Environtropica, August 2014, Vol. 11, 43-49 ISSN 1597-815X

Carbon Sequestration Potential of Tropical Forest Soils

✉[1]Jackson, O. I.; [1]Adeyemi, A. A.; [1]Odeleye, O. A.; [1]Amoo V. O.;
[2]Amujo, O. S. and [2]Abiodun F. O.

[1]*Environmental Modelling and Management Department, Forestry Research Institute of Nigeria, Jericho, Ibadan.*
[2]*Sustainable Forest Management Department, Forestry Research Institute of Nigeria, Jericho, Ibadan*
✉*Corresponding author: mail2oyeen@yahoo.com*

Accepted on June 3, 2014

Abstract

World's soils are under increasing pressure to meet the demands for food, water and energy, leading to loss and degradation of land resources. This study therefore aims to access the carbon sequestration capacity of tropical forest soils in order to convince all stakeholders (i.e. land-owners, policy makers and others) the importance of sustainable management of soils and forest resources. To achieve this, soil samples (0-15cm) were randomly collected from stands of tree species from Onigambari Forest Reserve, Ibadan South-Western, Nigeria. These samples were analysed for bulk density, pH, soil organic carbon (SOC), soil organic matter (SOM) and total nitrogen (TN) contents. The mean values for the pH, bulk density (g/cm^3), SOM (%), SOC (t/ha C) and TN (%) were 6.44 ± 0.75, 1.51 ±0.20, 3.12 ±1.31, 34.92 ±8.75 and 0. 18 ±0.08 respectively. Bulk density (g/cm^3) was shown to be strongly related to SOC (t/ha C) (r =0.873). The amount of organic carbon stored in the soil is governed by SOC concentration (%) and bulk density, therefore management practices that will improve bulk density and SOC concentrations are important. It was observed in this study that forest soils are important sink of carbon, thus if current trends of rapid and unprecedented change in land use to meet demands for food, water and energy continue, there will be rapid loss of soil organic carbon to the atmosphere in years to come. This will not only exacerbate climate change, but also increase the extent of soil degradation as well as diminish a wide range of important ecosystem services. Strategies that therefore encourage carbon sequestration in soils, which include protection of existing forests to preserve current soil carbon stocks, re-afforestation of degraded lands and the use of soil amendments should be adopted to ensure sustainable management of land resources.

Key words: soils, organic carbon, sequestration, forest.

Introduction

Forest ecosystems store carbon in different components including the biomass and soil. Under the Kyoto Protocol, carbon sequestration in forest soils can be used to mitigate greenhouse gas emissions hence climate change. Forests ecosystems store carbon (C) in different components including the vegetation and soils. The total forest cover is 30 percent of the world's land cover hence forests plays a significant role in the global C cycle (Lal, 2005). Globally, forest vegetation and soils contain 359 and 787 pentagrams of C, respectively for a total of 1146 Pg C (Dixon *et al.*, 1994). There are three main forest biomes which are boreal, temperate and tropical forests. Tropical forests have been found to store in soils C that range from 50% to 75% of the total forest C (Fonseca *et al*., 2011). Plants transform atmospheric carbon dioxide (CO_2) into sugars, plant fibre and other materials in the process of photosynthesis and when these plants die, CO_2 is released to the atmosphere. The soil C pool is determined by the C input by litterfall and rhizodeposition and the release of C during decomposition (Jandl *et al*., 2007).

Soil organic matter (SOM) is formed by the biological, chemical and physical decomposition of organic materials such as leaf litter, crop residues, animal wastes, roots and soil biota. Soil organic carbon (SOC) is the main form of C in the soil and also the main constituent of SOM (UNEP, 2012). SOC stock is important as it holds water and nutrients, decreases risks of erosion and degradation, improves soil structure as well as providing energy to soil microorganisms (Lal, 2004). The loss of soil C can lead to higher concentrations of atmospheric CO_2 through increased soil C oxidation, loss of soil functioning and biodiversity. When soil C is lost, there is reduced cohesion between soil particles, which leads to increased susceptibility of soil to water or wind erosion hence increases loss of bulk soil and alters water cycling. In turn, this can lead to increased overland flow, which exacerbates flooding and reduces groundwater recharge during rain events. Reduced groundwater recharge leads to water shortage and drought conditions (UNEP, 2012). Also, soil nutrients are lost when soil C are lost.

The concentration and amount of SOC in forest soils are dependent on some factors such as climate, soil and landscape, as well as natural and anthropogenic factors (Lal, 2005; Jandl *et al*., 2007). Precipitation and potential evapotranspiration (PET) are important climatic parameters and the ratio between PET and annual precipitation referred to as PET ratio affects the forest C stock such that C sequestration increases with decreasing PET ratio (Lal, 2005). Landscape position influences soil water regime, hence SOC stock. For instance, soils of high latitude have relatively higher concentrations of C influenced by permafrost dynamics and drainage. Fifty nine percent of C in forest soils is located in the high latitude (Dixon et al., 1994). Natural disturbances such as wind, fire, drought, insects and diseases cause changes in canopy cover, soil moisture and temperature regimes, thereby affecting soil erosion and SOC stock. Anthropogenic factors that may affect SOC stocks include forest management activities and deforestation. The terrestrial C pool has been reduced greatly by anthropogenic activities such as conversion of forests to agricultural lands and urban areas to meet the increasing demands for food, water, energy and shelter.

Carbon sequestration refers to any increase in the C content of soils resulting from a change in land management and this can mainly be achieved by increasing net photosynthesis and slowing down decomposition (Powlson *et al*., 2011). Recommended management practices (RMPs) that lead to C sequestration include mulch farming, conservation tillage, agroforestry and diverse cropping systems, integrated nutrient management (including use of manure and composts) and forest management (Lal, 2004; Powlson *et al*., 2011; UNEP, 2012). Forest management practices can be grouped into 2: (i) to maintain and expand existing C pools by minimizing deforestation and forest degradation and (ii) to create new C sinks by expanding tree and forest cover. Conversion of natural to agricultural ecosystems causes 60% depletion of SOC pools in soils of temperate regions and 75% depletion in tropic soils (Lal, 2004).

Developing countries are yet to stop the indiscriminate clearing of forests despite the negative effects of deforestation. Proper assessment of the carbon pools and fluxes in tropical forests is important for understanding the contribution of these forests to net carbon emissions and their potential to sequester carbon. Continued work is therefore required of researchers and scientists to produce results that would help convince stakeholders (i.e. land owners, policy makers and others) the importance of afforestation and protection of soil and forest resources. Proper quantification of carbon pools in tropical forests would also enable Africa to participate in the Clean Development Mechanism (CDM), proposed in the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Developing countries will be able to trade Carbon Emission Reduction (CER) credits, to or with industrial countries hence providing an incentive for participation in climate change mitigation. In addition to the socio-economic and ecological benefits of above ground forest resource, the importance of forest soils in carbon sequestration in tropical regions cannot be over-emphasized. This study therefore aims to determine the ability of tropical forest soils to sequester carbon in order to guide policy makers and other stakeholders in making the right decisions concerning soil and forest resources. To achieve this, the amount of SOC was obtained from stands of different tree species of Onigambari Forest Reserve, Ibadan, South-Western Nigeria.

Method

Study site

This study was carried out in Onigambari Forest Reserve, Ibadan, South-West of Nigeria. The climate is tropical with wet and dry seasons. The mean annual precipitation varies between 1007 and 1703 mm and mean annual temperature between 24 and 32 °C with the mean annual relative humidity of 80%.

Soil sample collection and laboratory analysis

Soil samples were randomly collected in triplicates from stands of six different dominant tree species (*Cordia spp*, *Tectonia grandis*, *Gmelina arborea*, *Cidrella odurata*, *Pinus cambea*, *Triplochyton sclerocylum*) in the forest reserve. In each sampled tree stand, a hand-pushed auger (100 mm diameter) was used to collect soil samples from a depth of 0 – 15 cm. Core sample were also collected using cylinder (44 mm diameter, 154 cm^3 volume) for bulk density determination. Bulk density was determined by dividing the mass of the soil (g) in the corer by the volume of the cylinder (cm^3). The soil samples were air-dried at room temperature and passed through a 2 mm sieve. Wet oxidation method was used to determine the organic carbon (OC) concentrations (%). The soil organic carbon (SOC) content ($t\ ha^{-1}$) was calculated as a product of C concentration (%), bulk density and depth. The SOM and total nitrogen (TN) contents were obtained using the formula: OC (%) x 1.724 and OC (%)/ 10 respectively. Soil pH in distilled water suspension with a ratio 10 g : 10 ml was measured using a digital HI96107 pH-meter (Hanna Instruments, Italy).

These analyses were carried out at the soils laboratory of Forestry Research Institute of Nigeria, Ibadan.

Statistical analysis

The mean, standard deviation and error of all the samples were calculated. All data were tested for normality using the Anderson Darling test. Statistical Package for the Social Sciences (SPSS) version 15 was used for the statistical analyses. The experiment was laid in complete randomized design. Analysis of Variance (ANOVA) was used to determine if there were significant differences among samples. The strength of the relationships between the measured soils parameters were tested using Pearson's correlation coefficient. Regression analyses were used to calculate the mathematical relationships of the significant correlations.

Results

Statistics of the environmental parameters measured from the sampled soils of the forest is shown in table 1. The bulk density (g cm^{-3}), pH, OC concentration (%), SOM (%), TN (%) and SOC (t C ha^{-1}) ranged from 1.07 – 1.82, 5.10 – 7.63, 0.71 – 3.08, 1.23 – 5.31, 0.07 – 0.31 and 17.17 – 49.69 respectively.

Table 1: Statistical summary of environmental parameters measured in the sampled forest soils

	N	*Mean*	*StDev*	*CoefVar*	*Minimum*	*Maximum*
Bulk Density (g cm^{-3})	90	1.51	0.20	13.25	1.07	1.82
pH	90	6.44	0.70	10.91	5.10	7.63
OC conc (%)	90	1.82	0.58	32.16	0.71	3.08
SOM (%)	90	3.12	1.01	32.30	1.23	5.31
TN (%)	90	0.18	0.06	32.05	0.07	0.31
SOC (t C ha^{-1})	90	34.92	8.75	25.07	17.17	49.69

As indicated in table 2, there are significant differences at significant levels of 0.05 in the environmental parameters measured across the forest.

Table 2: ANOVA of Bulk density (g cm^{-3}), pH, OC conc (%) SOM (%), TN (%)

		df	*SS*	*MS*	*F-cal*
Bulk Density (g cm^{-3})	Sample	29	3.4960	0.121	6050.00*
	Error	60	0.0012	0.00002	
pH	Sample	29	42.991	1.482	13.423*
	Error	60	6.627	0.110	
OC conc (%)	Sample	29	29.643	1.022	2.841*
	Error	60	21.587	0.360	
SOM (%)	Sample	29	88.589	3.055	2.853*
	Error	60	64.244	1.071	
TN (%)	Sample	29	0.294	0.010	2.820*
	Error	60	0.216	0.004	

*significant at 5% probability level

Pearson's correlation coefficients were used to determine the association between the parameters measured. Results showed that there was a strong positive relationship between the bulk density and SOC contents (r = 0.873). Bulk density had no significant relationship with the pH, OC, SOM and TN concentrations (Table 3). pH showed positive relationships with C concentration (r = 0.269), SOM concentration (r = 0.266) and TN concentration (r = 0.271). These relationships are weak but significant. No significant relationship was found between the pH and SOC showing that the pH of the soil did not affect the SOC storage of the forest soils. A strong positive relationship was found between the SOM and TN (r = 0.999). A non-significant weak but positive relationship was found between SOC, SOM and TN (Table 3). SOC had no significant relationship with OC, SOM and TN concentrations (Table 3).

Table 3: Correlation matrix among assessed environmental parameters

	Bulk Density ($g\ cm^{-3}$)	*pH*	*OC conc (%)*	*SOM (%)*	*TN (%)*	*SOC ($t\ C\ ha^{-1}$)*
Bulk Density ($g\ cm^{-3}$)	1	0.007	-0.122	-0.128	-0.123	0.873*
pH		1	0.269*	0.266*	0.271*	0.092
OC conc (%)			1	0.999*	1	0.167
SOM (%)				1	0.999*	0.161
TN (%)					1	0.166
SOC ($t\ C\ ha^{-1}$)						1

*correlation is significant at 0.05 level

Linear regression model was used to determine the effects of bulk density, depth and OC concentration on SOC stock. The regression coefficient of determination (R^2) is 0.839. This implies that 83.9% of the variation in the soil organic carbon stock is explained by the bulk density and organic carbon concentration and depth of the soil samples.

Discussion

The variability in the measured environmental parameters may be attributed to some inherent soil spatial variability. The spatial variation in the environmental parameters can be influenced by the soil conditions, topographic heterogeneity, tree species composition and structure, stand age and management of forests (Ostrowska *et al.*, 2010; Uri *et al.*, 2012; Yuan *et al.*, 2013). Though studies have shown that the stand age has implications on SOC stock (Ostrowska *et al.*, 2010; Fonseca *et al.*, 2011); Uri *et al.* (2012) found no statistical difference in soil C storage of stands of different ages. Yuan *et al.* (2013) showed that SOC content decreased where trees had higher relative basal area. SOC accumulation is also higher with low tree density, low elevation and slope, probably because these factors favour SOM decomposition. Litterfall and its spatial distribution is another key factor that influences small scale spatial variation in SOC. The accumulation and decomposition of litter is dependent on tree species composition, litter quality, light and temperature conditions, therefore canopy composition and structure influences C accumulation on the forest floor (Yaun *et al.*, 2013). This explains the differences in the SOC contents in our result. The previous land use, the number of years under the previous land use and management can also influence the SOC stock (Foneseca *et al.*, 2011). Since the history of this study site is not known, it is difficult to assume that the variations observed are as a result of these factors.

Bulk density is closely related to SOM, as SOM concentration increases, bulk density reduces (Perie and Ouimet, 2008). In this study, bulk density shows weak negative relationships with OC, SOM and TN concentrations, though these relationships are not statistically significant. The strong correlation found between SOC contents and bulk density shows that considering the depth of horizon is important in calculating SOC stocks. Aticho (2013) observed that organic C storage increases as soil depth increases, hence more organic C accumulation in deeper soil profiles. This is also similar to the findings of Ostrowska (2010). Unlike Yuan *et al.* (2013) that found pH as one of the main determinants of SOC patterns, there was no significant relationship between SOC and pH in this study. Results also show that measurement of bulk density is suitable for the estimation of C sequestration potential of tropical forests soils. Comparisons of the SOC stocks of the study with results from other studies cannot be properly done as measurements have been taken from different depths and results represented in various forms (e.g. t C ha^{-1}, kg C m^{-2} and Mg C ha^{-1} yr^{-1}). The highest C concentration recorded was 3.08%. This is similar to the findings of Anikwe (2010) that found 3.07% in natural undisturbed forest. Agricultural soils have been reported to store lower concentrations of carbon and nitrogen (Anikwe, 2010; Uri *et al.*, 2012). The high concentrations of C in forest soils show the C sequestration potential of tropical forest soils thereby reducing greenhouse gas emissions to the atmosphere, hence climate change.

Conclusion

This study has shown that forests soils are important reservoirs of carbon. The strong relationship between SOC and bulk density as found in this study shows that soil C accumulation is important to reduce the risks of soil degradation caused from soil loss to erosion and nutrient depletion. Stakeholders should therefore focus on sustainable land management activities that would promote soil C sequestration. Proper estimation of SOC stock in tropical forests has important implications in sustainable soil management and future climate change scenarios. Further studies that properly consider the factors that are responsible for spatial variations in sites are required for accurate estimation of SOC stock.

References

Anikwe, M. (2010). Carbon storage in soils of Southeastern Nigeria under different management practices. *Carbon Balance and Management,* 5: 5 – 11.

Aticho, A. (2013). Evaluating organic carbon storage capacity of forest soil: Case study in Kafa zone Bita district, southwestern Ethiopia. *American-Eurasian Journal of Agriculture and Environmental Science*, 13 (1): 95 – 100.

Dixon, R. K., Brown, S., Houghton, R. A., Solomon, A. M., Trexler, M. C. and Wisniewski, J. (1994). Carbon pools and flux of global forest ecosystems. *Science*, 263: 185–190.

Fonseca, W., Rey Benayas, J. and Alice, F. (2011). Carbon accumulation in the biomass and soil of different secondary forests in the humid tropics of Costa Rica. *Forest Ecology and Management,* 262: 1400 – 1408.

Jandl, R., Lindner, M., Vesterdal, L., Bauwens, B., Baritz, R., Hagedorn, F., Johnson, D., Minkkinen, K. and Byrne, K. (2007). How strongly can forest management influence soil carbon sequestration? *Geoderma*, 137: 253 – 268.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science,* 304: 1623 – 1627.

Lal, R. (2005). Forest soils and carbon sequestration. Forest *Ecology and Management,* 220: 242–258.

Ostrowska, A., Porebska, G. and Kanafa, M. (2010). Carbon accumulation and distribution in profiles of forest soils. *Polish Journal of Environmental Studies*, 19: 1307–1315.

Perie, C. and Ouimet, R. (2008). Organic carbon, organic matter and bulk density relationships in boreal forest soils. *Canadian Journal of Soil Science*, 88: 315–325.

Powlson, D. S., Whitmore, A. P. and Goulding, K. W. T. (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science*, 62: 42–55.

UNEP (2012). The benefits of soil carbon: Managing soils for multiple economic, societal and environmental benefits.

Uri, V., Varik, M., Aosaar, J., Kanal, A., Kukumagi, M. and Lohmus, K. (2012). Biomass production and carbon sequestration in a fertile silver birch (*Betula pendula* Roth) forest chronosequence. *Forest Ecology and Management*, 267: 117–126.

Yuan, Z., Gazol, A., Lin, F., Ye, J., Shi, S., Wang, X., Wang, M. and Hao, Z. (2013). Soil organic carbon in an old-growth temperate forest: Spatial pattern, determinants and bias in its quantification. *Geoderma*, 195–196: 48–55.