EFFECT OF LAND USE CHANGE AND SLOPE POSITION ON SOIL ORGANIC CARBON IN KITABI WATERSHED RWANDA

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Abstract

Soil organic carbon (SOC) is widely used as a proxy for soil health and soil fertility. Land use change (LUC) has been implicated as one of the factors leading to the loss of SOC and increased release of greenhouse gases (GHGs) to the atmosphere hence contributing to global climate change (GCC). Rwanda is a mountainous country and has faced a challenge of land use inter-conversions between forests, perennial crops and annual crops over the years. The impact of LUC on SOC stocks is poorly documented. The aim of this study was to investigate the effect of LUC and slope positions on SOC stocks in Kitabi watershed. Landsat TM-5 images of 2008 and 1986 were used to make a land use change map using Maximum Likelihood Classification (MLC) algorithm in Erdas. Slope positions were derived from the DEM using Topographic Position Index (TPI) tool and the output raster was overlaid with the LUC map to identify sample strata. Soil samples were obtained using stratified topo sequential random sampling from annual crops, community tea and factory tea. A total of 134 soil samples were taken from the three LU categories along each of the three slope positions: upslope, middle slope and down slope. Soil sampling was done at two depths 0-20 cm and 20-50 cm in each land use category using a soil auger. To make a composite soil mixture, five samples were taken from 10 m x 10 m plots in each land use category. SOC laboratory analysis was done using Loss on ignition (LOI). One-Way ANOVA and Games Howell tests were used to analyze the data. Results indicate that LU types significantly affect SOC stocks ($p < 0.001$) while slope position does not ($p = .491$). The interaction of LU and slope position has no significant effect on SOC stocks across the three land use types ($p = .061$). Good management practices in community tea and soil erosion control measures in annual crops are recommended.

Key Words: Land use change; slope position; soil organic carbon

Introduction

Land use change from natural forests to perennial or annual crops in the tropical regions has been implicated as the major cause for the depletion of soil organic carbon (Fernández-Romero etal., 2014). SOC is being used as a proxy for soil fertility and soil health (Moncada etal., 2014) in tropical landscapes. Tropical agriculture soils on sloping landscape have been regarded as "global hotspots" in terms of soil fertility loss, which is a threat not only to food security but also to climate stability of the region (Dorji etal, 2014). Fang et al (2012) found that SOC is affected by both land use type and soil depth in the watershed of Loess Plateau of China (Fang etal., 2012) and changing cropping land to pasture land increases SOC concentrations (Badgery et al., 2014). SOC concentrations in domestic trees were found to be higher than other land cover types in Leicester City (Edmondson et al., 2014). Management practices were reported to have a considerable effect on SOC in Australia (Badgery et al., 2014) and conversion of wetlands to croplands resulted in decline of SOC in China (Cui et al., 2014). Conversion of natural forests to agricultural land in Ethiopia reduced SOC and nitrogen (Gelaw et al., 2014). Land use type affects distribution pattern of litter carbon (John et al., 2005). Retention of crop residues increases SOC concentration (Dikgwatlhe et al., 2014). Slope positions have a considerable effect on SOC and Nitrogen content in China soils. Converting cropland to grassland, shrub land and woodland significantly improved soil aggregation, increase SOC and N stocks (Zhu et al., 2014) while unequal distribution of SOC along different slopes was reported in China (Zhang et al., 2013). Converting forest into crop land significantly decrease SOC stocks in South-Eastern Highlands of Ethiopia (Yimer et al., 2007) and reclaiming marshlands reduced SOC and soil nutrients in China highlands (Yang et al., 2013).

Some studies have been done on how SOC is affected by land use change (LUC) in Africa (Abdollahi et al., 2014) but the effect on conversion between tea and annual crops in Rwanda has not been well documented. The aim of this study was to find out the effect of land use change and slope position on soil organic carbon in Kitabi watershed, Rwanda. The focus was on annual crop fields, community tea and factory tea plantations located along different slope positions.

Location of study area

Figure 1 shows administrative sectors in Kitabi watershed and its location. The watershed is located between $2^{0}28'$-2^{0} $34'$ S and 29^{0} $23'$-29^{0} $29'$ E in Nyamagabe District in the Southwest part of Rwanda. In the eastern part Nyungwe forest Reserve partly covers the Kitabi and Uwinkingi sectors, where soil samples for this study were taken from. The study area covers an area of 11249.3 ha

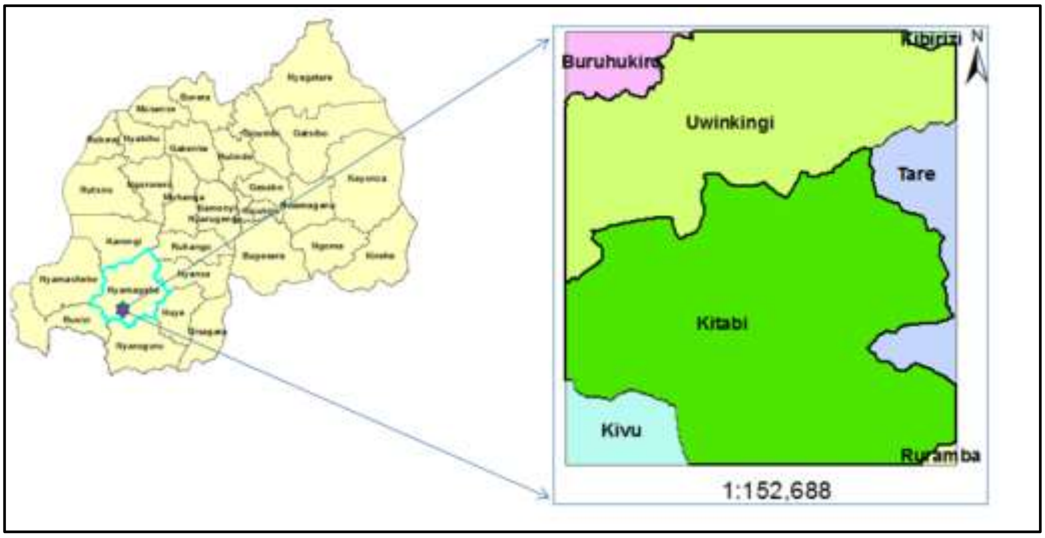

Figure 1: Location of Kitabi watershed, southern Rwanda

Methodology

Landsat TM-5 images of 2008 and 1986 were used to make a land use change map using Maximum Likelihood Classification (MLC) algorithm in Erdas software. Slope positions were derived from the DEM using Topographic Position Index (TPI) tool (Jenness, 2006; Weiss, 2001) and the output raster was overlaid with the LUC map to identify sample strata. Soil samples were obtained using stratified topo sequential random sampling (Mukashema, 2007) from annual crops, community tea and factory tea. A total of 134 soil samples were taken from the three LU categories along each of the three slope positions: upslope, middle slope and down slope. Soil samples were taken from 10 m x 10 m plots in each of the three land use categories at two depths 0-20 cm and 20-50 cm using a soil auger.

Data analysis

SOC was analyzed using Loss on ignition method (Tsui et al., 2013) as modified method(Cui et al., 2014) . One-Way ANOVA in SPSS 2010 and Games Howell post hock tests were used to compare the SOC concentrations across different land use systems and slope positions.

RESULTS

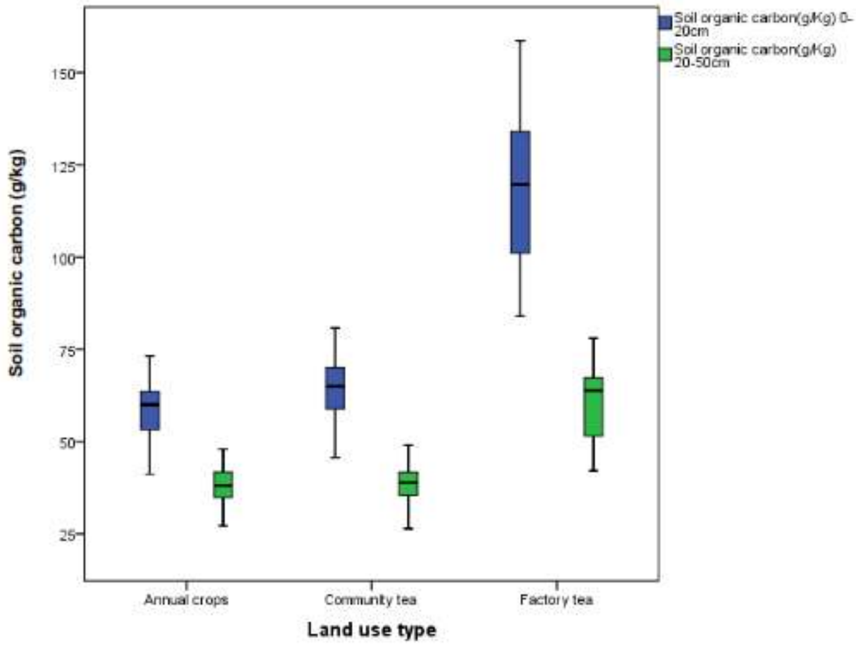

Figure 2 Soil organic carbon comparisons in annual crops, community tea and factory tea

Figure 2 shows the SOC stocks for both the surface (0-20 cm) and the sub-surface (20-50 cm) soil layers across three LU types. The concentrations of SOC follow the order factory tea > community tea> annual crops in the surface layer but in the soil sub-surface soil layer, SOC is highest in factory tea and almost the same in annual crops and community tea. One-Way ANOVA shows significant differences in SOC stocks across the three LU types, $F (2,131) = 52.5$, $p < = .001$. Levene test shows differences between groups regarding their variances; therefore, the Welch F ratio is reported. There are significant differences in SOC stocks across three LU types, $F (2, 49.6) = 21.2$, $p < .001$. Post Hoc Games Howell multiple comparisons shows significant SOC mean differences across all the three LU categories ($p < .001$) except between annual crops and community tea ($p = .985$). The mean differences of SOC stocks are significant across three land use types at 95% confidence level for annual crops and factory tea but not for annual crops and community tea. Factory tea has the highest SOC stocks but those from annual crops and community tea are almost the same.

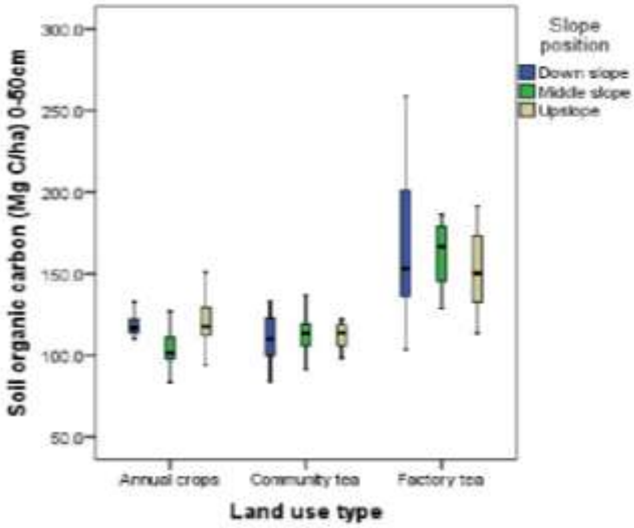

Figure 3 Variations of SOC along three slope positions

Figure 3 shows the variation of SOC stocks along three slope positions across three LU types. The figure indicates that in annual crops the median of SOC stock is lowest for the middle slope and almost the same for both down slope and upslope. In the community tea, the medians for SOC stocks are almost the same across all the three slope positions. In factory tea, SOC median is highest for the middle slope and almost equal for both down slope and upslope. Multiple ANOVA shows that LU types significantly affect SOC stocks, $F(2,125) = 55.5$, $p < .001$ but slope position does not, $F(2,125) = .715$, $p = .491$. The interaction between LU types and slope positions show no significant effect on SOC stocks across the three LU types, $F(4,125) = 2.3$, $p = .061$. Levene test shows significant differences between group variances. Post Hoc Games Howell multiple comparisons shows no significant SOC mean differences across all the three slope positions ($p > .05$).

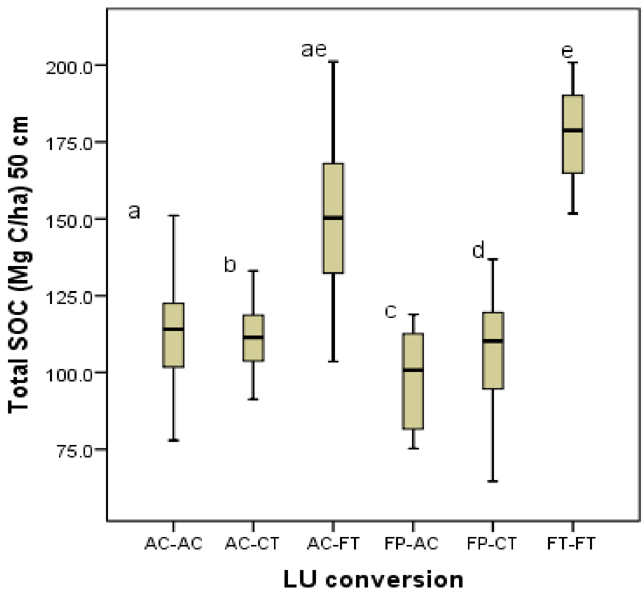

Figure 4: Variations of SOC stocks with land use conversions 1986-2010. Different symbols indicate significant differences at 5% level. AC represents annual crops, CT community tea, FT factory tea and FP forest plantation

Figure 4 shows LU conversions that occurred in Kitabi watershed from 1986 to 2010. Converting land from annual crops to community tea (b) does not show much effect on the SOC stocks but when LU was converted to factory tea from annual crops (ae), SOC stocks increase. Converting land from forest plantation to annual crops (c) shows a reduction in SOC stock compared to that of annual crops (a). When land use was converted from forest plantation to community tea (d) SOC stock becomes almost the same with that of annual crops. Unchanged factory tea plantations (e) have the highest SOC stocks. The SOC stocks in unchanged annual crops are lower than those for unchanged factory tea. Univariate ANOVA shows significant differences in SOC stocks across LU conversions, $F (1, 5) = 27.2$, $p < .001$. Levene test shows differences among the groups regarding their variances. Post Hoc Games Howell comparisons shows significant effect on SOC stocks upon all LU conversions ($p < .05$) except for conversion from annual crops to community tea and forest plantation to community tea or annual crops ($p > .05$).

DISCUSSION

Soil organic carbon comparisons in annual crops, community tea and factory tea

This study shows that there are significant differences in SOC concentrations across the three land use categories at 95% confidence level in Kitabi watershed. The findings of this research show that for the depth of 0-50 cm, least amount of SOC is in annual crops (75.2 Mg C/ha) and the highest is in factory tea (258.8 Mg C/ha). The results of this study agree with the previous studies done in Rwanda to a large extent. Rutunga *et al* (2007) in a review study estimated the SOC stocks in maize fields to be 80-150 Mg C/ha while studies in South of Rwanda reported 130-190 Mg C/ha SOC stocks in the 0-30 cm layer (Steiner, 1998). The differences between the SOC stocks from this study and previous studies may be partly attributed to the different methods used during SOC analysis. This study used Loss on ignition while the previous studies Walkley-Black.

Higher SOC stocks in factory tea than in community tea and annual crops can partly been explained by the differences in the above ground biomass (AGB), management practices and parent materials. In factory tea, the AGB, and application of fertilizers are more that than in community tea, and annual crops.

Variation of SOC stocks along three slope positions

This study shows that slope position has no significant effect on SOC stocks at 5% level when all LU types were combined. This is contrary to some of the findings from previous studies which showed that slope position significantly affect SOC stocks in agriculture soils (Hao *et al.*, 2002). This can be partly explained by the fact that the assumption of ANOVA of equal variance across the groups was violated leading to misinterpretation of the results Previous studies showed that violating ANOVA assumptions may result into misleading results (Moore & McCabe, 2009).

Variation of SOC stocks with slope positions in annual crops

This study shows that SOC stocks in annual crops are significantly different between middle slope and upslope; as well as between middle slope and down slope but not between upslope and down slope at 5% level. SOC stock is lowest on the middle slope. This can be explained by the effect of soil erosion that drives soil from the top of hills to the bottom together with OM and SOC. Soil erosion occurs more on the steeper middle slope than upslope hence the latter is likely to have more SOC amounts than the former. However, the magnitude of soil erosion depends on which annual crops are grown on a given plot at a point in time and the degree to which the soil is degraded and exposed. Similar studies in North Appalachian reported that slope position had a significant effect on the amount of SOC (Hao *et al.*, 2002).

Variation of SOC stocks with slope positions in community tea plantations

This study shows that slope positions have no significant effect on SOC stocks in community tea plantations. This can be partly explained by the fact that the tea bushes prevent soil erosion from taking place in the tea plantations. The presence of perennial tea bushes with an extensive root system ensures the aggregation of the soil particles and maintenance of the soil structure resulting into reduced water erosion. Previous studies done in South India also concluded that canopy development of tea has a direct relationship with reduction in runoff and soil loss (Madhu *et al.*, 2011).

Variation of SOC stocks with slope positions in factory tea plantations

This study shows that slope position has no significant effect on SOC stocks in factory tea and SOC is highest on the middle slope. This may be partly explained by the increased number of tea bushes per unit area and the management system in factory tea. Tea bushes being very compact together with a lot of litter on the ground and having an extensive root system prevent soil erosion from occurring thus preventing SOC loss. At the same time, regular application of NPK improves soil structure thus reducing soil erosion. The highest SOC on the middle slope is likely to be caused by the presence of contour ridges a cross the hills in factory tea plantations. In the early stages of tea plantations, soil erosion may have carried OM from upslope and deposited it along the ridges in the middle of the slope thus increasing SOC on the latter. This finding is consistent with previous studies done in South India which reported that construction of contour staggered trenches in tea plantations leads to reduction in runoff (29-51%) and soil loss (25-68%) resulting into increased mean yield of tea leaves (by 25-37%) (Madhu *et al.*, 2011).

Effect of land use conversions on soil organic carbon

This study shows a significant effect on SOC stocks associated with different LU conversions at 5% level. Converting land from annual crops to factory tea significantly increases SOC stocks (Figure 4). This may be partly explained by the increased above ground biomass and litter that add more OM to the soil after converting land from cropland to factory tea. Similar studies reported that converting soils under agriculture into perennial land use may increase SOC stocks (Lal, 2004). However, this study shows that land use conversion from annual crops to community tea shows no significant effect on the amount of SOC in the soil. This is likely to be caused by the farm management practices in annual crops that may significantly increase the SOC stocks in annual crops to the level similar to that in community tea. Research reported that improved fallow, fertilizer application associated with crop rotation and addition of crop residues have potential to increase SOC concentrations in the soil (IFPRI, 2010; SEI, 2009). The practices mentioned above are common in annual crops of Kitabi watershed and may have caused increased SOC stocks in annual crops.

Furthermore, this study also shows that converting land from forest plantation to annual crops significantly reduces the amount of SOC. This can be partly explained by the reduction in the AGB and increased rate of soil erosion associated with this LUC. Previous studies reported that forests have more SOC than agriculture land (Eaton *et al.*, 2008; Guo & Gifford, 2002) and converting land from forests to bananas reduced SOC by 37% due to decrease in ABG and surface litter (Powers, 2004). Similar studies reported that soil erosion results into decreased SOC in agriculture land (Lal, 2004) and results into increased loss of soil nutrients (Smaling *et al.*, 1993). However, this study shows that converting land use from forest plantation to community tea plantation has no effect on SOC stocks. This is contrary to what some studies reported. This may be partly attributed to the young age of the forest plantation in this area. Studies reported that trees of 6-12 years have low SOC stocks (Hansen, 1993) while older tea bushes sequester more Carbon (Kamau *et al.*, 2008). If the forest plantation in Kitabi watershed is younger in age than community tea, the difference in SOC stocks of the two LU types may not be very significant.

However, this study had some drawbacks that may have affected the interpretation of the results. The difficulty of separating factory tea from community tea during image classification may have affected the results of this study. To solve this problem, we merged the two into one class during image classification. At the same time the spectral signatures of different annual crops could not be separated from each other and therefore the researcher combined them into one class. These limitations may have affected the quality of the results from this study. At the same time, the LU history and soil properties of the study area could not properly be established due to lack of sufficient data. Therefore, this study was based on the assumption that annual crops, community tea and factory tea all had similar LU history and soil properties. Previous studies warned that results based on such an assumption may at times be misleading (Breuer *et al.*, 2006). Nevertheless, the results from this study agree with most findings in many parts of the world and can be used to complement previous studies with a reasonable degree of accuracy.

Conclusions and recommendations

One-Way ANOVA and Games Howell Post Hoc multiple comparisons indicate significant differences in SOC stocks in factory tea, community tea and annual crops. The highest amount of SOC is found in factory tea plantations and the least in annual crops. These differences in SOC stocks are partly attributed to land use changes in Kitabi watershed. Converting land from annual crops to factory tea significantly increases SOC concentrations but land use change from annual crops to community tea has no effect on the SOC stocks.

Slope position significantly affects the amounts of SOC in annual crops but not in tea plantations. However, Univariate multiple ANOVA indicates that the interaction of both land use types and slope positions has no significant effect on SOC stocks across all the three land use types. Soil erosion is likely to be the major cause of SOC differences along slope positions in annual crops.

SOC stocks in community tea plantations adjacent to factory tea need to be studied to gain more insight on the causes of SOC variations in this area. Community tea farmers need more training in record keeping and better farm management practices to increase green leaf tea production. Farmers and policy makers should consider use of farm management practices such as balanced use of fertilizers and construction of bench terraces to reduce soil erosion and SOC loss, and enhance crop production in Kitabi watershed.

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