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Original Research Paper

Soil organic carbon stocks in the dominant soils of the Miombo woodland ecosystem of Kitonga Forest Reserve, Iringa, Tanzania

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Few studies have determined the soil organic carbon (SOC) stocks in the Miombo woodlands ecosystem in Tanzania. Standard field and laboratory procedures were used to evaluate SOC storage in the Miombo woodlands ecosystem of Kitonga Forest Reserve Iringa, Tanzania. A study area of 52 km ^{2} was selected and ten soil profiles were studied. Representative sampling points were geo-referenced and soil samples collected from natural horizons to the depth of 60 cm. Results show that the total soil organic carbon stocks in soil profiles varied from 19.4 to 28.9 Mg C ha^{-1} in leptosols; from 45.6 to 80.1 Mg C ha^{-1} in fluvisols; and from 33.9 to 134.6 Mg C ha^{-1} in cambisols. The SOC increased significantly ($p< 0.05$) with increasing elevation, horizon thickness and % clay, but it decreased significantly ($p< 0.05$) with increasing slope gradient and increasing % sand. The areal distribution of the soil types was 61%, for cambisols, 19% for leptosols, 11% for fluvisols and 9% for natural forest which was not surveyed because of inaccessibility. Proper management of Miombo woodlands would increase the SOC storage and contribute to climate change regulation.

Key words: Miombo woodlands, soil types, soil organic carbon stocks, climate change regulation, Kitonga Forest Reserve, Tanzania

INTRODUCTION

An in-depth understanding of the content and distribution of the soil organic carbon (SOC) in a given area would enhance the capacity to predict and subsequently to mitigate the negative consequences of climate change. Efforts to study the potential of soils to regulate global warming and greenhouse gas effects as a function of the ability of soils to store large quantities of carbon are increasing worldwide (Aticho, 2013; Stockmann et al*.,* 2013; Jandl et al., 2014).

Soils represent the largest carbon reservoirs in the terrestrial ecosystem, with 11% of SOC held in forest soils worldwide (Eswaran et al., 1999; Dey, 2005; Negi et al., 2013; Yuan et al., 2013). Therefore, forest soils are one of the major carbon sinks on earth, because of the high amounts of organic matter stored in forest soils. The soils of the Miombo woodland ecosystems are also a major carbon sink because of their capacity to sequester large amounts of atmospheric carbon dioxide and, thus, can mitigate climate change and its effects (Ryan et al., 2011; Woollen et al., 2012). In Tanzania, the Miombo woodland ecosystem is found, among other places, in the Kitonga Forest Reserve. However, studies on the content and distribution of carbon in the soil component in the Kitonga Forest Reserve (KFR) have not been undertaken.

The Miombo woodlands, which cover 32 million hectares or 93% of the total forested land area and about 40% of total land area of Tanzania, are important as they provide diverse ecosystem services to adjacent communities. Such

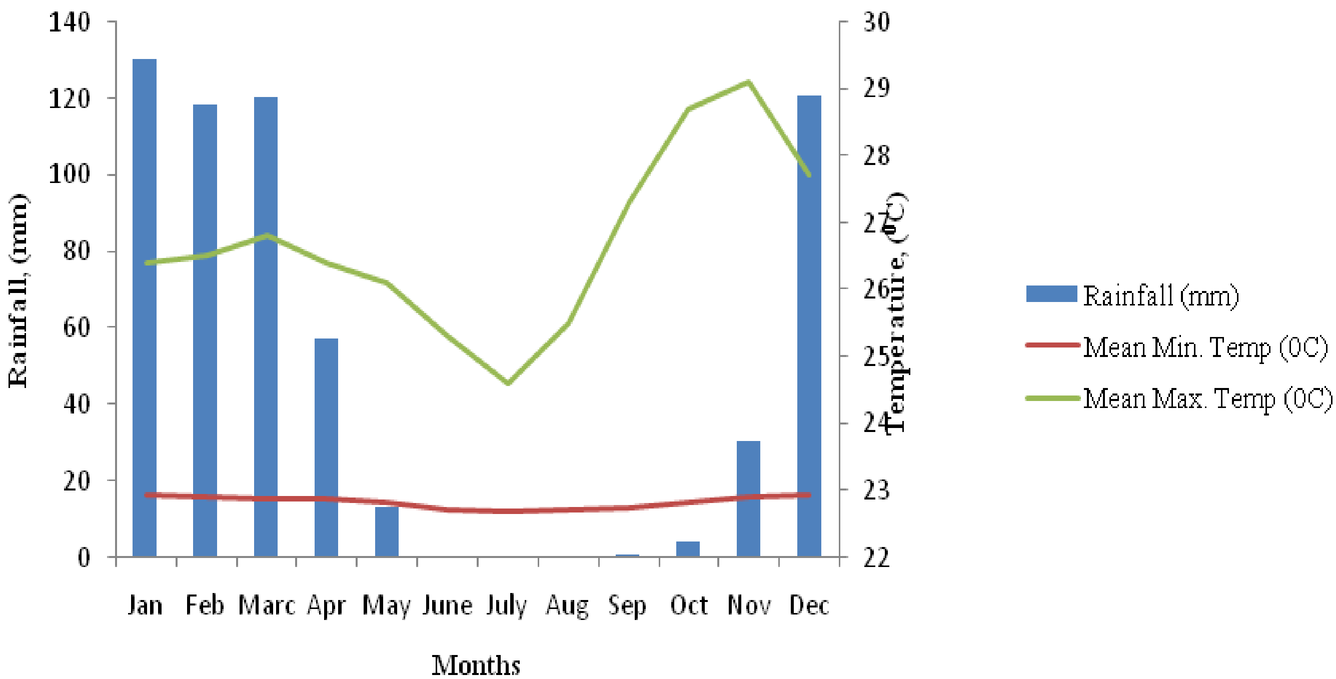

Figure 1: Mean monthly rainfall (mm), minimum and maximum temperature (⁰C) of the study area during the period 1981 to 2012

services include water catchment, provision of energy, fibre, food and construction materials, climate regulation, carbon sequestration, biodiversity, scenic beauty, provision of medicines and soil erosion control (Nshubemuki and Mbwambo, 2007; Lal, 2012; FAO, 2009).

The quantities of SOC stored in Miombo woodland soils would represent the potential for carbon that could otherwise be lost as a result of deforestation and forest degradation. The carbon stored in the upper horizons of soils is more susceptible to loss through soil erosion, when vegetation cover is disturbed. Tanzanian forest soils show alarming deterioration rates following disturbances and land degradation (FAO, 2009; Woollen et al., 2012), and it would be important to formulate plans and actions for minimizing such disturbances to prevent SOC losses.

The major aims of the study reported here were: (i) to determine quantities of SOC stocks in the dominant soil types of the KFR area, (ii) to establish the distribution patterns of SOC stocks in the study area and (iii) to determine the factors influencing the SOC stocks. Accurate quantification of SOC stocks would provide vital information to stakeholders in designing intervention/strategies in response to changes in global climate. Such interventions would assist in mitigation and adaptation to climate change in these Tanzanian forest soils as well as to provide information/data that may be of use to stakeholders like Ministry of Environment at the Vice Presidents office (VPO) and the National Reducing Emission from Deforestation and forest Degradation (REDD+ strategy) for purposes of analysis and coordination of national efforts to mitigate the effects of climate change.

MATERIALS AND METHODS

Description of the Study Site

The dominant soils of the KFR (07°35' - 07°43'S; and 37°07' - 37°10'E) in Kilolo District, Iringa Region, classify as cambisols, leptosols and fluvisols. The forest covers an area of 97 km², of which 90 km² are Miombo woodlands [Hunting Technical Services (HTS), 1997]. The area covered by the present study is 52 km² and consists of moderate to very steep slopes, with altitude ranging from 660 to 1880 m above sea level. Rainfall ranges from 520 to 737 mm, with a mean annual rainfall of 629 mm. The temperatures range from 12.0 to 29.1 °C, with maximum temperatures in July to November. cambisols (inceptisols) are found in upper slopes, whereas fluvisols (entisols) are in valleys and leptosols (entisols) in the lower slopes. Climatic data from 1981 to 2012 (Figure 1) show that monthly average maximum and minimum temperatures were 29.1 °C and 12.0 °C in the months of November and July, respectively. Although the mean annual rainfall is 629 mm, the highest monthly rainfall, 130 mm, is in January and the lowest, 0.1 mm in June.

The dominant vegetation types include trees of the genera *Brachystegia, Julbernardia, Diplorhynchus* and

Table 1: Total SOC stocks in Mg ha $^{-1}$ up the depth of 60 cm in dominant soil types in KFR

Soil type	Cambisols				Fluvisols			Leptosols		
Profile number	P1	P7	P9	P10	P3	P6	P8	P2	P4	P5
Ah (horizon) *	38.4	11.7	16.2	11.2	25.2	29.7	24.1	13.4	19.4	28.9
Bw/BA (horizon)	32.5	6.2	7.3	7.1	13.3	17.2	16.4	11.6	0	0
Bw/BC/Bt (horizon)	63.7	37.8	10.4	27	7.1	33.2	31.3	0	0	0
Total SOC	134.6	55.7	33.9	45.3	45.6	80.1	71.8	25	19.4	28.9
Total SOC for soil types	269.5				197.5			73.3		
Mean SOC per soil type	67.4				65.8			24.4		

* Horizon thicknesses are given in Table 2

Condylocarpon, grasses of the genera *Andropogon* and *Heteropogon,* shrubs of *Fadogia spp* and the herb *Commelina africana.* Severe deforestation and soil degradation occur in the lower elevations where the leptosols dominate.

Data collection

Within each soil type i.e. leptosols, fluvisols and cambisols a 20 m by 20 m square plot was set out, and partitioned into four 10 m by 10 m quadrants. Within each quadrant, four points were randomly selected for collecting soil samples. Soil samples were also collected from natural horizons in soil profile pits up to the depth of 60 cm, in three replicates, from each dominant soil type. The coordinates of the profiles were recorded. Sub-samples from each horizon were mixed together to make bulk samples of about 2 kg. At each sampling point, undisturbed core samples were taken from each horizon for the determination of bulk density (BD). For representative surface soil samples, eighty seven sampling points were selected and geo-referenced for follow up and monitoring in the future.

Data analysis

In the laboratory, soil samples were air dried to constant weight after which they were ground and sieved through a 2 mm sieve to get the fine earth fraction ready for laboratory analysis. The BD was determined using the core method (Black and Hartge, 1986), and texture was determined by the hydrometer method (Day, 1965). The pH was measured in water and in 1 M $CaCl_2$ at the ratio of 1:2.5 soil:water or soil:$CaCl_2$, respectively (McLean, 1986). Organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982). Total N was determined using the micro-Kjeldahl digestion-distillation method as described by Bremner and Mulvaney (1982). Extractable phosphorus was determined by the Bray and Kurtz-1 method (Bray and Kurtz, 1945) and determined by spectrophotometer following colour development by the molybdenum blue method (Watanabe and Olsen, 1965). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were extracted by 1N NH_4OAc and determined by atomic absorption spectrophotometer (Thomas, 1982). The extractable micronutrients Fe, Mn, Zn and Cu were extracted using buffered DTPA (Diethylene triamine pentaacetic acid) and the concentrations of Fe, Mn, Zn and Cu in the DTPA extracts determined by an Atomic Absorption Spectrophotometer (AAS), (UNICAM 919 model)(Lindsay and Norvell,1978). The SOC stocks were calculated based on the formula given by Spiota and Sharma (2013):

$$SOC_{st} = \% \ SOC/100 \times BD \times D \times 100$$

where: SOC_{st} is the soil organic carbon stocks (Mg C ha^{-1}), SOC is the soil organic carbon concentration (%, which is then converted to g C g^{-1} soil), BD is the bulk density (g cm^{-3}), D is the horizon thickness (cm) and 100 is the multiplication factor to convert the SOC from g cm^{-2} to Mg C ha^{-1}.

The carbon stocks in each dominant soil type were obtained by the summation of C stocks of each natural soil horizon to the soil depth of 60 cm.

Statistical analysis

The SOC data were subjected to one-way analysis of variance (ANOVA) following the Completely Randomized Design (CRD). The analyses were performed by using the statistical analysis system (SAS version 9.2). Descriptive statistics were used to summarize the data into variables such as means, standard deviation, standard error, minimum and maximum values.

RESULTS AND DISCUSSION

Soil organic carbon stocks of the dominant soil types

The total SOC stocks in leptosols, fluvisols and cambisols which are the dominant soil types of the study area are presented in Table 1. The minimum total SOC stocks across the soil types varied from 19.4 Mg C ha^{-1} (Profile, No. 4) in leptosols to the maximum of 134.6 Mg C ha^{-1} (Profile, No. 1) in cambisols. The overall minimum average SOC stocks varied from 24.4 Mg C ha^{-1}) in leptosols to 67.4 Mg C ha^{-1} in cambisols. The large variations between cambisols which stored relatively higher SOC of 135 Mg ha^{-1} (Profile No. 1)

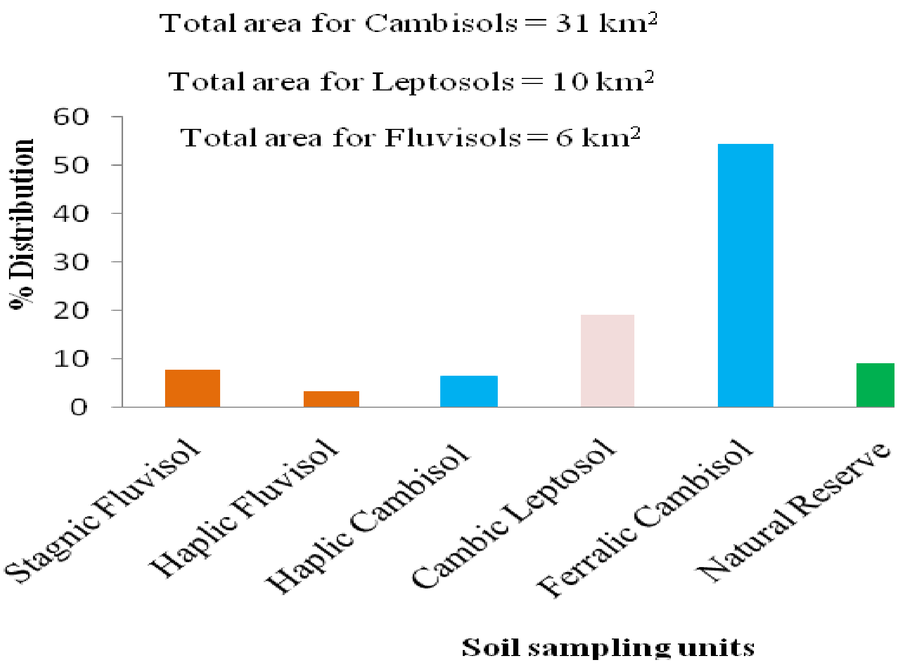

Figure 2: Summary of soil mapping units and their distribution

as compared to cambisols which stored relatively smaller SOC of 34 Mg ha^{-1} (Profile No. 9) was due to differences in elevations at which these profiles are located. Profile No.1 is located at 1598 masl, whereas profile No.9 is located at 1258 masl. The relatively higher elevation conditions favoured relatively more accumulation of SOC compared to the relatively lower elevation as also explained by others (Yao et al., 2006; Egli et al., 2009; Hattar et al., 2010; Djukic et al., 2010; Grand and Lavkulich, 2011; Tang et al., 2012; Hoffmann et al., 2014).

Don et al. (2011) reported the worldwide mean SOC stocks to be 106 Mg C ha^{-1} (up to 1 m depth), and Gorte (2009) reported the worldwide mean SOC stocks in tropical forests to be 68.75 Mg C ha^{-1} (1 m depth). Hoffmann et al. (2014) reported a mean of 64 Mg C ha^{-1} SOC stocks to the depth of 30 cm in the Rocky Mountains of Alberta. Brahim et al. (2010) reported a mean of 71.4 Mg C ha^{-1} and 101 Mg C ha^{-1} SOC stocks to the depth of 100 cm in Spain and Tunisia, respectively. Thus, the variation in SOC stocks worldwide could be contributed by different soil types, climate and different management strategies undertaken.

The results of the present study are in consistence with those reported by Woollen et al. (2012) for the Miombo woodlands in Mozambique, where the mean SOC stock to the depth of 40 cm was 40.1 Mg C ha^{-1}, and were consistent with those of Negi et al. (2013) from the plantation forest soils of Uttarakhand State, India, where the SOC stock ranged from 27.73 Mg C ha^{-1} to 66.32 Mg C ha^{-1}. However, C stocks in the present study were generally lower (except for cambisols -Profile 1) as compared to those obtained by Negi et al. (2013) for natural forest soils of Uttarakhand State, India, where the SOC stock ranged from 58.45 Mg C ha^{-1} to 140.72 Mg C ha^{-1}, and also lower (except Profile 1 and fluvisol Profile 6) than those of Saha (2012) in forest lands in the Himalayas of India which had a mean of 83.5 Mg C ha^{-1}. The relatively low levels of SOC stocks in our KFR study area could be attributed to periodic wild fires and continual grazing, charcoal burning, deforestation and soil erosion, which reduce the organic matter contents of the surface soil horizons. These findings call for sustainable conservation and management strategies of the Miombo woodlands in Tanzania and to avoid those activities that decrease SOC stocks. Thus, proper management of Miombo woodlands in Kitonga Forest Reserve would increase the SOC storage and contribute to climate change regulation and adaptation when CO_2 emissions are kept low.

Soil organic carbon stocks as influenced by areal coverage of different soil types

The area coverage of those dominant soil types are shown in Figure 2. The distribution is cambisols (61%) in 31 km^2 > leptosols (19%) in 10 km^2 > fluvisols (11%) in 6 km^2 and 9% (5 km^2) for natural forest where its soil type was not determined due to inaccessibility. The average SOC storage in all the cambisols were 67.4 Mg C ha^{-1} (Table 1), followed by fluvisols (65.8 Mg C ha^{-1}) and lastly the leptosols (24.4 Mg C ha^{-1}. Despite their relatively larger areal coverage, compared to the fluvisols, the leptosols had relatively lower soil organic carbon contents (due to thinner soil layer), and

Table 2: Some salient characteristics of the study area and implications on SOC stocks

Elevation (masl)	Profile No.	Natural Horizons	Horizon thickness (cm)	Parent Material	Sand %	Clay %	Soil class FAO-WRB	Slope gradient	SOC Mg ha-1
831	5	Ah	20	Colluvium	63	24.3	Leptosol	25	28.9
928	3	Ah	16	Alluvial,Colluvial	85	10.3	Fluvisol	15	25.2
928		BA	17	Alluvial,Colluvial	87	10.3	Fluvisol	15	13.3
928		Bw	12	Alluvial, Colluvial	85	10.3	Fluvisol	15	7.1
980	4	Ah	16	Biotitic/Quartz	79	14.3	Leptosol	12	19.4
1083	2	Ah	10	Biotitic/Quartz	73	22.3	Leptosol	17	13.4
1083		Bw	15	Biotitic/Quartz	85	10.3	Leptosol	17	11.6
1241	8	Ah	18	Alluvial, Colluvial	77	8.4	Fluvisol	10	24.1
1241		Bw	12	Alluvial, Colluvial	93	6.3	Fluvisol	10	16.4
1241		2Bgb1	30	Alluvial, Colluvial	93	6.3	Fluvisol	10	31.3
1258	9	Ah	15	Biotitic/Quartz	85	10.3	Cambisol	10	16.2
1258		Bw	17	Biotitic/Quartz	89	8.3	Cambisol	10	7.3
1258		BC	28	Biotitic/Quartz	79	16.3	Cambisol	10	10.4
1320	10	Ah	10	Biotitic/Quartz	79	12.3	Cambisol	22	11.2
1320		Bw	12	Biotitic/Quartz	67	28.3	Cambisol	22	7.1
1320		Bt	18	Biotitic/Quartz	74	26.3	Cambisol	22	27
1377	7	Ah	10	Biotitic/Quartz	79	12.3	Cambisol	25	11.7
1377		Bw/BC	12	Biotitic/Quartz	67	28.3	Cambisol	25	6.2
1377		Bt	13	Biotitic/Quartz	77	26.3	Cambisol	25	37.8
1548	6	Ah	15	Alluvium	66	26.3	Fluvisol	10	29.7
1548		BA	12	Alluvium	75	20.3	Fluvisol	10	17.3
1548		Bt1/Bt2	33	Alluvium	73	24.3	Fluvisol	10	33.2
1598	1	Ah	15	Biotitic/Quartz	57	34.3	Cambisol	1	38.4
1598		BA	17	Biotitic/Quartz	59	34.3	Cambisol	1	32.5
1598		Bw	28	Biotitic/Quartz	63	30.3	Cambisol	1	63.7

therefore could not surpass the fluvisols' SOC stocks. Similar results were reported by Rojas et al. (2012) in soils of Southern Spain, and by Batjes (2002) in soils of Central and Eastern Europe, where cambisols formed the largest soil type with highest SOC stocks compared to fluvisols and leptosols.

Literature has acknowledged the importance of cambisols, fluvisols and leptosols soil types in providing livelihoods worldwide, especially to people living in mountain areas. Thus, proper management of these soils would guarantee their capacity to store carbon and thereby contribute to climate change mitigation.

Variation of SOC stocks as affected by different properties of the soils

The SOC stocks in the study area varied spatially within and between profile horizons and soil types (Table 2). This variation could be attributed, among others, to variations in elevation, soil texture, horizon thickness and slope gradient as shown in (Figure 3).

Variation of SOC stocks as affected by elevation

The SOC stocks increased with elevation due to relatively Higher moisture levels and lower temperatures at the higher elevations (Hoffmann et al., 2014). Lower temperatures slow organic matter decomposition rates, because OM decomposition activities by microbes are slower at cooler temperatures, thus facilitating accumulation of thicker litter layers and higher soil organic matter. These conditions lead to low CO_2 emission from the soil, and thus contribute to higher SOC accumulation/stocks. The results of this study showed that the SOC stocks significantly increased with elevation ($p< 0.05$) (Figure 3a). These results are in consistence with the results of other researchers elsewhere. Studies by Spiotta and Sharma (2013) reported that, in tropical soils, climate (rainfall and temperature) play a major role in carbon storage than other factors do. Dai and Huang (2006) reported that in Eastern and Southern China, variations in precipitation, temperature and altitudes were key factors regulating surface soil organic matter contents. The influence of altitude in the present studies can also be related to the effects of higher elevations in increasing precipitation (hence soil moisture) and lowering environmental temperature.

Studies on SOC stocks in different parts of the world by Hoffmann et al. (2014), Tang et al. (2012), Grand and Lavkulich, (2011), Djukic et al. (2010), Hattar et al. (2010), Egli et al. (2009), Seibert et al. (2007) and Yoo et al. (2006) established the same relationship that SOC stocks increase with increasing elevation. However, Sheikh et al. (2009) reported SOC stocks to decrease with elevation due to increased in sustainable management strategies at lower elevation to support livelihood of increasing population. Thus, proper forest management plays important role in C accumulation and storage.

Variation of SOC stocks as affected by soil texture

The results of this study showed that as clay content increased, the SOC stocks increased and the vice-versa ($p< 0.05$) (Figure 3b, c) whereas as sand content increased, the SOC stocks decreased and the vice-versa. For example, the surface horizon (Ah) of Profile No. 1 of the cambisols, with a relatively high clay content of 34.3% and relatively lower sand content of 57% stored more SOC (38.4 Mg ha^{-1}) as compared to the leptosols with clay content of 10.3% and sand content of 85% in the Ah horizon of the Profile No. 4 that stored relatively lower SOC (11.6 Mg ha^{-1}). Thus, soils with relatively higher clay contents and relatively lower sand contents store more SOC stocks, and the vice-versa.

The present results are in consistence with the results of other studies conducted elsewhere. Studies by Negi et al. (2013) reported variable values of SOC from 27.7 to 140.76 Mg ha^{-1} in different forest types of the Himalaya zone in India. Cosel et al. (2011) reported SOC of 43 Mg ha^{-1} in a 100 year old in Panama. Woollen et al. (2012), in the African miombo woodlands, indicated SOC of 40.1 Mg C ha^{-1} to 30 cm depth. Saiz et al. (2012 reported SOC variation in the Sahelian savanna from 20 Mg ha^{-1} in Mali to 120 Mg ha^{-1} in Ghana. Rojas et al. (2012) reported SOC storage to vary between 15.9 and 107 Mg ha^{-1} in Mediterranean soils of Spain, and Ciais et al. (2011) reported highly variable SOC of 30 – 140 Mg ha^{-1} in the African savanna and woodlands. The differences in SOC storage in those soil types could be associated with varying levels of clay and sand contents which affect soil moisture storage in those soils and consequently affect SOC stocks (Rojas et al., 2012; Yao et al., 2010). Thus, the relative proportions of clay and sand influence the SOC stocks. It may be noted that, generally the SOC stocks ranges cited seem to be in some agreement with those found in the KFR Miombo woodlands in the present studies. It should be noted that although the winter temperatures are lower in temperate areas, the higher summer temperatures, which speed up microbial decomposition rates of organic materials, are generally similar between temperate and tropical zones. This may result in similar ceilings of SOC stocks in temperate as in the tropical zones.

Variation of SOC stocks as affected by horizon thickness

The results of this study showed that as the soil thickness increased, the SOC stocks significantly increased ($p< 0.05$), and the vice-versa. The leptosols, which had the lowest SOC stocks, had a thin soil layer, followed by fluvisols with thick soil layers of deposited soil as found in valleys and depressions and sometimes in mid elevations. The cambisols, with high SOC stocks, had relatively thicker layers and occupied the mid to higher elevations in the study area. As the sampling horizon thickness of soil increased, the SOC stocks also increased (Figure 2d). Thus, overall, deep soil profiles like those of cambisols and fluvisols lead to larger organic carbon storage than the soils with shallow depths like leptosols. The results of this study are in consistence with the results of others. Studies by Cambule et al. (2014) in Mozambique, Wiesmeier et al. (2012) in Germany and Aticho (2013) in Ethiopia have reported soil thickness to be among the important factors which affect SOC stocks.

Variation of SOC stocks as affected by slope gradient

The SOC storage increased significantly ($p< 0.05$) with decreased in slope gradient, and the vice-versa (Figure 3e). The soils which are found in areas with relatively small slope gradient stored generally more SOC compared to those which are situated in relatively steep slopes. For example, the Ah horizon of the cambisols (Profile No. 1) at 1% slope stored 38.4 Mg C ha^{-1} as compared to the Ah horizon of the cambisols (Profile No.7), at 25% slope, which stored 11.7 Mg C ha^{-1}. In leptosols, the Ah horizon (Profile No.4) at 12% stored 19.4 Mg C ha^{-1} as compared to the Ah horizon of the leptosols (Profile No.2) at 17% which stored 13.4 Mg C ha^{-1}. As slope gradient increases, erosion of the soil increases. As as a result, SOC stocks decrease (Hoffmann et al., 2014). These results are consistent with those of Xiaojun et al. (2013) in China, Wang et al. (2012) in China, Karchegani et al. (2012) in Iran, Fantappiè et al. (2011) in Italy, Djukic et al. (2010) in the Alpine region and Koulouri and Giourga (2007) in the Mediterranean who reported the slope gradient to be among the important factors in determining spatial and temporal variation in SOC stocks. Thus, soils differ in C storage capacity due to variation in their positions along a topo-sequence. Reducing soil erosion in steep slopes will increase the SOC storage of the soils.

Soil organic carbon stocks as influenced by vegetation types

The diversity of species and the dominant vegetation types in Kitonga Forest Reserve varied with elevation (Table 3), where species richness generally increased with increasing elevation up to 1548 masl and decreased with further increasing elevation. The variations in dominant vegetation

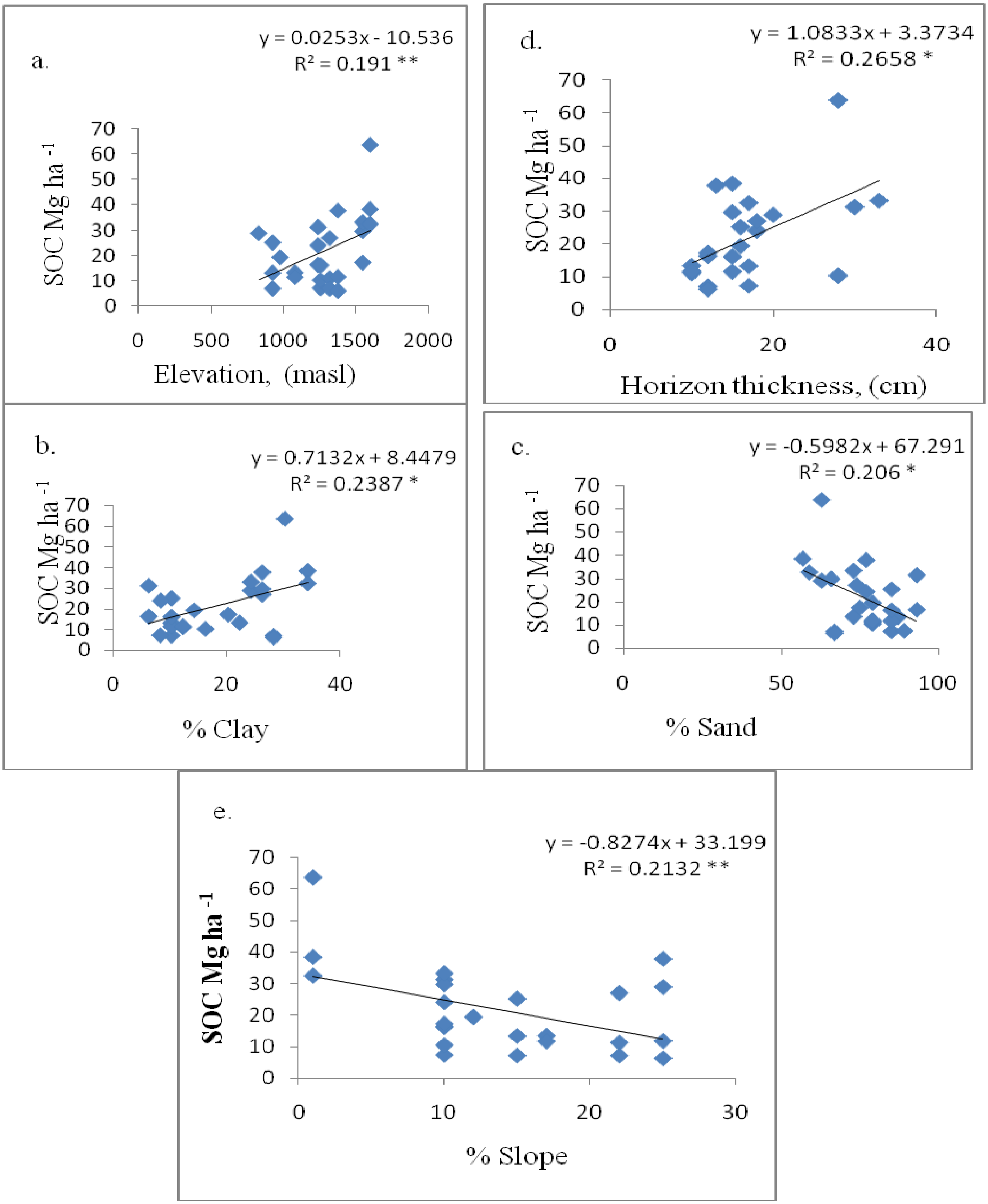

Figure 3: Regression analysis between soil organic carbon stocks and elevation, soil profile thickness, texture (clay and sand) and slope gradient

Table 3: Dominant vegetation types across elevation in Kitonga Forest Reserve

Elevation (masl)	Dominant vegetation type
831	*Dalbergia lactealVatke* (tree),
	Margaritaria discoidea (Baill.) Webster (tree),
	Andropogon spps (grass,
920	*Brachystegia spiciformis* Benth
980	*Brachystegia spiciformis* Benth
1083	*Diplorhynchus condylocarpon* (Müll. Arg.) Pichon (tree)
	Andropogon spss and Heteropogon spps (grass)
	Aspilia spps (herb)
1241	*Julbernardia globiflora* (Benth.) Troupin (tree)
	Indigofers spps (shrub)
	Commelina africana (herb)
1258	*Julbernardia globiflora* (Benth.) Troupin
	Lannea schimperi (A.Rich.)Engl.
	Commelina africana (herb), *Indigofers spps* (shrub)
1320	*Brachystegia spiciformis (*Benth.) Troupin
	Julbernardia globiflora (Benth.) Troupin
	Andropogon spps (grass)*, Commelina africana* (herb)
1377	*Brachystegia longifolia* Benth
	Erica arborea L.
	Faurea saligna Harvey
	Protea gaguedi J.F.Gmel.
1548	*Uapaca kirkiana* Müll.Arg.
	Protea gaguedi J.F.Gmel.
	Albizia antunesiana Harms
	Brachystegia longfolia (Benth.)
	Julbernardia globiflora (Benth.) Troupin
1598	*Uapaca kirkiana* Müll.Arg.
	Brachystegia spiciformis Benth
	Faurea rochetiana Chiov. ex Pic.Serm.

types and species richness with elevation have been explained as the reason for increased SOC stocks with elevation (Giliba et al., 2011; Grand and Lavkulich, 2011; Yao et al*.,* 2010). The higher percent of SOC stocks at those elevations could be due to dominance of certain species and dense canopy, providing higher inputs of litter, which results in more SOC stocks (Giliba et al., 2011; Grand and Lavkulich, 2011; Yao et al., 2010). The results of this study indicated variation in vegetation types (Table 3), which reflected variation in SOC stocks in different elevations (Table 2) with different vegetation types. The plots at elevation of 1548 had the highest number of trees and tree species. As the elevation increased beyond 1550 masl, the number of trees and tree species decreased. This trend has also been reported by Yao et al*.* (2010). Thus, elevation gradient influenced SOC stocks and hence climate change regulation.

Studies by Sreekanth et al. (2013) in different forest types in India revealed the highest SOC stocks of 165 Mg C ha^{-1} in Shola forest and the lowest SOC of 104.9 Mg C ha^{-1} in a Riparian forest. Usuga et al. (2010) reported SOC in different tropical forests to be 76.1 Mg C ha^{-1} in *Pinus patula* and 19 Mg C ha^{-1} (to the depth of 25- 50 cm) in *Tectonia grandis* tropical forest tree species. Negi et al. (2013) in India reported variation of SOC storage in forests under different tree species to follow this order: *Abies pindrow* and *Picea smithiana* forests (140.7 Mg C ha^{-1}), followed by *Cedrus deodara* (118 Mg C ha^{-1}), *Quercus leucotrichophora* (96.4 Mg C ha^{-1}), *Pinus wallichiana* (67.6 Mg C ha^{-1}), *Pinus roxburghii* (61.1 Mg C ha^{-1}) and miscellaneous forests (58.95 Mg C ha^{-1}). Thus, vegetation type plays an important role in SOC storage, and the same may be inferred from the present results.

Conclusions

The total SOC stocks in the dominant soil types i.e. cambisols, fluvisols and leptosols of KFR varied from 33.9 Mg C ha^{-1} (Profile No.9) to 134.6 Mg C ha^{-1} (Profile No. 1) in cambisols, from 45.6 Mg C ha^{-1} (Profile No. 3) to 80.1 Mg C ha^{-1} (Profile No. 6) in fluvisols and varied from 19.4 Mg C ha^{-1} (Profile No. 4) to 28.9 Mg C ha^{-1} (Profile No. 5) in leptosols. On average, between soil types, all cambisols stored 67.4 Mg C ha $^{-1}$ followed by fluvisols (65.8 Mg C ha^{-1}) and lastly leptosols (24.4 Mg C ha^{-1}). The areal distribution of the soil mapping units in KFR was cambisols (61%, ≡ 31 km^2), leptosols (19%, ≡ 10 km^2), fluvisols (11%, ≡ 6 km^2)

soil types and natural forest 9%, ≡ 5 km^2). The soil organic carbon increased with increasing elevation, horizon thickness and % clay, but it decreased with increasing slope gradient and with increasing % sand. cambisols, fluvisols and leptosols in KFR, Tanzania have a high potential in storing SOC which could contribute to climate change mitigation.

RECOMMENDATIONS

In view of the above, the following recommendations are made:

1. Due to differences in amounts of carbon stored by each soil type it is recommended that the specific land management for each soil type be devised, considering also where it is located in a toposequence. For example, if a soil type is found in an area which is degraded, avoidance of deforestation, cultivation within the forest/woodlands, fires and grazing should be applied. These efforts will enhance the building up of organic matter and accumulation of greater SOC stocks.
2. More detailed information/data on the contents and distribution of SOC for those soil types should be gathered, taking into consideration specific soils, topographical features, soil physico-chemical properties, soil environment and vegetation types.

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