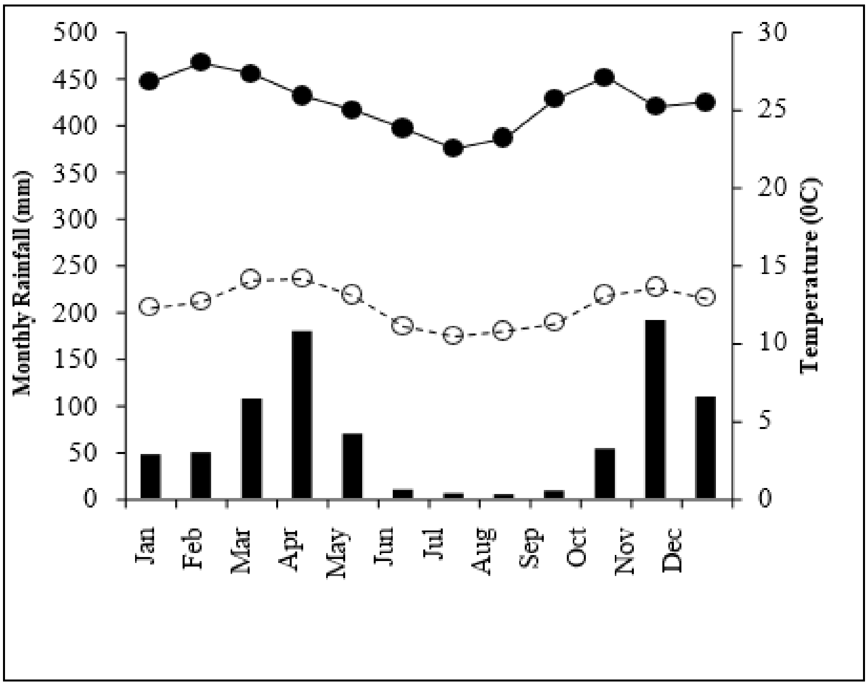


Figure 2: Monthly rainfall (mm) shown as bars, minimum (o) and maximum (●) air temperature (^{0}C) for Iveti forest, Machakos county. Rainfall and temperature data are based on10year average. (Data source- Kenya meterological department)

Table 1: **Description of sampling points in Iveti with forest Centre as reference point**

Sampling point *(S)*	**Coordinates**	**Altitude (m)**	**Slope (%)**	**Slope classification¶**	**Ecosystem**	**Land use**	**Major vegetation cover**
1.	01^{0}27.31’S; 037^{0}16.88’E	2042	< 3%	Nearly level	Agricultural	Maize	Maize cropping, sweet potato and Napier grass
2.	01^{0}27.14’S; 037^{0}16.88’E	2042	3-5%	Gently sloping	Agricultural	Grassland	Open farm (terraced)
3.	01^{0}27.12’S; 037^{0}16.86’E	2051	3-5%	Gently sloping	Agricultural	Maize	Maize cropping and napier grass
4.	01^{0}27.04’S; 037^{0}16.82’E	2060	3-5%	Gently sloping	Agricultural	Vegetables	*Vegetables, Persea americana*, napier grass, maize
5.	01^{0}27.02’S; 037^{0}16.76’E	2074	15%	Moderately slopy	Agricultural	*Eucalyptus saligna*	Closed canopy of *Eucalyptus saligna*
6.	01^{0}27.02’S; 037^{0}16.68’E	2075	10 -15%	Moderately slopy	Agricultural	*Eucalyptus saligna*	Closed canopy of *Eucalyptus saligna*
7.	01^{0}27.02’S; 037^{0}16.61’E	2076	25 - 30%	Moderately steep	Agricultural	*Acacia mearnsii*	Open canopy of *Acacia mearnsii*
8.	01^{0}27.00’S; 037^{0}16.52’E	2084	25 - 30%	Moderately steep	Agricultural	*Acacia mearnsii*	Open canopy of *Acacia mearnsii*
9.	01^{0}27.49’S; 037^{0}16.97’E	2122	20 - 25%	Moderately steep	Forest	*Juniperus procera*	Open canopy of *Juniperus procera*, *Dombeya goetizenii*
10.	01^{0}27.55’S; 037^{0}16.97’E	2030	25 -30%	Moderately steep	Forest	*Juniperus procera*	Open canopy of *Juniperus procera*, *Dombeya goetizenii*
11.	01^{0}27.63’S; 037^{0}17.03’E	2022	25 - 30%	Moderately steep	Forest	*Juniperus procera*	*J. procera* undergrowth
12.	01^{0}27.74’S; 037^{0}17.05’E	2006	< 3%	Nearly level	Forest	*Pinups patula*	*Pinus patula* canopy with undergrowth of shrubs
13.	01^{0}27.85’S; 037^{0}17.069'E	2006	< 3%	Nearly level	Forest	Open canopy	Open canopy (fire break)
14.	01^{0}27.96’S; 037^{0}17.12’E	2025	30%	Moderately steep	Forest	*Pinus patula*	*P. patula* canopy
15.	01^{0}28.04’S; 037^{0}17.17’E	2039	< 3%	Nearly level	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy
16.	01^{0}28.10’S; 037^{0}17.24’E	2052	< 3%	Nearly level	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy
17.	01^{0}28.18’S; 037^{0}17.31’E	2034	30%	Moderately steep	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy
18.	01^{0}28.26’S; 037^{0}17.317^{1}E	2012	< 3%	Nearly level	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy
19.	01^{0}28.40’S; 037^{0}17.430^{1}E	2049	25%	Moderately steep	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy,
20.	01^{0}28.49’S; 037^{0}17.44’^{1}E	2073	35%	Steep	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy; soil covered by fern and shrubs
21.	01^{0}28.63’S; 037^{0}17.36’E	2096	30%	Moderately steep	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy; soil covered by fern and shrubs
22.	01^{0}28.66’S; 037^{0}17.42’E	2002	35%	Steep	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy; soil covered by fern and shrubs
23.	01^{0}28.88’S; 037^{0}17.42’E	2106	30%	Moderately steep	Forest	*Cuppressus lustanica*	*C. lusitanica* canopy; soil covered by fern and shrubs
24.	01^{0}28.82’S; 037^{0}17.29’E	2128	30%	Moderately steep	Forest	*Pinus patula*	*Pinus patula* canopy
25.	01^{0}29.09’S; 037^{0}17.77’E	2001	< 3%	Nearly level	Forest	Open canopy	Open canopy of *E. saligna*
26.	01^{0}29.08’S; 037^{0}17.09’E	1999	< 3%	Nearly level	Agricultural	Grassland	Open canopy grassland
27.	01^{0}29.09’S; 037^{0}17.02’E	1970	< 3%	Nearly level	Agricultural	Legumes	Legumes and napier grass.
28.	01^{0}29.19’S; 037^{0}16.97’E	1950	< 3%	Nearly level	Agricultural	*Grevillea robusta*	Grevillea robusta, nappier grass along terraces
29.	01^{0}29.22’S; 037^{0}16.87’E	1924	< 3%	Nearly level	Agricultural	*Grevillea robusta*	Grevillea robusta, nappier grass along terraces
30.	01^{0}29.32’S; 037^{0}16.92’E	1894	3- 8%	Gently sloping	Agricultural	Vegetables	*Vegetables, P. americana* and *G. robusta*
31.	01^{0}29.31’S; 037^{0}16.68`E	1877	3- 8%	Gently sloping	Agricultural	Coffee	Coffee plantation
32.	01^{0}29.24’S; 037^{0}16.55’E	1808	30%	Moderately steep	Agricultural	*Eucalyptus saligna*	*E. saligna* canopy
33.	01^{0}28.21’S; 037^{0}17.33`E	2050	< 3%	Nearly level	Agricultural	Grassland	Open grassland
34.	01^{0}27.49’S; 037^{0}17.39’E	1811	25%	Moderately steep	Agricultural	Coffee	Coffee plantation
35.	01^{0}27.47’S; 037^{0}17.39’E	1808	20%	Moderately steep	Agricultural	Coffee	Coffee plantation
36.	01^{0}27.45’S; 037^{0}17.39’E	1791	< 3%	Nearly level	Agricultural	Maize	Maize plantation
37.	01^{0}27.48’S; 037^{0}17.40’E	1830	20 - 30%	Moderately steep	Agricultural	*Eucalyptus saligna*	*Eucalyptus saligna*
38.	01^{0}27.48 S; 037^{0}17.40’E	1833	25 - 30%	Moderately steep	Agricultural	*Eucalyptus saligna*	*Eucalyptus saligna*
39.	01^{0}28.14’S; 037^{0}18.95’E	1884	3- 8%	Gently sloping	Agricultural	Legumes	Legumes

¶ *USDA Soil Science Division Staff, (2017).*

Table 2: Summary of forest stands studied

Forest stratum	Area (ha)	Mean height(m)	Diameter at Brest height DBH (mm)	Density	Volume /Ha (M^3/Ha)
Indigenous forest area					
Juniperus procera	3.6	32.1	474.1	116.7	262.5
Plantation area					
Cupressus lusitanica	3.9	19.2	233.8	691.7	328.7
Eucalyptus saligna	2.4	24.3	190.6	725.0	275.7
Pinus patula	3.0	27.4	427.9	250.0	313.8

In the forest, the sixteen (16) sampling points were established starting from edge of the northern upper part of the forest to the southern lower parts of the forest using a line transects 200 meters apart, and it traversed through different forest stands including *Juniperus procera*, *Pinus patula* and *Cupressus lustanica* and open canopy (Table 2). The starting point, for the first sampling point was chosen randomly on the northern part of the forest designated as sampling point *S9*.
In the adjacent farmlands, from the northern upper part of Iveti forest and southern lower part, a line transect was established from the edge of the forest towards the inside the farmlands. The sampling points were 200 meters apart. Eight sampling points were established in the northernupper part while the remaining eight points were on the southern lower part of the Iveti forest (Figure 2). Thus, the forest sampling points comprised of undisturbed forest areas with indigenous tree species or areas which have been replanted with exotic trees; land which was once forested but currently with regrowth; while the farmlands comprised of 'cropped fields' (field under cultivation with various crops and varying management practices). During the study period the farmlands sampled had varying proportion of land under: maize, vegetables, Eucalyptus *spp*, Acacia *spp*, grassland, legumes, *Gravellia robusta* and coffee trees (Table 3).

Table 3: Description of non-forested areas (agro-ecosystems) sampling units adjacent to Iveti forest

Sampling Unit	No of sampled plot	Land use and management	Main crops/trees
Agroforestry	5	Single or multiple trees	*Coffee arabica, Eucalyptus saligna,, Acacia mearnsii, Grevillea robusta, Persia americana*,
Cropped land	7	Annual or perennial crops with tillage and manure	Sweet potato, Napier grass, Maize, Beans, Cassava, Vegetables, Legumes
Grasslands	3	Open grazing area	Diverse grass species, herbs and shrubs

Field data collection methods

From each of the selected location, three 3*3m plots sizes were demarcated and soil samples obtained from six locations using a 5-cm soil auger. Additional data on the age of tree stands withinthe forest and major land use type of adjacent farmlands was collected. To determine the age of tree stands in the farmlands, observations and interviews with foresters and farmers were done, while line transect and plot methods were employed during the soil sampling. Secondary data collected was on the tree species type, diameter at breast height (DBH), estimated volume of the forest stands and forest management practices, estimated volume and of trees. This data was obtained from Iveti forest station records provided by the forest manager.

Soil sampling and analysis

Soil sampling was done at the plot center up to a depth of 30 cm using a 5 cm diameter soil auger. Soil sampling plots measured 3 m × by 3 m whereby in each plot, six sampling cores were determined, then mixed together to form a composite sample. Two hundred (200g) of soil was air dried at room temperature, ground and sieved to pass through 2 mm sieve for subsequent analysis in the laboratory. A small sample of soil was fine ground for analysis of organic carbon. Organic carbon was determined by Walkley Black wet oxidation method (Nelson and Sommers, 1982) while pH was determined in soil: water at 1.2.5 ratio (Okalebo *et al.*, 2002, Thomas, 1996) at Kenya Agricultural and Livestock Research Organization (KALRO) Laboratory.

Data Analysis

All statistical data analysis was conducted using STATISTICA 10.0 computer package (Statsoft, Tulsa OK). Soil organic carbon and pH were presented as means ± SD. Before analysis, normality of the data was confirmed by Shapiro-Wilk Tests. Spatial differences in SOC and pH were analyzed using One-Way ANOVA. When differences were discerned, means were compared using Post-hoc HSD test.

RESULTS

Soil Organic Carbon (TOC) and pH of forest stands in Iveti forest

The average forest soil TOC was 18.8 - 5.1 mg C/ha and ranged between 5.8 to 42.2 mg C/ha (Figure 3). Soil total organic carbon differed significantly in the different sampling points in the forest (F = 20.285; df = 15, P = 0.000), where the general trend showed an increase in the TOC from the northern upper part of the Iveti forest (12.8 ± 4.2 mg C/ha) to a peak in stations near the middle of the forest (*S13* to *S16*) (31.2 ± 36.7 mg C/ha) and a recline of TOC from the centre towards the southern lower part of the forest (8.1 ± 13.7 mg C/ha). Mean PH values of the forest soil was 6.27 - 0.47 with significant variation at the various sampling points in the forest (F = 6.119, df = 15, P = 0.000). Generally, soils at the forest edge (sampling points S9-*S10* in the eastern side and *S22-S24* in the western sides) had low pH values (4.4 - 5.3) compared to pH in the inner part of the forest (Figure 3).

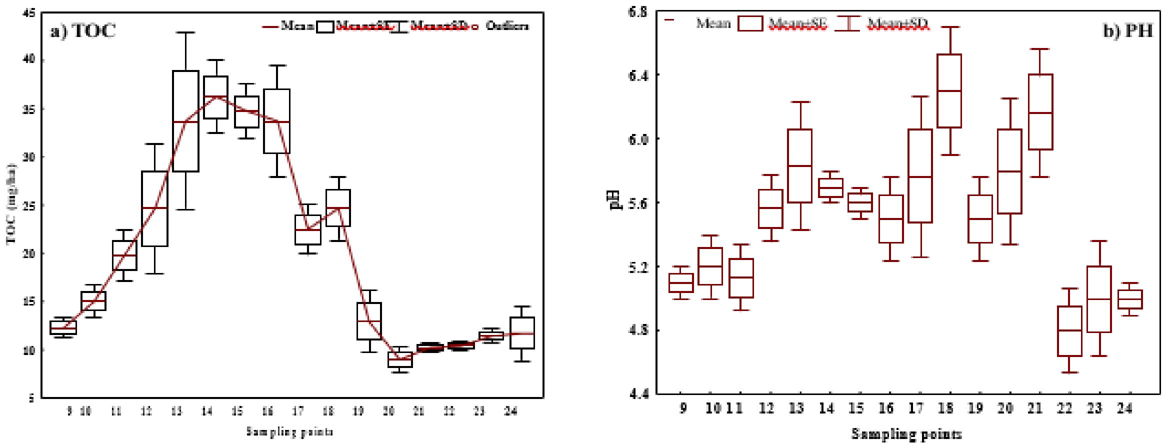


Figure 3: Variation in Soil Total Organic Carbon (TOC) (a) and pH (b) at different sampling pointsin the forest from the northern upper part (*S 9*) to the southern lower part (*S 24*). Sampling pointsare described in Table 1.

Soil Total Organic Carbon and pH in different forest stands of Iveti forest.

The total organic carbon and pH values for soils from the sampled forest stands is shown in Figure 4. The TOC content in the forest stands was highest in the open canopy (32.5 ± 4.5 mg C/ha) followed by *P. patula* stands (24.2 ± 2.3 mg C/ha) while *J. procera* stand had the lowest (15.8 ± 3.4 mg C/ha). The differences were statistically significant (F = 5.653, df = 3, P = 0.004). Moreover, in the *C. lusitanica* stands, there was large variation in the value of TOC ranging between 7.2−40.5 mg C/ha. Soil pH values in the different forest stands surveyed differed significantly (F = 12.903, df = 3, P = 0.000). The open canopy had the highest pH values of 6.36 ± 1.25) followed by *C. lusitanica* stands.

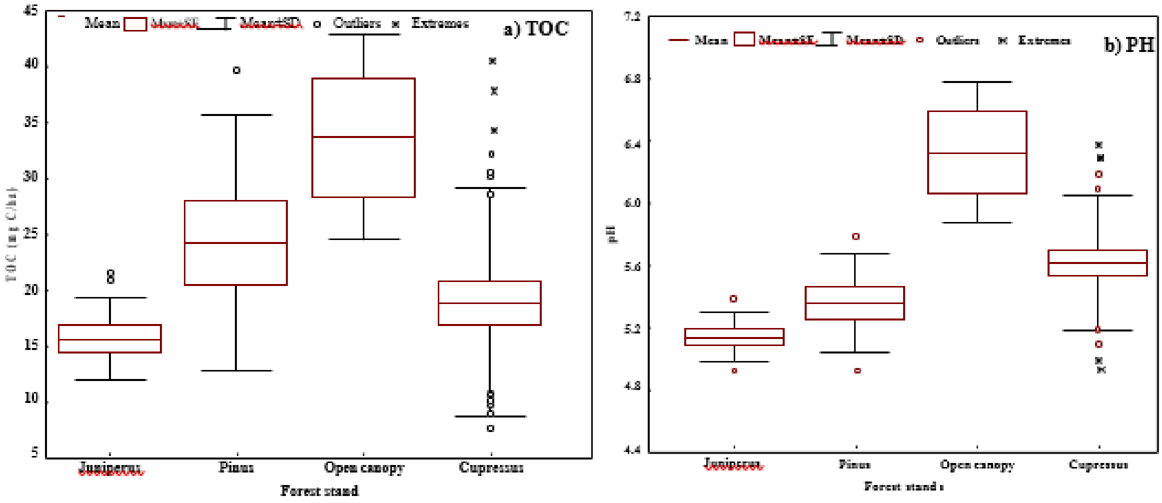


Figure 4: Soil total organic carbon (a) and pH (b) in different forest stands and open canopy in Iveti Forest, Machakos County. Sampling points are described in Table 1.

Soil Total Organic Carbon (TOC) and pH in farmlands adjacent to Iveti forest

There was a significant difference in soil total organic carbon in different sampling points in the northern and the southern parts of the farmlands adjacent to Iveti forest. The average soil total organic carbon in the farmlands was 7.78 - 1.51 mg C/ha with a range of 4.8 to 10.2 mg C/ha. Sampling points *S1*, *S2* and *S3* had the lowest TOC which ranged from 5.4-9.8 mg C/ha) and pH ranged from 4.6- 5.7 (Figure 5).

There was a significant difference in soil pH values in different sampling points in the northern and the southern parts of the farmlands adjacent to Iveti forest (F = 7.155, df = 15, P = 0.000). The average pH value was 5.17 ± 0.43. Generally, soils from the edge of northern upper side of the forest had lower soil pH while the soils in the lower southern part within the farmlands were highest. The mean - SD of pH in the agricultural landscape was 5.17 - 0.43. There was asignificant variation in the soil pH across the sampling units in agricultural lands (F = 3.871, df = 15, P = 0.0002). Generally, soils at the edge of the forest (*S9*□*S10* in the eastern side and sampling point *S22*□*S24* in the western sides) had low pH values compared to the pH of soils in the inner partof the forest.

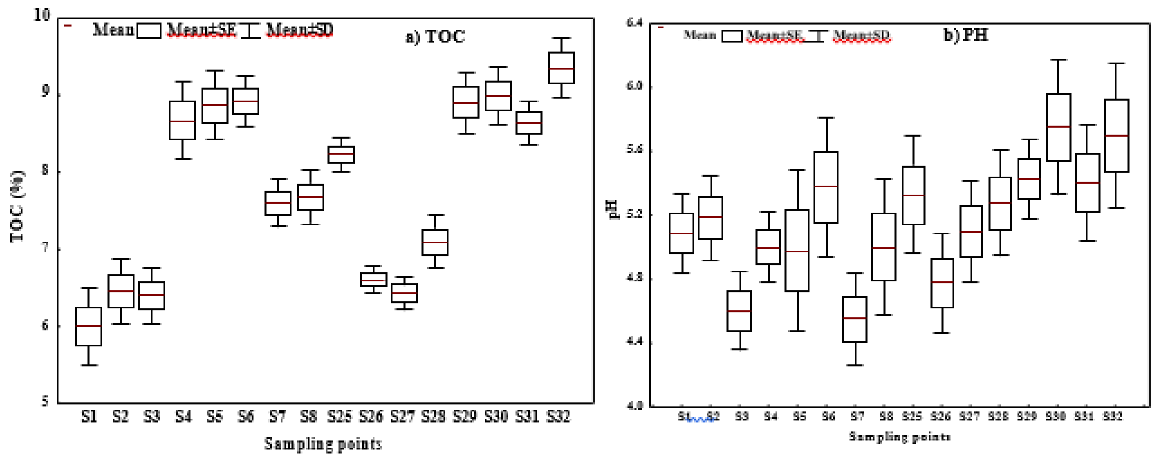


Figure 5: Total Organic Carbon (TOC) and PH of soils in the farmlands adjacent to Iveti forest. Sampling points are described in Table 1.

Comparison of Soil Total Organic Carbon in forest stands and agricultural landscapes adjacent to Iveti forest

Figure 6 presents the total organic carbon and pH of soils in the identified land uses on the forest and agricultural farmlands adjacent to Iveti Forest. The TOC content at the agricultural landscapes was highest in the *G. rubusta* stand (8.9 - 1.8 C mg C/ha) followed by Eucalyptus stands (8.8 - 1.8 mg C/ha), coffee farms (8.6 □ 1.7 C mg C/ha) and vegetable farms (8.5 - 1.5 mg C/ha). However, maize and legume farms had the lowest TOC, with large variations in TOC occurring in the grassland. In the forest stands, high TOC was obtained in stands dominated by P. patula trees and open canopy. The pH content in the farmlands was highest in farms with *G. robusta* farms (6.92 ± 1.11) followed by vegetable (5.85 ± 1.03) while the soil pH values in farms with Acacia trees was the lowest (4.58 ± 0.94). The Eucalyptus stands had a large variation in soil organic carbon and pH values (Figure 6). In the forest, areas dominated with *J. procera* and *C. lustanica* had the lowest pHvalues.

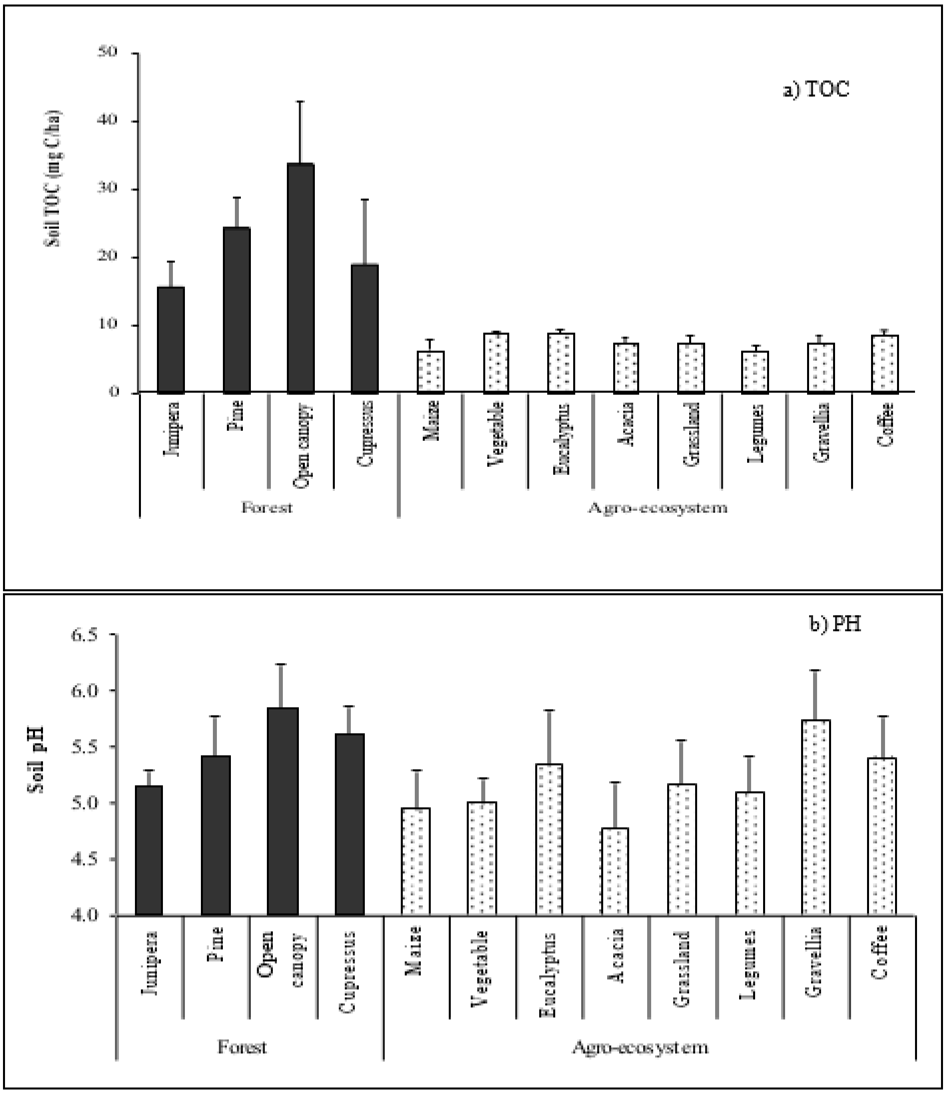


Figure 6: Comparison of (a) Soil Total Organic Carbon and (b) pH between Iveti forest and the adjacent agricultural farmlands in Machakos County.

DISCUSSION

Forest soils represent a large portion of the carbon reservoirs of the terrestrial carbon cycle. The high TOC in the forest soils contribute to the carbon sinks on earth (Murty *et al.*, 2002). In this study, the mean TOC in the forest ranged from 5.8 to 42.2 mg C/ha (mean 18.8 - 5.1 mg C/ha), which is comparable to values in studies done elsewhere. For example, Shisanya *et al.*,

(2009) reported a maximum and minimum total organic carbon of 18.56 mg/C ha and 16.08 mg C/ha in *Quercus leucotrichophora* forest soils. Similar findings have been reported by Alamgir and Amin (2008), where soil total carbon stock in *Pinus roxburghii* forest soils, was reported to be between 14.16 mg C/ha and 12.48 mg C/ha. The findings of this study indicated an increment in soil total organic carbon from the forest edge into the forest interior. This could be attributed to rapid decomposition of forest litter as the forest interior provides favorable temperature and soil moisture which enhances biological activity (Wang *et al.,* 2001).

Type of vegetation, available nutrient, land use patterns and management regiment are responsible for the changes in the SOM (Six and Jastrow, 2002; Baker, 2007). Meanwhile the soil properties such as structure, particle size, and composition have also been established to fundamentallycompromise the soil TOC (Sevgi and Tecimen, 2008).

There was a significant variation in the soil pH across the upper to the lower part of the forest with soils at the edge of the forest having low pH values compared to the pH of soils in the inner part of the forest. The soil pH in the inner part of the forest was closer to neutral pH compared to the edge of the forest. This is because the inner part of the forest has minimal human activities and pollutants that can increase soil pH as previously established in studies by Walker and Desanker, (2004).

The observed differences in the soil TOC between the forest edge and forest interior may be attributed to more human activities such as poaching of medical plants, firewood collection, illegal gazing, removal of plant materials, and erosion along foot paths than in the forest interior. Depending on the tree species planted, Iveti forest stands had varying soil total organic carbon. Forest stands planted with *P. patula* tree species had the highest total organic carbon while stands with *J. procera* species had the lowest. This study also established that different forest stands had different soil pH. Particularly, forest soil sampled under open canopy of *J. procera*, *Dombeya goetizenii* and under *C. lusitanica* canopy together with soils covered by fern and shrubs were acidic.

Forest vegetation liberates organic acids including acetic, oxalic, tannic and humic acids when plantlitter accumulates on or is incorporated to the soil. This is especially acute in soils under coniferous trees such as pine, Juniperus, spruce, cypress and fir, which return fewer base cations to the soil than do most deciduous trees (Maitima *et al.,* 2005). The low pH in these sites may eventually affect the biological activities and the rate of decomposition. In natural humid and forest ecosystems without human disturbance, the living and non-living components are in dynamic equilibrium with each other (Guillaume *et al.,* 2015). A high soil biological activity has often been observed on the soil surface due to the rapid decomposition of litter underneath different canopy layers. The mechanisms that maintain a biological activity include living and decaying plant, soil microfauna, rooted plants, and nutrients cycles in the soil. Soil microfauna cause the decay and biogeochemical cycling of macro- and micronutrients, and their biological activities therefore will dictate the soil structure, tilth and production and thus soil quality.

Selection of tree species in forest plantations seems therefore an important factor in forest management strategies aimed at mitigating carbon dioxide emissions to the atmosphere (Eriksson 2007). One important aspect of mitigating carbon dioxide emissions is the extent to which organic carbon is accumulated in the soil. In Iveti forest, *P. patula* forest stands had dense canopy and high input of litter which resulted in maximum storage of carbon stock, thus the high soil organic carbon recorded. In *J. procera* forest stand, low organic carbon was probably due to less accumulation of plant litter and in turn yielding less storage of carbon stock in these forest soils. However, further studies are required to determine amount of litter accumulated in different tree species and the effects of tree spacing on storage of carbon stocks. Nevertheless, it should be noted that it was in areas with open canopy that the highest soil total organic carbon was recorded, which could be attributed to higher temperatures that favored biological activities and break down of organic matter (Sevgi and Tecimen, 2008). Moreover, presence of dense undergrowth composed mainly of shrubs resulted in high input of rapidly decomposable litter.

The soil total organic carbon in the farmlands ranged from 4.8 to 10.5 mg C/ha indicating presence of farm management practices that affected soil carbon storage. Marinari *et al.*, (2006) in their study on total SOC content in organic farming land use system found an increase in total SOC in organic farming land use system. It is notable that they had different crops planted and, in some areas, there were tree species and grasses planted. This conquers with the result of this study whereby land use system which had received application of manure and mulching had higher SOC content. The type of mulch influences other soil chemical properties especially nitrogen status as this depends on the mulch chemical composition.

The difference in the soil TOC across the farmlands land uses was significant. Terraced farmlands with no crops on them and farmlands under: maize, sweet potato and napier grass cultivation (sampling point 1-3) had the lowest soil total organic carbon. There was a significant variation inthe soil pH across the sampling units in agricultural lands. Coffee farming is done as monoculture and due to the coffee leaf fall in the adjacent farms, it may affect soil organic carbon as was established in studies by Pabst et *al.*, (2013). The crop residues may therefore contribute further to the increase of SOC by enhancing the incorporation of the carbon in the soil. The pH content in the farmlands was highest in the vegetable field which may be attributed to use of lime and other fertilizers. Normally agricultural lime ($CaCO_3$ or $MgCO_3$) is the most commonly used substance to amend soil pH the soils in the area. It was also established that in the vegetable farms there is heavy use of ammonium-based fertilizers such as urea and potassium-based fertilizers that can increase thesoil pH. The low pH and possible acidity in Acacia fields may be attributed to the decomposition, nitrification or leaching processes. Forest in the tropical region experience faster mineral decomposition due to high temperatures thus results in low concentrations of organic matter and low pH.

Decomposition of plant litter leads to the release of a variety of chemicals. In addition, organic forms of nitrogen, phosphorous and sulphur are converted into simple inorganic compounds that can be utilized by plants (Alamgir and Amin, 2008). These processes within the soil tend to make the soil more basic and hence high acidity. These pH reducing effects are very dependent on the exact nature of the organic matter decomposing; therefore, soils under Acacia trees stands can be much more acidic than soils under *Grevillea robusta*.

The findings of this study indicate that soil total organic carbon content and pH were higher in the forest than in the adjacent farmlands. Converting forest land into farmlands for growing crops clearly reduced soil carbon content. This can be attributed to disturbances, erosion and lack of material for decomposition. Land use changes may destroy litter, reduce the amount of organic matter returned to the soil as well as kill the soil microfauna. Studies carried by Shevliakova *et al.*, (2009) on change of land use from cropland to vegetation cover after abandonment showed a significant increase in soil total organic carbon over several decades. Similarly, studies by Six *et al*., (2002), showed increase in soil organic matter when cropland was converted to woodland.

Human activities utilize and modify soil physical and chemical properties thereby changing the composition and the complexity of the soil system. Soil management practices may affect carbon balance. For example, addition of organic matter to the soil through manuring or application of leaf litter only improves carbon balance of one site while diminishing that of another. Eliminating the vegetation cover in the soil causes increased soil erosion, depletes the soil organic carbon, and increases greenhouse gases. It further destroys soil aggregates and affects soil quality. This in the long run affects soil ecosystem floral and faunal diversity.

CONCLUSIONS

From this study, we can conclude that there was a gradual increase in soil total organic content in Iveti forest from both the northern and southern parts to reach a peak in the forest interior. The same pattern was observed for the soil pH values which progressively increased towards the forest interior. Further, we can conclude that different plant species planted within the forest have effects on soil total organic content and soil pH with soils under *P. patula* tree species having high soil total organic carbon.

Based on the study, soil TOC and pH across the agricultural landscapes differed with land use type with higher TOC and pH content occurring in vegetable fields, eucalyptus stand, *Gravellia* stand and coffee farms. Differences in TOC and pH between the forest and agricultural landscapes were significant with TOC content and pH being higher in the forest than in the agro-ecosystem. There was significant interaction between sampling sites and cropping stands on the soil TOC and pH. This was evident in the forest areas (dominated with pine and open canopy) while in the agro- ecosystem fields with *Grevillea* and coffee farms had higher TOC. For pH levels forest areas (dominated with *Cupressus*, pine and open canopy) and in the agro-ecosystem, (*Grevillea* and coffee farms) had highest pH.

Soil carbon is easily lost but difficult to rebuild. Because it is central to agricultural productivity, climate stabilization and other vital eco-systems services; creating policy incentives around the sustainable management of soil carbon could deliver numerous short and long-term benefits. Such policy incentives would need to target better allocation of soil resources to different land uses and management practices. There is need for forest managers to take action towards protection of forest edges to ensure soil organic carbon content is maintained or improved for proper plant growth and maintenance of soil biodiversity and soil functioning. Forest managers also need to take notice of the tree species used in plantation forests as it may affect soil organic carbon and pH. Farmers need to pay attention to the fact that clearing natural forests vegetation lowers soil organic carbon and can affect soil pH and consequently farm productivity and therefore there is need to come up with practices that maintain soil organic carbon while sustaining a conducive pH for plant growth and biological processes to take place.

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