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Full Length Research Paper

Impact of Land Use on Soil Organic Carbon Dynamics in Mount Cameroon National Park

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Increasing effects of climate change has led to an urgent need for reliable estimates of the soil carbon pool (SOC) which is one of the carbon sinks in the world. This is especially true in Africa where there is lack of basic data. This study conducted in the southern part of Mount Cameroon National Park (MCNP) seeks to determine SOC patterns and estimate CO_2 equivalence from SOC pool following land-use changes. Nine prominent land-use types were identified (under rubber, virgin forest reserve, oil palm, cassava, mixed cropping, tea, maize, banana and sugar cane). Soil samples were collected from 98 plots of 2,500 m^2, each spread over the different land uses in five villages at 0 - 30 cm of soil. The collected Soils samples were analyzed for SOC and other physicochemical properties. Mean SOC ranged from 56.1± 11.00 t ha-1 (for rubber) to 225.24 ± 33.65 t ha-1 [1] (for forest) giving an average for the area of 130.80 Mg/ha. The mean SOC in forest soil was significantly higher than that for cassava (p=0.038), oil palm (p=0.045) and rubber (t=4.849, p=0.0046). Losses in CO_2 equivalence, as a result of land use change from forest to other land use systems, ranged from 234.15 (for mixed cropping) to 620.74 t/ha (for rubber). The study provided estimates of carbon pools for different land uses in MCNP. Mixed cropping was only second to forest in terms of SOC values indicating that agroforestry can mediate between food production and environmental protection.

Key words: Soil organic carbon, land use systems, CO_2, carbon sequestration, soil quality.

INTRODUCTION

Climate change is one of the most important challenges to sustainable development bearing more negative than positive effects on aquatic and terrestrial ecosystems. The leading factor of climate change is attributed to CO_2 accumulation in the atmosphere (IPCC, 2001).

The reductions of atmospheric CO_2 by artificial means are very expensive and so carbon sequestration by soils, oceans and plants turn out to be the simplest and most economically practical way to face the climate change crises (FAO, 2001). Terrestrial ecosystems play an important role in the global carbon cycle and hence modify the atmospheric CO_2 mixing ratio because they can act as carbon sink due to net carbon uptake during vegetation growth and as carbon source through land use

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changes, or deforestation or forest degradation (Schulze, 2006). Conversion from forests to agricultural and grazing lands and deforestation are examples of human induce land use change that lead to the increasing amount of CO_2 in the atmosphere (Shrestha et al., 2004). By the end of the 20th century, changes in land use and deforestation were responsible for the emission of over 498 Gt of CO_2 to the atmosphere, approximately half of which has been lost from soils (Lal, 1999; IPCC, 2000). Each tonne (tMg) of C stored in soils removes from the atmosphere about 3.67 tonnes of CO_2. The rate of increase in atmospheric carbon pool as a result of fossil fuel combustion and land use change at the start of the 21st century stood at 0.5% $year^{-1}$ (Lal, 2002).

Though photosynthesis by plants will convert atmospheric CO_2 into organic soil material, agricultural practices such as chemical spraying, tillage and burning may have an impact on the efficiency of plant conversion. further results in a decrease in soil organic matter. This is because microorganisms feed on crop residue and soil organic matter exposed by tillage, and readily converts the organic matter into CO_2 as end-product. When the soil is tilled, a "burst" of CO_2 is released into the atmosphere. Simultaneously, oxygen enters the soil and shifts the whole reaction process to enhance organic decomposition, which is an undesirable result (Jones et al., 2006).

The total global C-stock (organic and inorganic C) in terrestrial systems is estimated to be about 3,170 GT (where 1 GT = 1 petagram = 1 billion metric tons) out of which 2,500 GT is in the soil and 560 GT and 110 GT in plant and microbial biomass, respectively (Jansson et al., 2010). Soil C pool is 3.3 times the size of the atmospheric C pool (760 GT) but soil still has the capacity to hold much more (Lal, 2004). Soil C includes about 1,550 GT (62%) of soil organic carbon (SOC) and 950 GT (38%) of soil inorganic carbon (SIC), (Lal, 2008). Of the C present in the world's biota, 99.9% is contributed by vegetation and microbial biomass; animals constitute a negligible C-reservoir (Jansson et al., 2010). SOC constitutes approximately 60% of all soil organic matter (SOM) (Wilkes, 2005) correlated with productivity and defines soil fertility and stability (Herrick and Wander, 1998).

Adoption of appropriate crop management practices can yield considerable enhancements of the soil carbon pool. Lemus and Lal (2005) reported a model based on more than 50% of US cropland which predicted a 15% increase in SOC with reduced tillage practices, and 50% with no-till farming. A pan-tropical study in 52 tropical countries, suggested that reforestation practices could result in additional C sequestration of 56 GT by 2050 (Butcher et al., 1998). Globally, appropriate forest policies could increase the amount of C sequestered in terrestrial biomass by up to 100 GT, or up to 2 GT/year (Dahlman et al., 2001).

Soil organic carbon (SOC) has long been of interest to scientists, technical advisers and land managers, as an indicator of soil health. The link between the C cycle and global climate change is providing increased impetus for quantification and, ultimately, management. Few attempts have been made in Cameroon, to relate soil carbon pool with land use/management practices.

Mt Cameroon National Park (MCNP) is an area of dense forest and shrubs threaten by agricultural land use practices in the area, but even then, there have so far been no quantification studies of the soil carbon of this area. Quantifying the soil carbon will add more impetus to the conservation of the park and suggest better land use practices that will enable Cameroon to contribute positively, its quota in the reduction of atmospheric CO_2, while providing sufficient food yields to the locals. This study has as objective, to determine a baseline for SOC under different land use types in the southern parts of the MCNP, and to calculate CO_2 equivalents of SOC in each of these land use types. The working hypothesis is that changing from forest land use to cultivated agricultural land uses leads to significant changes in SOC.

MATERIALS AND METHODS

Study site

The Mt Cameroon region supports forests known to be of exceptional scientific, economic and social value, containing a great variety of endemic and endangered flora and fauna species, supplying many commercial and subsistence forest products, as well as providing valuable ecosystem services such as watershed protection (MINEF, 2006). The forest resources constitute an important asset supporting rural livelihoods for the approximate 300,000 people living within the area; however, the forest resources and high biodiversity are under threat from unplanned land use (MINEF, 2006). Land clearing for local farming and agro-business expansion, urbanization, and uncontrolled exploitation of forest resources are major practices in this region. The natural vegetation of this area ranges from evergreen lowland rainforest at sea level, through montane forest, to montane grassland and alpine grassland near its summit. The area is currently being threatened by increasing human populations but it is the most diverse ecosystem in Cameroon and presented as the 10th most conservable places in the world (IUCN, 1994). This link between ecosystems largely accounts for the biological diversity of the region.

Mt Cameroon lies on the coast, in the Gulf of Guinea, between 3°57' - 4°27' N and 8°58' - 9°24'E. It is a huge volcanic mass with its long axis (about 45 km long and 30 km wide) running SW to NE and the main peak is at 4°7'N, 9°10'E, at 4,100 m. Its western slope is probably the most diverse and richest area (MINEF, 2006). Soils on Mt Cameroon are principally of recent origin, mostly on young and older tertiary volcanic rocks, and are relatively fertile but often with poor water retention capacity (Payton, 1993). The soils are thus non allophanic Andosols and classify as Aluandic Andosols (leptic) by Yerima and Van Ranston (2005) based on the WRB system of soil classification.

Mt. Cameroon area has an equatorial climate of four seasons, as indicated by data from the weather stations across this area, over the past 11 years, from 2001- 2011. The dry season runs from December-February, dry-wet season from March-May, wet season from June-August and wet-dry season from September - November. This study is limited to the buffer zone in the southern parts of Mount Cameroon, that is, from Ekona through Likomba to Idenua

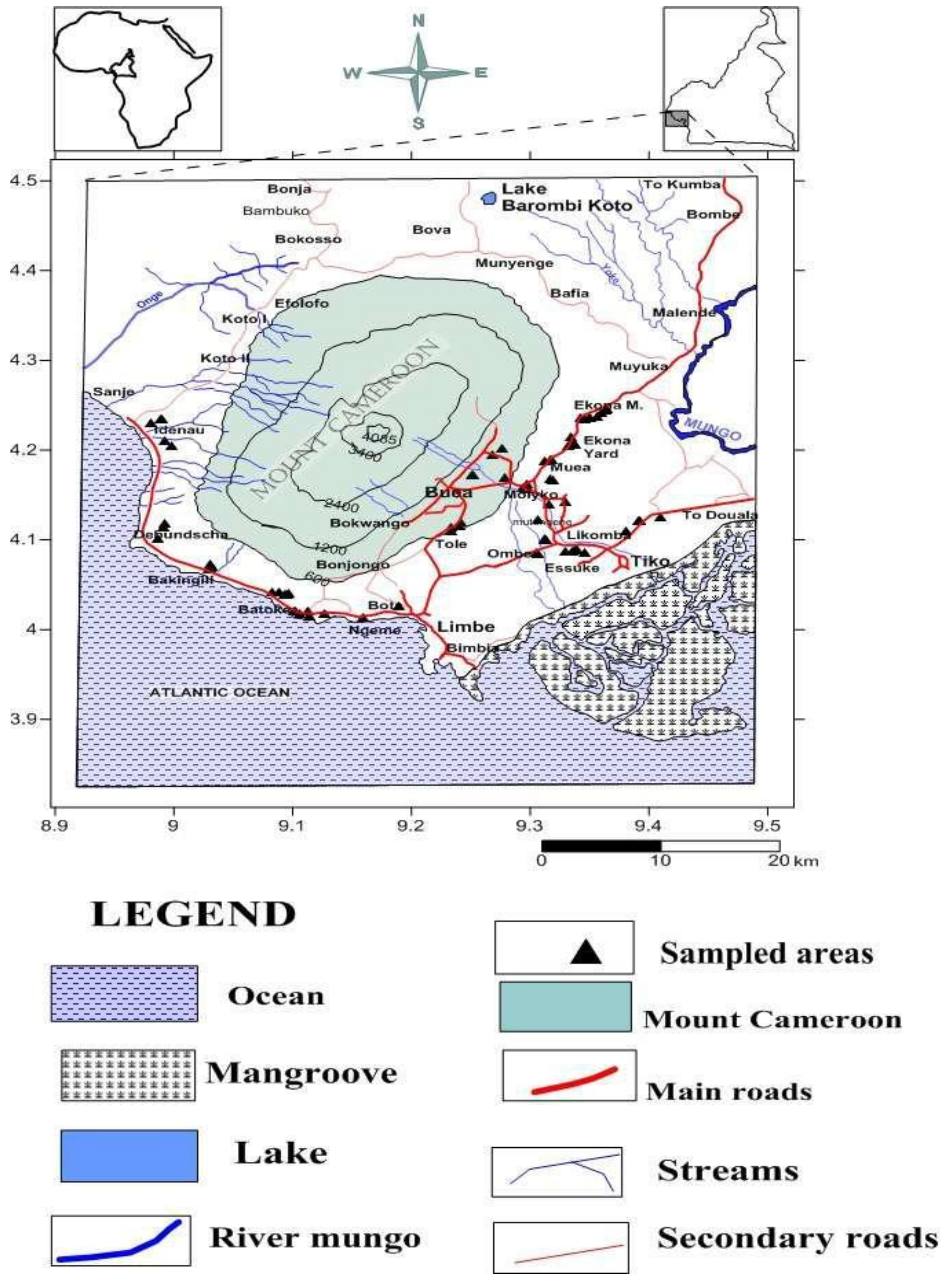

Figure 1. Map of Cameroon with the MCNP indicated and magnified to show the southern area of the park which is the study site.

(Figure 1). This is because of immense pressure from the local population as a result of agricultural and settlement land constraints, and also because the Cameroon Development Cooperation (CDC) has various plantation land concessions around this area. These factors are making land more scares for the rising local human population, making the population to exert more pressure on the forest which has been deserted as the MCNP and is being protected.

Table 1. Eleven-year average annual rainfall and temperature at various whether stations around the southern parts of the Mt. Cameroon National Park from 2001-2011.

Parameter	Temperature (°C)	Rainfall (mm)
Idenau	27.3	7410.4
Batoke	25.4	4971.2
Ekona	26.1	1685.4
Buea	25.1	2027.8
Likomba	27.2	1918.4

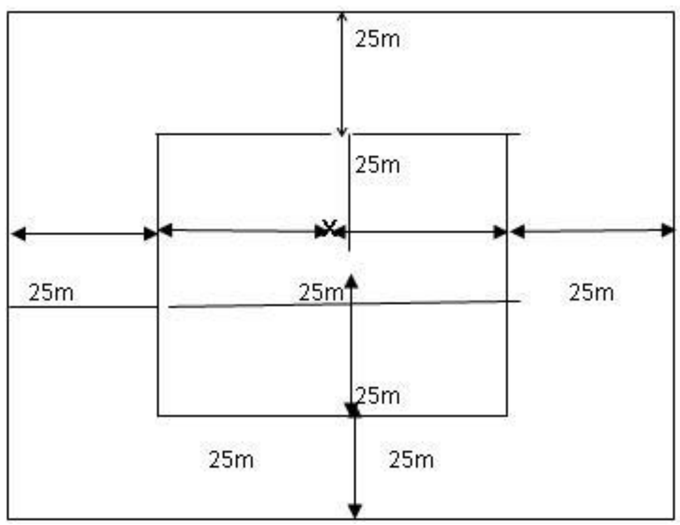

Figure 2. Layout of sample collection in selected land-use plots. Samples were collected at the Centre and at mid points from the centre to each side of the square (25 m from centre to each side of the square).

Land-use/management types in the southern part of the MCNP

In the study area, nine different land-use/management types were identified to be highly practiced. These included: cassava (*Manihot esculenta* Crantz) farms, maize (*Zea mays*) farms, banana (*Musa sapientum* Linn) farms, oil palm (*Elaeis guineensis* Jacq.) farms, mixed cropping systems (comprising of plantain, cocoa yams, maize, cassava and trees), tea farms, sugar cane farms, rubber farms and virgin forest areas. Oil palm had the largest farm area probably because large areas are required for its establishment (planted at least 9 m distance apart for better crop performance).

Most of the oil palm, rubber and banana are owned by the Cameroon Development Corporation (C.D.C.), who have land consensus for such large demarcated areas to cultivate these economic crops. The tea estate is a whole area demarcated for sole cropping of tea for commercial purposes. Cash crops like sugarcane; maize, mixed cropping; and cassava were cultivated by the locals and were characteristically smaller in farm size probably due to the enclaved nature of most of the villages which makes transportation to and from the market very difficult. Another reason could be that the local farms are used to provide basic family needs but not for commercial purposes. The type of farming method employed by indigenous people and farmers in establishing their farms is of importance to the Mt. Cameroon forest. This is because land use changes are a major factor to ecosystem degradation and habitat loss. Initially, the farmers apply slash and burn to convert from the forest to the desired land-use type. After that, there is spraying with chemicals at the beginning of each planting season to control weeds, diseases and pest. This greatly affects the ecosystem of the MCNP and the soil microorganisms.

Selection of land-use/management types

A transect was drawn across the study area, from which five major villages were selected for sample collection, based on microclimatic difference (Table 1 and Figure 1). The prominent land-use types were selected in each village base on land use history of at least 5 years. Four of the nine land use types were found in all five villages (virgin forest, maize, mixed cropping and oil palm), one was found in four villages (cassava), two in two villages (banana and rubber), and two in just one village (tea and sugar cane). All the land use types selected were under no tillage and non-fertiliser application management system. This is due to the fact the soils in this area are basaltic volcanic soils very fertile and result in high yields even without application of fertilisers. There is high application of pesticides and herbicides to kill pest and grass.

Soil collection

In each selected land use type, a plot of 0.25 ha was chosen and samples were collected from 0 to 30 cm depth (Figure 2) with the aid of a soil auger. The five samples from each plot were later mixed to form a composite sample for that plot. Three plots were chosen, for every land use type, in each of the five villages, giving rise to 90 samples. These samples were air dried and sieved through a 2 mm screen. In all five villages, the three samples from each village (corresponding to one land use type) were bulked to give a composite sample for that land use type. This resulted now to 30 experimental replications for analysis. Samples for bulk density were collected separately following dimensions of the hand auger and depth of soil collection.

Analysis of samples

The parameters analysed included the following: pH, bulk density (BD), cation exchange capacity (CEC), weatherable elemental ions (Ca^{2+}, Mg^{2+}, Al^{3+}, K^{+}, Na^{+}, etc.), available P, total N and SOC content. They were sent to the Institute for Agricultural Research and Development (IRAD), Ekona for analyses as previously used by Djomo et al. (2011). Organic carbon (OC) was determined following the method described by Walkley-Black (1934). Soil organic carbon (SOC) pool and total SOM was estimated using the conversion formula given by Wairiu and Lal (2003):

$= \% \times \rho \times$

Where: C% is the weight percentage of carbon in the soil depth, ρ is the bulk density of the soil in Mgm^{-3} and V the volume (m^3) of soil per hectare.

$= \quad \times .$

To estimate the amount of CO_2 equivalence being held in the soil from the atmosphere, the ratio of 12 g of C : 44 g of CO_2 was used, based on mass of carbon in the molar mass of CO_2. Deterioration

Table 2. Mean values of sand, silt and clay for the various land use types in the southern parts of MCNP.

Land-use type	Sand (%)	Silt (%)	Clay (%)	Textural type
Banana	52.19	26.50	21.32	Sandy clay loam
Cassava	37.54	39.06	23.39	Loam
Forest	46.65	27.72	25.63	Loam
Maize	35.64	36.41	27.95	Clay loam
Mixed cropping	45.17	34.15	20.66	Loam
Oil palm	41.21	31.95	26.84	Loam
Rubber	50.95	22.35	26.70	Sandy clay loam
Sugar cane	46.45	24.90	28.64	Clay loam
Tea	58.51	24.90	28.64	Sandy clay loam

index (DI) was applied according to Awotoye et al. (2011) to compute the rate of deterioration of the soil properties to those of the forest in the study.

$$\mathbf{DI} = \frac{\ddot{X} -}{\ddot{x}}$$

Where: $\ddot{X}$ = mean value of soil parameter in forest site, while X_i = mean value of soil parameter in compare site (mixed cropping, maize, cassava, banana, oil palm, rubber, tea and sugar cane).

Statistical analysis

Results from the laboratory were all keyed into Microsoft Excel 2010 and computed into secondary parameters (mean, standard deviation and standard error) to facilitate comparison between soil properties. These parameters were imported to SPSS 17 and R i3862.15.2 statistical packages to test for significant differences, compute box plots and inferential statistics. A one way ANOVA was carried out to test the level of significance between SOC of the different land-use practices for cases where the number of samples (N) is greater than two, while an independent sample t test was used for cases where the number of samples is exactly two.

RESULTS

Soil properties

Soil bulk density, texture and pH

Particle size analysis revealed variability in the textural properties in the soils of the land use types. The soils of all the land use types were generally loamy. Banana, rubber and tea farm, land use types revealed a sandy clay loam textural type, while the rest were purely loam (Table 2).

Bulk density values ranged from 1.15 (maize) to 2.9 g/cm^3 (rubber) with no significant differences among the BD values of the different land uses at α = 0.05 (Table 3). The values were however, higher in forest and continuous cultivated lands (rubber, palm, tea, cassava, banana and sugarcane).

Mean soil pH ranged from 3.8 (tea) to 4.87 (forest); however, the pH values did not differ significantly among different land uses (α = 0.05).

Soil organic matter content

The highest and lowest SOC values were encountered in forest (5.92%) and rubber land uses, respectively (1.45%). Soil fertility values (OC, total N and average P) are generally high with significantly difference recorded between available P of forest and maize at α = 0.05 (Table 3). Table 3 also reveals that the highest CEC and moisture content values were found in forest and the least in rubber.

Table 4 shows the index of deterioration of the soil properties under the various land uses from forest. Deterioration indices of SOC, CEC and total nitrogen contents were highest in the soils of sole cultivated plantations, while available P was highly degraded under mixed cropping land but more than rubber and oil palm soils (Table 4).

Soil carbon dynamics

The mean SOC density in kgC/m^2 ranged from 5.61±1.10 for rubber land-use to 22.53±3.36 for forest land-use (Table 5) and the range of values in each land use are shown in Figure 3. Mean total SOC in t/ha for 30 cm depth gave a maximum 225.24±33.65 t/ha for forest and a minimum of 56.1±11.00 t/ha for rubber giving an average for the area of 130.80 t/ha (Table 5). Total average soil organic matter (SOM) in t/ha for the 0-30 cm depth for the land-use systems ranged from 99.86±19.58 t/ha in Rubber land-use to 401.28±59.89 t/ha in forest landuse (Figure 4). Estimated amounts of CO2 equivalence from the SOC values in each land-use type revealed highest values of 826.63±123.37 t/ha by forests and lowest values of 205.89±40.33 t/ha by rubber plantations (Table 5).

Comparison of SOC density (kgC/m^2) for various land-use types (cassava, maize, banana, mixed cropping, rubber and oil palm,) against forest using one way ANOVA test, revealed that SOC for forest is significantly higher than for cassava, oil palm, and rubber at α = 0.05 (Table 6). SOC for forest had a mean value of 22.53 kgC/m^2 with N=5. SOC for mixed cropping was also found to be significantly higher than rubber (p=0.013, df=5).

Table 3. Mean values of soil properties (physical and chemical).

Land use types	Moisture (%)	BD (g/cm^3)	OC (%)	Total N (%)	C/N	Av. P (mg/kg)	pH $CaCl_2$	Na^+ (cmol/kg)	K^+ (cmol/kg)	Mg^{2+} (cmol/kg)	Ca^{2+} (cmol/kg)	Al^{3+} (cmol/kg)	CEC
Banana S. E.	10.86 2.61	1.22 0.03	3.63 1.11	0.39 0.13	9.50 0.05	62.50 23.50	4.42 0.28	0.04 0.01	0.96 0.56	3.41 1.63	4.12 2.13	0.25 0.13	24.18 7.92
Cassava S. E.	12.03 1.91	1.23 0.05	2.94^{b} 0.68	0.38^{c} 0.07	8.75 1.11	39.00^{c} 8.87	4.60 0.18	0.03 0.00	0.86 0.18	2.36 0.67	3.21 0.88	0.27^{c} 0.06	23.57 6.10
Forest S. E.	14.43 1.34	1.27 0.064	5.92 0.86	0.72 0.17	9.20 1.16	17.80 4.53	4.87 0.19	0.03 0.004	0.81 0.135	2.61 0.60	3.88 0.866	0.13 0.02	37.30 8.06
Maize S. E.	12.96 1.74	1.15^{c} 0.03	4.20 0.78	0.50 0.11	8.75 0.48	38.80^{b} 8.16	4.85 0.09	0.03 0.003	0.81 0.04	2.54 0.43	3.95 0.39	0.17 0.03	23.24 4.34
Mixed cropping S. E.	13.11 1.79	1.21 0.02	4.48 0.75	0.59 0.10	7.60 0.40	33.00 11.67	4.75 0.17	0.03 0.003	0.95 0.33	2.701 1.02	3.71 1.21	0.15 0.03	29.19 4.57
Oil palm S. E.	11.88 1.31	1.17 0.05	3.46^{b} 0.66	0.40^{c} 0.08	8.80 0.73	30.80^{c} 5.60	4.55^{c} 0.11	0.03 0.003	0.46^{b} 0.10	1.53^{c} 0.19	2.59 0.31	0.27^{c} 0.06	19.83^{b} 3.06
Rubber S. E.	5.47^{b} 1.22	1.29 0.01	1.45^{b} 0.33	0.26^{b} 0.04	8.50 0.50	17.00 8.00	4.41 0.61	0.02^{c} 0.00	0.34^{b} 0.06	1.54 0.48	2.46 0.81	0.59 0.29	12.56^{b} 2.69
Sugar cane	11.21nd	1.22nd	2.39nd	0.32nd	7.00nd	54.00nd	4.57nd	0.03nd	1.55nd	3.08nd	4.76nd	0.78nd	16.31nd
Tea	12.94nd	1.25nd	3.72nd	0.70nd	5.00nd	54.00nd	3.80nd	0.03nd	0.38nd	1.13nd	1.38nd	0.76nd	36.51nd

b = Significantly different from control (forest) at α=0.05, c = significantly different from control (forest) at α= 0.1, nd= not determine (this is because one way ANOVA compares data with more than two values, but sugarcane and tea were located in just one of the five villages, hence had just single values).

DISCUSSION

Plot design

Research relating to carbon estimations are often associated with uncertainties that need due consideration to minimize them. The first source of errors is plot design and the method in which it is establish. The probability of errors in results decreases with increasing plot size (Keller et al., 2001). The minimal plot size for biomass estimations including SOC as stated by Chave et al. (2004) is one quarter of a hectare. Plot sizes below this are associated with large error proportions. The plots used in this study were exactly 0.25 ha, large enough to minimize large errors.

Another source of uncertainty are the environmental and physical factors including topography, vegetation types and climatic gradients, which can create serious bias on SOC estimates (Chave et al., 2004). The plots were located based on climatic, topographic and land cover variations to minimize these errors and get a true homogenous sample for the area.

Soil properties

Soil bulk density, texture and pH

Land use types affect soil texture characteristics which in turn affect the fertility status of a field (Yao et al., 2010). The variation recorded in the soil texture of these land uses from the results agrees with the fact that land use types can be

Table 4. Deterioration indices (DI) in percentages of some soil properties.

Soil properties (%) / Land use types	Moisture	Bulk density	Total nitrogen	Organic carbon	pH	Available phosphorus	CEC
Banana	24.7	3.9	45.8	38.7	9.2	-251.1	35.2
Cassava	16.6	3.2	47.2	50.3	5.5	-119.1	36.8
Maize	10.2	9.4	30.5	29.1	0.004	-118.0	37.7
Mixed cropping	9.2	4.7	18.1	24.3	2.5	-85.4	21.7
Oil palm	17.7	7.8	44.4	41.6	6.6	-73.0	46.7
Rubber	62.1	-1.6	63.9	75.5	9.5	4.5	66.3
Sugar cane	22.3	3.9	55.5	61.2	6.2	-203.4	56.3
Tea	10.3	1.6	2.8	37.2	22.0	-203.4	2.1

Values above 50% show high deterioration and negative indices for bulk density depict highly compacted.

Table 5. Soil carbon dynamics for the various land-use types around MCNP.

Land use types ± S.E	SOC Den (kgC/m^2)	TOC (t/ha)	SOM (t/ha)	CO_2 Eq. SOC (t/ha)
Banana	13.15 ± 3.72	131.68 ± 37.2	234.43 ± 66.22	483.27 ± 136.40
Cassava	10.77 ± 2.95	107.72 ± 29.49	191.62 ± 52.49	395.33 ± 108.12
Forest	22.53 ± 3.36	225.24 ± 33.65	400.96 ± 59.89	826.63 ± 123.37
Maize	14.64 ± 2.89	146.40 ± 28.87	260.55 ± 51.40	537.29 ± 105.87
Mixed cropping	16.14 ± 2.54	161.44 ± 25.43	287.29 ± 45.27	592.48 ± 93.26
Oil palm	12.16 ± 2.79	121.60 ± 27.89	216.41 ± 49.64	446.27 ± 102.25
Rubber	5.61 ± 1.10	56.10 ± 11.00	99.86 ± 19.58	205.89 ± 40.33
Sugar cane*	8.75	87.48	155.71	321.05
Tea*	13.95	139.52	248.35	512.04

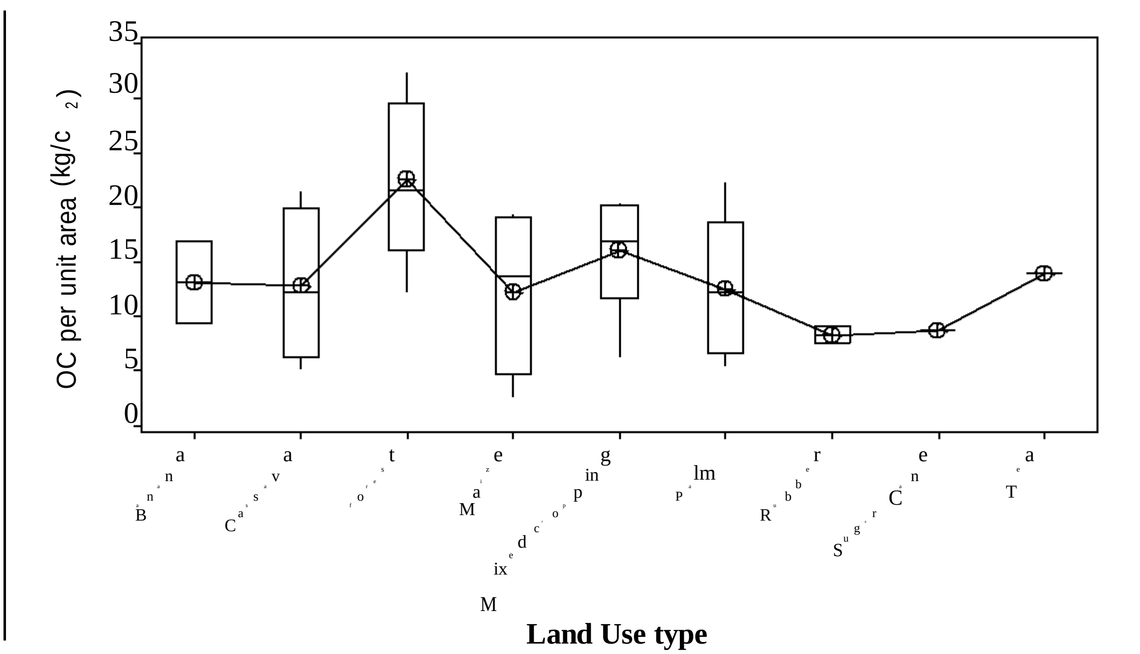

Figure 3. Box plots of OC showing range of C in each land-use and their mean on the southern part of the MCNP. Sugarcane and tea are not in boxes because there were only single values for them. The points in the boxes represent the mean values while the boxes represent the range of the values.

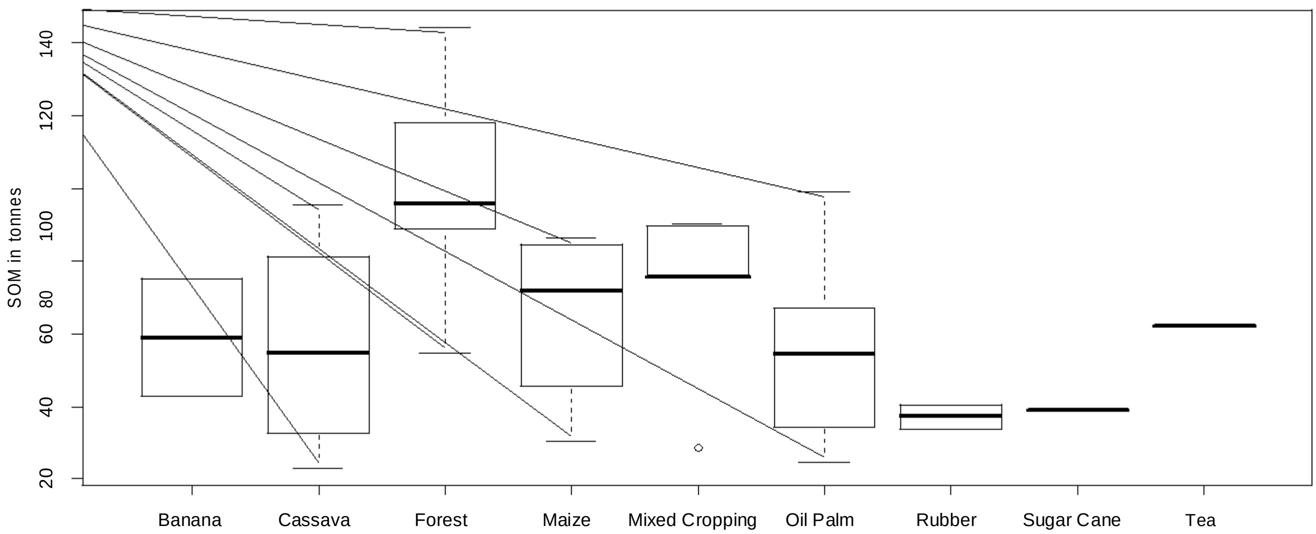

Figure 4. Total SOM values for the different land-uses in the southern parts of the MCNP.

Table 6. One way ANOVA results for SOC between forest and the other land-uses.

Land-use	Mean SOC	Df	p-value
Banana (N=2, t=1.638)	13.17	5	0.0.2430
Cassava (N=4)	10.77	7	0.0381*
Maize (N=4)	14.64	7	0.0600
Mixed cropping (N=5)	16.14	8	0.1686
Oil palm (N=5)	12.16	8	0.0451*
Rubber (N=2, t=4.849)	5.61	5	0.0046*

*Significant at α=0.05.

shown by Omotoso and Akinbola (2007) even though no significant differences were found between forest texture and any of the land uses. The higher BD values revealed in forest and the cultivated lands are in accord with those of Sahani and Behera (2001) and Hajabbasi et al. (1997), who also reported higher BD in deforested and continuously cultivated lands. The BD values increased from maize to forest exempting rubber which is in line with the work of Murphy et al. (2004). This could be as a result of heavy illegal logging in the forest which may be responsible for compaction of soil particles and resulting in higher bulk densities. Since the soils had high clay content, it is possible that particles will compress and compact easily with the movement of this logging equipment. However, this trend could be further researched on to reveal the detailed reason for this increase from other land uses to forest.

The low variability in pH (3.8 to 4.87) across all land use types indicates that the pH is uniform or homogenous in the study area. This agrees with the work of Omotoso and Akinbola (2007). This homogeneity can be attributed to the management practices by farmers where use of chemical fertilizers is almost non-existence in the area. The more acidic nature of soils under banana, rubber, oil palm, and tea indicates the effects of some spraying with chemicals on these land uses. This acidic nature of the soils under cultivated land is in conformity with the findings of Ndukwu et al. (2010) whose results revealed low pH for soils under continued cassava and oil palm cultivation.

Soil organic matter content

There were high differences in SOC across the different land use types. According to research, these differences in SOC distribution depend on large scale factors at regional climate, vegetation, soil type and topography (Wang et al., 2010; Wiesmeier et al., 2013). In the study, samples were collected following the different microclimates and at various elevations of the area to get a homogenous sample for each land use. The study area is relatively small and made of single soil type, as such, these variables could be overlooked. Hence, this conforms to the assumption that land use type patterns will largely contribute to any significant differences in SOC content (Su et al., 2006).

The SOC range of 2 to 6% are slightly less than the results of Sieffennan (1973), which stood at 4 to 8% SOC on the volcanic soils at the base of Mt. Cameroon. Lower values in this study are probably due to increased land-use changes and cultivation practices by the growing populations. These activities open up the soil to the atmosphere and increase the breakdown of SOM to yield CO_2.

Soil fertility (SOC and total N) values were highest in forest, mixed cropping, maize, tea, banana, oil palm, cassava, sugarcane and rubber in that order with significant differences between forest; and cassava, oil palm and banana at $p < 0.05$ (Table 3). Higher soil fertility under forest is possibly due to the higher accumulation and decay of leaf litter and roots within the forest than the cultivated lands in accordance with Awotoye et al. (2011). The observed losses of SOC and N in the cultivated land uses could also be attributed to rapid mineralization of SOM following cultivation, which disrupts soil aggregates, and thereby increases aeration and microbial accessibility to organic matter (Solomon et al., 2000). Another possible reason for lower soil fertility in the cultivated lands could be the lack of understory vegetation in the land uses which leaves the soil exposed and vulnerable to erosion that washes away topsoil nutrients (Boley et al., 2009).

Considering the critical value for phosphorus in soils (around 15 mg/kg for Bray-II), all these land-use types are rich in phosphorus, indicating the good soil quality of the zone and making the area suitable for agriculture. The higher average P values in the cultivated land uses (except rubber) than in the forest are probably due to higher input of organic manure. This is in accord with the results of Shrestha et al. (2007) who also attributed higher values of P in Bari soils to application of organic manure and chemical fertilizers.

The soil deterioration index revealed that soils under sole plantations are the most degraded except for P where mixed cropping is degraded more than some sole plantations. This could be the case because P is needed in large amounts for healthy plant growth as such can be easily depleted in mixed cropping where we have diversity of plants.

Soil carbon dynamics

This research goal is to set a baseline for SOC stocks in the area. Setting the baseline is important for future SOC stock estimation and comparing the C sequestration potential of various land use systems. In Cameroon, a national SOC database is not available and this could limit the country's ability to access funds from the Clean Development Mechanism (CDM) as proposed under article 12 of the Kyoto Protocol of the UNFCCC. This implies that SOC density estimation at local levels could serve as a starting point for large scale estimations and help provide some accuracy for a national SOC data.

Soil carbon density ranged from 5.6±1.10 (rubber) to 22.53±3.36 kg/m^2 (forest) and is a key indicator for SOC stock estimation. Average SOC pool (130.8 t/ha) for the area studied was higher than the value of 101 mg/ha obtained during the study of Djomo et al. (2011) for below-ground carbon over different vegetation types and land uses of a moist evergreen forest. The SOC stock range from 56.1±11.00 (rubber) to 225.24±33.65 t/ha (forest) was higher than those of Nasi et al. (2009) in their compilation of SOC from various sources and ecosystems in the Congo basin obtained with a mean value of 38 t/ha (range 35 to 82 t/ha).This higher SOC stock could be explained to be the result of basaltic volcanic soils, rich in SOM of the study area.

Forest system showed the highest organic C stocks, followed by mixed cropping, maize, tea, banana, oil palm, cassava, sugarcane and rubber in that reverse order. The significant difference observed in SOC density of forest from those of rubber, oil palm and cassava ($p < 0.05$) (Table 6) is an indication that SOC pool changes in response to changes in land use or land management practices. This is because the conversion of forest land to cultivated land increases mineralisation in soils, leading to SOC decline and consequently soil degradation (Lal, 2003, 2004). In the forest, land use with highest SOC stock, was also recorded the highest moisture content and cation exchange capacity (CEC). High moisture content and CEC might explain this high SOC found in forest, since moisture and CEC play an important role in the determination, mineralization rates and conservation of SOM in the soils.

Soils under mixed cropping follow those under forest in SOC content as was expected because plant species diversity is known to enhance SOC (FAO, 2001). This is probably due to diversity in residue that decays directly into the soil. Soils under maize follow as the first in single crops. This was probably because farming practices in the study area are such that maize plants stems are left standing in the farms after harvest (and are later ploughed in or buried in the ridges) to degrade and become humus. This kind of activity will enhance the SOC.

Conclusions

The land use types identified in this study are not exhaustive of the area. There are others, such as tomatoes and other garden crops, cocoa and other mixed cropping systems. These were not considered because of lack of information on the various farm practice carried out during their cultivation. Values of SOC for tea and sugarcane were not used during the comparison for significant differences with forest. This is because each of these land use types was found in only a single village.

The potential ability to sequester carbon in the soils as SOC was found to be in the order: forest > mixed cropping > maize > tea > banana > cassava > oil palm > sugar cane > rubber. This trend reflects the current management practice. The forest here is part of the MCNP, which is protected by forest guards who enforce law by preventing human activities and illegal cuttings. Even then, there are still some signs of human activities in some areas. Agro-forests (here referred to as a mixed cropping system) are currently an open access area, where the uses vary from illegal cutting to clear cutting for agriculture.

Cassava, oil palm and rubber land-use systems indicated significantly lower amounts of SOC, an indication that these land use types are detrimental to SOC sequestration and possibly contributing to rising levels of atmospheric CO_2. Rubber land-use systems were found to be exceptionally poor in SOC and highly degraded in other soil properties. The rest of the land-use systems contained reasonable amounts of SOC, which could be improved through better soil management practices such as the use of organic manure. The CO_2 equivalent held by soils of these land-uses types follow the same order as SOC, with forest having the highest value and rubber the least. The significant difference between virgin forest, and rubber, cassava and palm proves that forest conservation is important and needed, if the fight against climate change is to be faced. This therefore gives additional reasons for the protection of the MCNP (for the forest helps to hold reasonable amounts of CO_2 in the soil in the form of SOC).

Conflict of interest

The authors have not declared any conflict of interest.

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REFERENCES

Awotoye OO, Ogunkun CO, Adeniyi SA (2011). Assessment of soil quality under various land use practices in a humid agro-ecological zone of Nigeria. Afr. J. Plant Sci. 5(10):565-569.

Boley DJ, Drew AP, Andrus RE (2009). Effects of active pasture, teak (*Tectona grandis*) and mixed native plantations on soil chemistry in Costa Rica. For. Ecol. Manag. 257:2254-2261.

Butcher PN, Howard JM, Regetz JS, Semmens BX, Vincent MA, Denning AS, Keller AA (1998). Evaluating the carbon sequestration potential of tropical forests. Donald Bren School of Environmental Science and Management, University of California, Santa Barbara.

Butler RA, Koh LP, Ghazoul J (2009). REDD in the red: Palm oil could undermine carbon payment schemes. Conserv. Lett. 2(2):67-73.

Chave J, Riéra B, Dubois MA (2001). Estimation of biomass in a neotropical forest of French Guiana: Spatial and temporal variability. J. Trop. Ecol. 17:79-96.

Dahlman RC, Jacobs GK Metting FB Jr (2001). What is the potential for carbon sequestration by the terrestrial biosphere? First National Conference on Carbon Sequestration. Washington, D.C.; www.netl.doe.gov/publications/proceedings/01/carbon_seq/5c0.pdf. Retrieve June 30, 2010)

Djomo AN, Knohla A, Gravenhorst G (2011). Estimations of total ecosystem carbon pools distribution and carbon biomass current annual increment of a moist tropical forest. Elsevier. For. Ecol. Manag. 261:1448-1459.

FAO (2001). Soil carbon sequestration for improved land management. World Soil Resources Report. 96. Rome

Hajabbasi MA, Jalalian A Karimzadeh HR (1997). Deforestation effect on soil physical and chemical properties, Lordegan, Iran. Plant Soil 190:301-308.

Herrick JE, Wander MM (1998). Relationships between soil organic carbon and soil quality in cropped and rangeland soils: The importance of distribution, composition and soil biological activity. In: Lal R, Kimble J, Follett R and Stewart BA, eds. Advances in soil science: Soil processes and the carbon cycle. pp. 405-425. Boca Raton, Florida, USA, Lewis Publishers, CRC Press.

IPCC (2000). Land use, Land-use change, and forestry. Watson R.T. ed. Special Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, USA, Cambridge University Press. 377pp.

IPCC (2001). Third Assessment Report 2001. Cambridge, UK, Cambridge University Press. (http://www1.ipcc.ch/ipccreports/tar/vol4/english/index.htm, accessed August 2011).

IUCN (1994). International Union for Conservation of Nature, Red list Categories IUCN. Species Survival Commission, Gland Switzerland.

Jansson C, Wullschleger SD, Kalluri UC Tuskan GA (2010). Phytosequestration: Carbon biosequestration by plants and the prospects of genetic engineering. American Institute of Biological Sciences. Bioscience 60:685-696.

Jones SK, Rees RM, Kosmas D, Ball BC, Skiba UM (2006). Carbon sequestration in a temperate grassland: Management and climatic controls. Soil Use Manag. 22:132-142.

Keller M, Palace M, Hurtt G (2001). Biomass estimation in Tapajos National Forest Brazil examination of sampling and allometric uncertainties. For. Ecol. Manage. 154:371-382.

Lal R (1999). Global carbon pools and fluxes, and the impact of agricultural intensification and judicious land use. In: Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable land management with a focus on Latin America and the Caribbean. World Soil Resources Report. 86. FAO, Rome. pp. 45-52.

Lal R (2002). Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degrad. Dev. 13:45-59.

Lal R (2003). Global potential of soil carbon sequestration to mitigate the greenhouse effect. Crit. Rev. Plant Sci. 22:151-184.

Lal R (2004). Soil carbon sequestration to mitigate Climate Change. Geoderma. 123:1-22.

Lal R (2008a). Carbon sequestration. Philos. Trans. R. Soc. 363:815-830.

Lemus R, Lal R (2005). Bioenergy crops and carbon sequestration. Crit. Rev. Plant Sci. 24: 1-21.

MINEF (2006). Draft Management Plan for the Mt. Cameroon National Park. Ministry of Forestry and Wildlife, Cameroon.

Murphy CA, Foster BL, Ramspott ME, Price KP (2004). Grassland management effects on soil bulk density. T. Kansas Acad. Sci. 107(1-2):45-54.

Nasi R, Mayaux P, Devers D, Bayol N, Eba'a Atyi R, Mugnier A, Cassagne B, Billand A, Sonwa DJ. (2009). Un apercu des stocks de carbone et leurs variations dans les forêts du Bassin du Congo. Office des publications de l'Union Européenne, Luxembourg. pp. 199-216.

Ndukwu BN, Idigbor CN, Onwudike SU Chukwuna MC (2010). Evaluation of the effects of selected land utilization types on soil properties in Nando, south eastern Nigeria. ISSN 2079-2107

Omotoso SO, Akinbola GE (2007). Variability of Soil Properties at transitional zone between two parent materials in S. W. Nigeria. Int. J. Soil Sci. 2(3):218-223.

Payton RW (1993). Ecology, altitudinal zonation and conservation of tropical rainforest of Mount Cameroon. Final Project Report R4600. ODA, London, Mount Cameroon Project, P 70.

Sahani U, Behera N (2001). Impact of Deforestation on Soil Physicochemical Characteristics, Microbial Biomass and Microbial Activity of Tropical Soil. Land Degrad. Dev. 12:93-105.

Schulze ED (2006). Biological control of the terrestrial carbon sink. Biogeosciences 3:147-166.

Shrestha BM, Sitaula BK, Singh BR, Bajracharya RM (2004). Soil

organic carbon stocks in soil aggregates under different land use systems in Nepal. Nutr. Cycl. Agroecosyst. 70:201-213.
Shrestha BM, Singh BR, Sitaula BK, Lal R, Bajracharya RM (2007) Soil aggregate- and particle-associated organic carbon under different land uses in Nepal. Soil Sci Soc Am J 71(4):1194–1203
Sieffennan G (1973). Les sols de quelques régions volcaniques du Cameroon: variations pédologiques et minéralogiques du milieu équatorial au milieu tropical. Mém. ORSTOM 66, 183pp.
Solomon D, Lehmann J, Zech W (2000). Land use effects on soil organic matter properties of chromic Luvisols in the semiarid tropics: Carbon, nitrogen, lignin and carbohydrates. Agric. Eco. Environ. 78:203-213.
Su ZY, Xiong YM, Zhu JY, Ye YC, Ye M (2006). Soil organic carbon content and distribution in a small landscape of Dongguan, South China. Pedosphere 16:10-17.
Wairiu M, Lal R (2003). Soil organic carbon in relation to cultivation and topsoil removal on sloping lands of Kolombangara, Solomon Islands. Soil Till. Res. 70(1):19-27.
Walkley A, Black IA (1934). An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 63:251-263.
Wang Z M, Zhang B, Song KS, Liu DW, Ren CY (2010). Spatial variability of soil organic carbon under maize monoculture in the Song-Nen Plain, Northeast China. Pedosphere 20:80-89.
Wiesmeier M, Prietzel J, Barthold F (2013). Storage and drivers of organic carbon in forest soils of southeast Germany (Bavaria) - Implications for carbon sequestration. For. Ecol. Manag. 295:162-172.
Wilke BM (2005). Determination of chemical and physical soil properties. In: R Margesin and F Schinner, (eds). Manual for soil analysis: Monitoring and assessing soil bioremediation. 16:72. Berlin, Heidelberg, Springer. P 366.
Yao MK, Angui PKT, Konaté S, Tondoh JE, Tano Y, Abbadie L, Benest D (2010). Effects of land use types on soil organic carbon and nitrogen dynamics in mid-west Cote d'Ivoire. Eur. J. Sci. Res. 40:211-222.
Yerima BPK, Van Ranst E (2005). Major Soil Classification System Used in the Tropics: Soils of Cameroon. Trafford Publication, Victoria.