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Quantification of Soil Organic Carbon Stocks across Different Land Use Types, Soil Types and Agro-Ecological Zones in Murang'a County, Kenya

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***Abstract**: Declining soil fertility causes substantial net losses of soil carbon resulting in increased carbon flux to the atmosphere; hence the need for sustained efforts for carbon sequestration through sustainable land management practices. The specific objectives of this study were to quantify soil organic carbon stocks at different soil depths across different land use types, soil types and agro-ecological zones in Murang'a County. The top soils were sampled at a depth of 0-30 cm while the sub-soils were sampled at 30-60 cm depth for evaluation of percentage organic carbon, bulk density, pH, and clay percentage. The data collected was subjected to analysis of variance to test for differences in soil organic carbon stocks in different soil types, land use types across different agro-ecological zones. The results showed that tea production systems had the highest stocks at 98.31 t C ha^{-1} and 81.74 t C ha^{-1} at top and sub-soils, respectively. The Andosols soil type had higher carbon stocks of 182.1 t C ha^{-1} compared to Nitisols which had 118.6 t C ha^{-1}. There were significant differences ($p < 0.05$) of stocks among the land use types across the agro-ecological zones with 180.1 t Cha^{-1} in upper highland, 117.2 t C ha^{-1} in lower highlands and 78.8 t C ha-1 in upper midlands. This suggests that there is low potential for smallholder farmers to accrue adequate soil carbon stock to engage in the carbon trading owing to the high transaction fees.*

***Key Words**: Soil carbon stocks, Production systems, land managemnet practices, Soil sampling*

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I. Introduction

Increased greenhouse gases (GHGs) concentration in the atmosphere creates a threat to the global climate system and the environment (Makipaa et al., 2012). Therefore, efforts to reduce or minimise GHGs emissions from all sources is required. Soils are critically important in determining global carbon cycle dynamics because they serve as the link between the atmosphere, vegetation and oceans (World Bank, 2012). On the other hand, soil organic carbon (SOC) has vital ecosystem functions and major influence on soil structure, water-holding capacity, cation exchange capacity, and the soils ability to form complexes with metal ions and to store nutrients (van Keulen, 2001).

It is widely accepted that soil organic matter is largely concentrated in the top 0-30 cm depth of the soil, but there is growing evidence that deeper soil horizons have the capacity to sequester high amounts of SOC despite the concentrations in the subsoil (Jobbagy and Jackson, 2000). This is likely to occur where the land use type consists of deep rooted crops and the management practices are likely to lead to minimal soil disturbances and also substantial amounts of organic matter is added over time through litter fall. Examples of such land use types include tea, coffee and fruit trees production systems. However, data on vertical distribution of the SOC pool in relation to vegetation and land use is scanty (Jobbagy and Jackson, 2000).

The distribution of SOC with soil depth tends to vary with different soil types (Schrumpf et al., 2011). More than 50% of the organic carbon is stored in the topsoil horizon (0–25 cm) which is the layer more susceptible to change upon land use change especially agricultural and "forest" management (Munoz-Rojas et al., 2012). Alcantara et al. (2014) observed that the highest totals of SOC stocks are found in Luvisols and the lowest in Leptosols. Munoz-Rojas et al. (2012) while studying soils in Southern Spain observed that the average values of SOC in the various soil types ranged from 15.9 Mg C ha^{-1} to 107.6 Mg C ha^{-1}and was also influenced by land use type. In Kenya, soils with the highest SOC content are mainly the Andosols, Nitisols, Phaeozems, Gleysols and Alisols (Batjes, 2004).

It is estimated that global soils contain between 1400-1600 Pg C (1 Pg = 1015g) in the upper meter, whereas the next 1 m of soil contains an additional 500-1000 Pg C (Batjes, 1996). These estimates imply that the soil organic carbon pool is more than twice the size of the atmospheric carbon pool (ca. 800 Pg) and about three times the amount of carbon in vegetation (ca. 550 Pg C) (Govers et al., 2013). Soil carbon is an important attribute of soil quality and productivity, and is among the largest terrestrial reservoirs of carbon that hold potential for expanded carbon sequestration (Venkanna et al., 2014).

The land use type has a major effect on SOC storage, since it affects the amount and quality of litter input, litter decomposition rate and stabilization of SOC (Guangyu et al., 2010). The SOC loss from continuous land use often leads to negative impacts on both terrestrial and aquatic ecosystems, and on atmospheric environment (Reeder et al., 1998; Bronson et al., 2004).

The agro-ecological zoning, as applied in FAO studies, defines zones on the basis of combinations of soil, landform and climatic characteristics (FAO, 1996). The particular parameters used in the definition focuses attention on the climatic and edaphic requirements of crops and on the management systems under which the crops are grown. Each zone has a similar combination of constraints and potentials for land use, and serves as a focus for the targeting of recommendations designed to improve the existing land use situation, either through increasing production or by limiting land degradation (FAO, 1996). Batjes (1999) discussed the total soil carbon stock distribution of major ecological zones and urges that different zones show large differences in organic carbon storage mainly in relation to temperature and rainfall.

As outlined by Jaetzold et al. (2006), the main land use types (LUTs) in Murang’a County are tea, dairy, coffee, bananas, maize and beans, avocadoes, mangoes, poultry, pigs, fodder and horticultural crops. Farmers in the County practices continuous cropping over time and lacks knowledge on the impact that these practices have on the variability of SOC stocks across the different LUTs, soil types and AEZs. This study therefore aimed at quantifying the SOC stocks in different LUTS and soil types across AEZs in Murang’a County with an aim of assessing the feasibility of smallholder farmer’s engagement in the carbon markets.

II. Materials And Methods

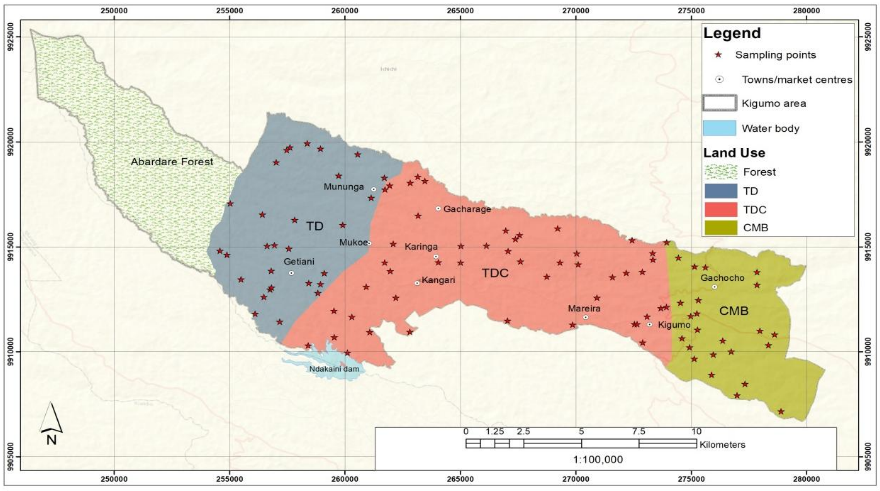
Location of Study Site

The study was conducted in Kigumo Sub-County of Murang’a County which is located on the eastern slopes of the Aberdare Ranges. The County is located between longitudes 36^0 30’E and 37^0 30’ E and latitudes 0^0 30’ and 1^0 S (Jaetzold et al., 2006). Murang’a County is bordered by Nyeri County to the north, Kiambu to the south, Nyandarua to the west and Kirinyaga, Embu and Machakos Counties to the east (Ojwang’ et al., 2006). According to Jaetzold et al. (2006), the dominant land use types are tea, coffee, maize, horticulture crops and dairy farming. The soils are predominantly mountain slope well drained andosols, volcanic foot ridge fertile soils of ando-humic nitisols and humic andosols (Jaetzold et al., 2006).

Selection of sampling points and soil sampling

A stratified random sampling procedure was adopted using the ArcGIS10.2 software and LUTs were used as the strata. The spatial extent of each land use type provided the proportion information needed to divide out sample total into stratified sub-samples of the appropriate size using the ArcGIS tool “create random points”. Based on their sizes, 48% was allocated to tea and dairy, 29% to tea, dairy and coffee and 23% coffee, maize and beans, respectively. The “add x-y-coordinates” tool was used to add the coordinates for each generated point to the attribute table. The created stratified random spatial sample file was uploaded into a hand held Global Positioning System (GPS) unit Garmin Etrex 30 that was used to locate the points in the field.
The sampling point’s distribution in the study area is shown in Figure 1.use fig 1 in page 50 and delete this.

Figure 1: Land use type and location of sampling points in KigumoSub-County, Murang’a County



The soil samples were collected at 0-30 and 30-60 cm depths at the predetermined sampling points in each LUT. A composite soil sample was prepared for laboratory analysis from each depth band. Intergovernmental Panel on Climate Change (IPCC) guidelines recommends the use of 0-30 cm layer since it is within this layer that the influence of land management practices are more pronounced (Bationo et al., 2007). However, two of the land use types under consideration in this study (tea and coffee) are deep rooted with rooting systems going beyond 30 cm depth. Hence there was need to sample deeper than 30 cm to allow for a comprehensive assessment of the carbon stocks in these two LUTs. All the sampling points were geo-referenced using the hand held Garmin Etrex 30 GPS unit.

Soil Chemical Analysis

The soil organic carbon was determination through use of the modified Walkley-Black chromic acid wet oxidation method (Anderson and Ingram, 1993). This method has been used by Okalebo et al. (2002) and Wang et al. (2010) and it is based on the reduction of $Cr_2O_7^2$ (Dichromate solution) by organic matter. Oxidizable matter in the soil sample is oxidized by $Cr_2O_7^2$ and the reaction is facilitated by the heat generated when the two volume of concentrated H_2SO_4 (sulphuric acid) are mixed with 1 volume of N (0.1667M) $K_2Cr_2O_7$ (potassium dichromate solution).

Data Analysis

Data collected was entered into Microsoft excel spread sheet and then exported into statistical software to generate general and summary statistics using SPSS version 20. Data was then subjected to analysis of variance (ANOVA) to determine the effects of different land management practices on the SOC stocks at different LUTs and soil depths; influence of different land management practices on SOC stocks at different soil types across the identified AEZs. Statistical significant differences were declared at 1% - highly significant and 5% - significant levels, unless otherwise stated. Hypothesis tests were conducted using descriptive measure of spread by box plot and independent t-test to further establish the levels of differences in SOC stocks t C ha^{-1} accruals across AEZs, LUTs and land management practices. To test for the hypothesis for the three LUTs, they were grouped in to two categories; that using good agriculture practices (GAPs) and those not using GAPs. Good agriculture practices in this case are minimum and zero tillage practices, use of organic manure and farm residue retention on farms. These were the management practices that this study identified as having significant influence in accruals of SOC stocks t C ha^{-1} among LUTs, depths, soil type across AEZs.

Total soil carbon estimated per hectare was based on soil bulk density and percentage of carbon analysed from soil samples of known depths.

Determination of the total SOC was done using the formula:

SOC =% OC * BD (kg/m^3) * D (cm) ………………………………… Equation 1.

Where; SOC – Total soil organic carbon

%OC – Is the concentration of organic carbon %

BD – Bulk density D – Depth or thickness of the soil layer

Figure 1: Land use types and location of sampling points in Kigumo Sub-County, Murang'a County

Figures 2,3,a nd 4 to be inserted at appropriate place

III. Results And Discussion

Soil Carbon Stocks across Soil Depths and Land Use Types

There were significant differences (F (1, 80) =7.92, $p < 0.05$) in SOC stocks along the depths in tea production system. However, there were no significant differences ($p = 0.199$) in SOC stocks along the depths in coffee but slight significant difference (F (1, 54) =4.46, $p < 0.05$) in SOC stocks along the depths is observed in maize production systems

The data presented in Table 1 shows that across the three LUTs, tea production system had the highest levels of SOC stocks with a mean of 98.3 (t C ha^{-1}) and 81.7 (t C ha^{-1}) in top soils and sub-soils respectively. Coffee production system recorded the lowest SOC stocks of 9.3 and 5.8 (t C ha^{-1}) in both the topsoil and sub-soil, respectively though with higher means of 62.4 and 54.9 (t C ha $^{-1}$) than for maize farms. However, maize farms had the lowest means of 42.6 and 36.2 (t C ha^{-1}) in both topsoil and sub-soil, respectively.

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TABLE I: MEAN SOC STOCKS (T C HA-1) FOR TOPSOIL AND SUB SOIL ACROSS LUTS IN KIGUMO SUB-COUNTY, MURANG'A COUNTY

	Land Use Types					
	Tea (n=41)		**Coffee (n=31)**		**Maize (n=28)**	
Depth (cm)	0-30	30-60	0-30	30-60	0-30	30-60
Mean (t C ha^{-1})	98.3	81.7	62.4	54.9	42.6	36.2
Min (t C ha^{-1})	31.3	28.1	9.3	5.8	22.6	17.0
Max (t C ha^{-1})	143.8	128.0	116.8	94.3	72.3	65.5
CV %	29.7	29.2	39.0	38.6	25.4	32.9
Std Dev	29.2	23.9	24.3	21.2	10.8	11.9

The SOC stocks across the three LUTs were significantly different ($p < 0.05$). However, pair wise comparison of stocks among the LUTs displayed no significant difference in coffee and maize except in tea production system where significant difference ($p < 0.05$) was recorded. Cumulatively, there is significant difference ($F(1, 198) = 6.32$, $p < 0.05$) in SOC stocks along the depths across the three LUTs (Figure 2). At soil depths of 30-60 cm, the mean SOC stocks of 81.7 t C ha^{-1} in tea production system is significantly higher compared to coffee and maize production systems at 54.9 and 36.2 t C ha $^{-1}$ respectively. The cumulative vertical variability of SOC stocks for the 0-30 and 30-60 soil depths across the LUTs is 71.6 t C ha^{-1} and 60.7 t C ha^{-1}, respectively (Figure 2). Cumulatively, the soil organic carbon stocks were higher in top soils compared to the sub soils.

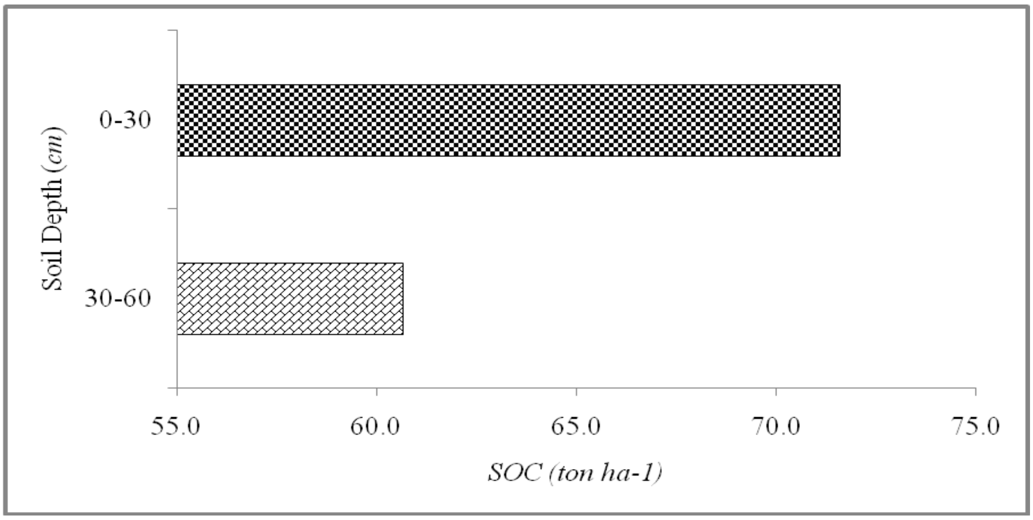

Figure 2. Cumulative vertical variability of SOC stocks along the depths across the LUTs in Murang'a County

Horizontal cumulative SOC stocks variability across LUTs show that, tea production systems exhibit higher stocks compared to coffee and maize production systems. Across depths the top soils accrues higher stocks in the three LUTs (Figure 3).

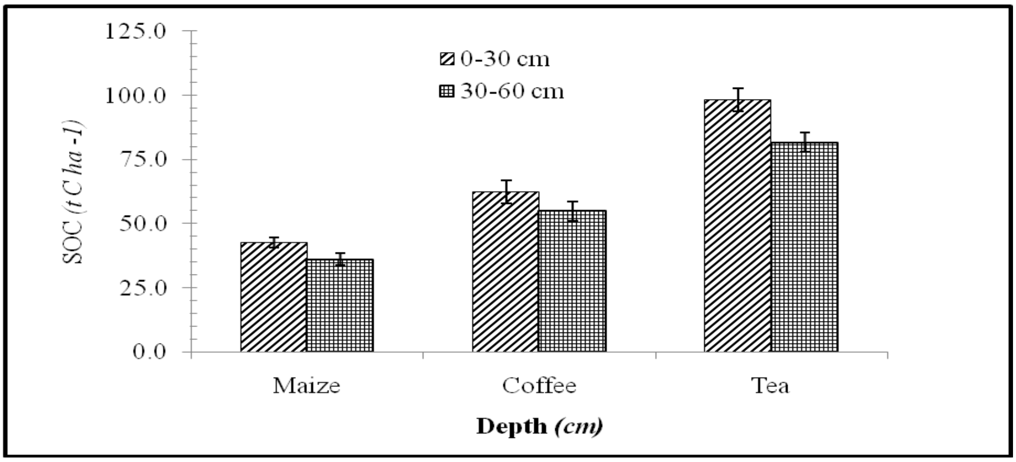

Figure 3. Cumulative SOC stocks (t C ha¯1) for each depth across land use types in Kigumo sub County, Murang'a County

Land management practices considered in this study were tillage practices, organic and inorganic fertilizer use, farm residue retention regimes, crop rotation and use of soil and water conservation measures. However land management practices that showed remarkable effects on SOC stocks accruals were tillage practices, use of organic manure and farm residue retention regimes.

A trend observed across the three LUTs is that top soils exhibit higher carbon stocks compared to the sub soils. However, in tea production system significant difference is observed, slight difference observed in coffee and no significant difference recorded in maize. Different land management practices are employed across tea, coffee and maize production systems, which are likely to influence the SOC stocks. For example, tea recorded nearly total residue retention (97.6%) while maize recorded 100% residue removal. These two residue retention regimes score at extreme opposite ends of the scale in SOC stocks accruals in the soil. High residue retention attracts higher stocks accruals and low residue retention results to minimal SOC stocks storage.

Tillage practices in tea production system are mainly zero or minimum. These practices entails minimal soil disturbance leading to minimal loss of soil carbon to the atmosphere; hence longer retention of SOC stocks into the soils. Coffee had its farm residue partially or fully removed (72.4%) or (24%), respectively. Further tillage practices in coffee alternate between minimum and conventional at 48% each. Therefore, SOC stocks are not stored steadily for a long time due to frequent soil disturbance and residue removal patterns.

When stocks are compared at multiple levels across LUTs, the difference is significant. This may be attributed to the diversity in land management practices for each land use type. This is so especially in tea farms where the management practices results to soil organic matter accrual due to minimal soil disturbance and hence the carbon stocks accruals. The lack of significant difference at pair wise comparison between coffee and maize can be attributed to management practices under these production systems which allows for soil pulverization, farm residue removal and minimal use of organic manure. These practices allow for carbon loss to the atmosphere, loss through erosion and hence minimal SOC stocks accruals.

Coffee production system has significant amount of its residue partially and fully removed, while in maize, the residues are fully removed. This has a negative influence on soil carbon dynamics in term of quantities stored and residence time in the soil. Horizontal SOC stocks variability across LUTs indicates potential accruals of SOC stocks for each LUT across the depths. Top soil has higher stocks compared to sub soils with tea production system recording the highest (98.3 and 81.7 t C ha ¯1) and maize the least at (42.6 and 36.2 t C ha ¯1) at both depths.

The cumulative vertical variability of SOC stocks for both depths across the LUTs is an indication of the potential that exists in stocks accruals across the LUTs. It is likely to be due to the wide variability of stocks across the LUTs signifying the cumulative potential that exists at both depths across LUTs. However, horizontal variability in stocks accruals would be preferred in assessment of sequestration potential. This is due to uniformity of management practices undertaken in each LUT and the ease of identifying the management practices that is likely to result in significant accruals.

This study recorded a significant decrease of SOC stocks with depth across land use types similar to findings of Morisada et al. (2004) and Su et al. (2006) who observed that SOC content decreases with increasing depth across land use types. The current findings are similar to those of Shiyu et al. (2011) who found that SOC content within the top soil layer in tea farms contributes the highest percentage of SOC storage compared with lower soil horizons, and SOC density decreased with increasing soil depth. Zhangi et al. (2012) found out that SOC content decreased with increasing soil depth of the soil profile for all the land use types with small amplitude at 40–100 cm depth. Similarly, Dhakal et al. (2010) found that there was gradual decrease in SOC content with depth in all the LUTs in the study.

Soil Carbon Stocks in Andosols and Nitisols across Agro-Ecological Zones

The predominant soil types in the study area are Andosols and Nitisols. Andosols recorded higher SOC stocks with a mean of 182.2 t C ha^{-1} compared to Nitisols with 118.6 t C ha^{-1}.

The soil organic carbon stocks in Andosols was significantly (F (1.198) =81.1 $p<0.05$) higher than that found in Nitisols. The variation in SOC stocks in Andosols and Nitisols soil types indicate their potential to accrue different amounts of stocks across different AEZs. Andosols are mainly in the upper highland, under tea production system which enjoys significant levels of residue retention and minimum tillage. Precipitation and temperature regimes in this AEZ allows for slow rate of residue and litter decomposition which in turn prolongs resident time of soil carbon in the soil.

There was significant difference (F (2, 97) =55.57, $p <0.001$) in SOC stocks across the AEZs (Figure 4). Upper highlands recorded higher levels of SOC stocks with a mean of 180 t C ha^{-1} compared to lower highlands that recorded stocks of 117 t C ha^{-1} and the lowest stocks recorded at upper midlands of 78 t C ha^{-1}, respectively (Figure 4)

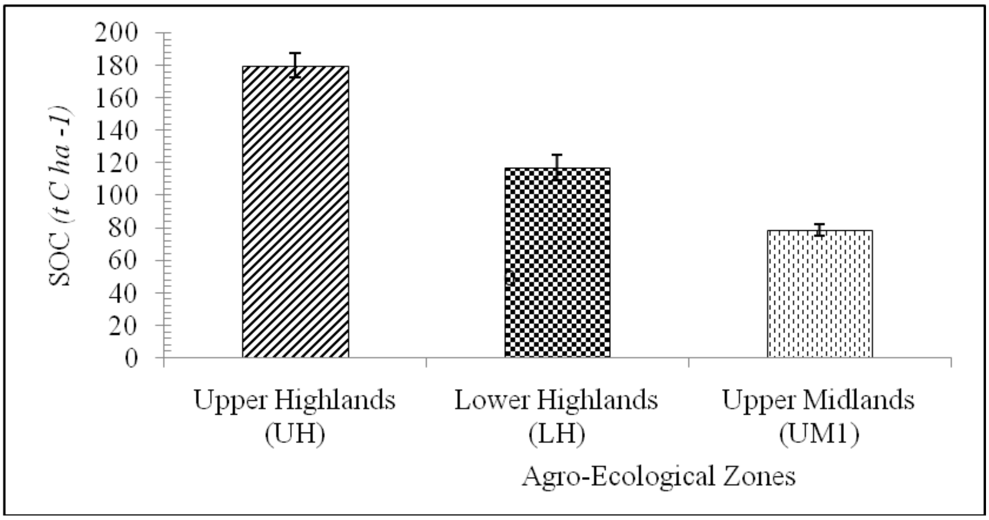

Figure 4. Soil organic carbon stocks for the three LUTs across AEZs in Murang'a County

According to Batjes (2004) Kenya's national SOC amounts within the top 100 cm soil depth ranges between 3,452 to 3,797 Tg C and the soils with the highest SOC content are mainly the Andosols and Nitisols. This study recorded high mean levels of SOC stock for Andosols and Nitisols at 182.1 t C ha^{-1} and 118.6 t C ha^{-1} respectively, which is similar to Batjes (2004) findings, where Andosols recorded 178 t C ha^{-1} and nitisols 139 t C ha^{-1} respectively. In both cases Andosols has higher SOC stocks compared to Nitisols within the same ranges. This similarity in high stocks accruals, especially in Andosols, signifies the ability of the Andosols soil type to store high SOC stocks.

The low temperatures at the upper highlands allows for slowed decomposition rate, which leads to prolonged residence time for organic matter on the soil surface, hence soil carbon accumulation (Shelukindo et al., 2014). The high rainfall in high elevations are known to encourage increased biomass density generation leading to higher litter fall and increased organic matter on the soil surface. The findings are consistent with those of Spiotta and Sharma (2013), who reported that in tropical soils, rainfall and temperature plays a big role in carbon storage than other factors. Similarly Dai and Huang (2000) found that in Eastern and Southern China, variation in temperature, rainfall and altitude were key factors regulating surface soil organic matter content; thus carbon stocks storage. Hoffmann et al. (2014) asserts that SOC stocks increases with elevation due to high moisture content and lower temperatures in the higher elevations. This condition leads to low carbon dioxide emission from soils, contributing to higher SOC accruals. Shelukindo et al. (2014) established that SOC stocks significantly increases with elevation due to increased precipitation and lower environmental temperatures.

IV. Conclusions and Recommendation

The results of this study established that accruals of SOC stocks across LUTs, AEZs and soil types differed at varying levels. The tea production system exhibited higher capacity to accrue SOC stocks at top and sub soil levels. Higher elevations had higher SOC stocks accruals compared to lower elevations probably due to higher precipitation leading to higher biomass growth and lower temperatures that allow for slow organic matter decomposition hence higher soil carbon storage. The Andosols soil type exhibited higher SOC stocks compared to Nitisols this is likely due to occurrence of Andosols in the higher elevations and Nitisols in lower elevations and accompanying management practices. The results further showed that the potential amounts of soil carbon stocks in the studied smallholder farms are not feasible for engagement in the carbon market either as individual farmers or on pooled arrangement. This is due to high aggregator's fees and commissions required to be foregone by farmers during trading, which is likely to leave farmers in debt due to low market prices for carbon.

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