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Soil Carbon Pool as Affected by Forest Degradation in some Reserved Natural Forests in Southwest Nigeria.

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Abstract
One of the major impacts of anthropogenic activities is forest degradation. Forest degradation can affect soil organic matter and nutrients and through soil respiration, influence atmospheric CO_2 concentrations and global warming. This study examined the impact of forest degradation on soil properties and carbon pool. Soil samples were collected at three depths (0-20cm 20-35cm and 35-50cm) from undisturbed and degraded parts of the selected Forest Reserves and subjected to various laboratory tests. There was no significant difference in soil textural properties but bulk density was higher under the degraded forests. Topsoil OC, total N also varied significantly with forest type. Soil carbon pool was higher in undisturbed forests with Eda Forest Reserve (undisturbed) giving the highest value (64.46 t/ha) while the lowest (28.79 t/ha) was observed under Omo Forest Reserve (degraded).
Keywords: forest degradation, soil nutrients, carbon storage

Introduction

Nigerian population is presently above 140 million and most of the people are in the rural areas. The rural communities are characterized by poverty, hunger, ignorance, diseases, lack of basic social amenities and small land holding. Forest ecosystem, by virtue of its location and the so many goods and services it can supply 'for free', is highly depended upon for daily sustenance and livelihood by the rural people. The growth in human population around the forest, the demand for more agricultural land for food production, urbanization and increase in land use activities have exerted pressure on the tropical forest resulting in a gradual change in tree composition, cover, and structure.

It has been reported that rainforests are being removed at a rate of 100,000 to 200,000 km^2 per year; with approximately the same area being greatly disturbed (Skole et al., 1993; Katzman et al., 1990). Forest conversion has been reported to have serious impacts on soils (Neill et al., 1997; Oke 2008). A large proportion of forest conversion is related to agricultural use of the land. Agricultural activities can change the soil chemical, physical, or biological properties. Such activities as cultivation, tillage, weeding, deep ploughing, fertilizer applications, liming, draining, irrigation and biocide application on cultivated crops may affect soil properties (Hartemink et al., 2008). Tiessen et al. (2003) observed that changes in organic carbon contents after deforestation strongly depend on soil type.

Forests play a critical role in global carbon cycle and offer significant potential to capture and hold carbon. Forest ecosystems store nearly two third of terrestrial C and have a larger C density than any other land uses (Zou et al 2008). The anthropogenic actions and natural disturbances such as pests and fire can result in forest degradation and reduction in the productivity which inevitably reduces the potential for C sequestration. Wang et al (2001) in their study on the impact of human disturbances on vegetation carbon storage in forest ecosystem in China, concluded that apart from change in land use, forest degradation can also cause a significant carbon release from existing forest ecosystem.

Degradation reduce the potential of forest to function as regulator of the environment. It affects natural regeneration, soil and water conservation and carbon dynamics. The impact of forest degradation with respect to carbon dynamics is still not well understood. The estimation of changes in forest soil carbon pool is useful for understanding carbon storage associated with various levels of degradation in various forest types.

The extent and nature of soil changes after forest degradation may be influenced by soil type and extent of degradation. In this study, the extent and nature of the changes in the properties of a forestland following its conversion into other uses were examined with a view to quantifying the impact of forest degradation on soil.

Materials and Method

Site Selection and Sampling procedure

The study was carried out in three of the six states in southwest Nigeria. The states are Ogun, Ondo and Ekiti states. Four Forest Reserves were purposively selected from the list of forest reserves in each of these states. Eda and Ogbese Forest reserves were selected in Ekiti state while Omo Forest Reserve and Oluwa Forest reserve were selected in Ogun and Ondo states respectively. The Forest reserves were visited and based on the observed level of anthropogenic activities study sites of about 500m x 500m were marked out in each of the forest reserves and categorized as follows:

Table 1: Distribution and nature of selected research sites

State	Forest reserve	Description of selected Research site
Ogun	Omo	Undisturbed forest
	Omo	Degraded forest
Ondo	Oluwa	Undisturbed forest
	Oluwa	Degraded forest
Ekiti	Eda	Undisturbed forest
	Ogbese	Degraded forest

Two parallel transects (500m km in length and at 200m interval) were cut in each of the sites and four equal size plots (25 x 25m) were laid at 100m interval on each transect in alternate positions. Soil samples were collected at 0-20, 20 – 35 and 35 – 50 cm depths using a 3.5 cm diameter soil auger. There were five auger points along the diagonals of each plot. Samples from same depth in each plot were bulked and a composite was taken to the laboratory for analysis.

Determination of soil physical and chemical properties

Soil bulk density was determined using a 2.5 cm diameter cylindrical core sampler. The cylinder was hammered into the soil to collect bulk density samples which were placed in the oven at 65^{o}C until a constant weight was attained. The weight of empty cylinder, diameter, radius and height were also determined to get the volume. Bulk density was calculated as:

$$Bulk\ density = \frac{Mass}{Volume}$$

Soil particle size distribution was determined by the hydrometer method (Bouyoucos, 1962). Soil pH was determined in water suspension at 1:2 soils to water ratio using pH meter. Soil organic carbon was determined by the Walkley-Black wet oxidation method (Walkley and Black, 1934). Organic matter content was estimated by multiplying the carbon value by a factor of 1.727 (56% oxidation was assumed). The samples for total nitrogen determination were using the semimicro Kjeldahl method (Bremner, 1965). The digested samples were distilled after addition of sodium hydroxide and the ammonia thus released was determined by simple acid-base titration.

Phosphorus was determined by extracting with 0.2M H_2SO_4 at soil solution ratio of 1:20 and was colorimetrically determined by the reduced molybdenum blue method using ascorbic acid as reducing agent (Murphy and Riley, 1992). The soils were leached with 1N neutral ammonium acetate solution to obtain extracts used for the determination of exchangeable cations. The calcium and magnesium content were determined ethylene diamine tetra-acetate acid (EDTA) titration method while potassium was determined using flame photometer.

Estimation of soil organic carbon pool

Soil organic carbon (SOC) pool was determined using soil samples collected at 0-20 cm depth. calculated using the following equation.

$$C-pool = d \times BD \times SOC$$

Where,

C-pool = soil carbon pool in (t/ha),

D = sampling depth (cm),

BD = bulk density (Mg/m^3),

SOC = soil organic carbon (%)

Data analysis

Data relating to basic soil properties and soil carbon pools were analyzed using the general linear model procedure of SPSS. Data were log transformed to meet requirement for normality when necessary. Statistical comparisons of the measured soil properties were performed by analysis of variance (ANOVA) for randomized complete block design (RCBD) and appropriate follow up test was conducted where it applies using Duncan's Multiple Range Test .

Results

Properties of soils under the various forest types

The results of analyses of soil properties (0-20 cm depth) in each of the selected forest types are presented in Table 2. The soils were generally sandy loam and ranged from acidic to slightly alkaline. The least pH value (3.93) was obtained for soil under the degraded forest in Oluwa Forest Reserve while the highest was from the undisturbed forest in Omo Forest Reserve. The undisturbed forest in Omo Forest Reserve also had the highest soil organic matter content (5.51%). Available phosphorus was highest (10.58 ppm) in Omo (undisturbed) while Calcium content was highest in the degraded forest of Ogbese Forest Reserve. Values of pH, soil organic matter, total nitrogen and phosphorus were generally higher in the undisturbed forests than in the disturbed forests from the same area. Statistical analysis shows that soil pH, organic matter and magnesium content were significantly higher in the undisturbed forest of Omo Forest Reserve. There were no significant differences in the values obtained for exchangeable potassium and total nitrogen among all the forest types.

Table 3 shows the values of soil characteristics at 20-35 cm depth under the various forest types. The results of the particle size analysis still justify the classification of the soil as sandy loam. Values of pH, organic matter content, phosphorus, calcium potassium and magnesium were generally lower than those obtained at 0-20 cm depth. Also, except in very few cases, undisturbed forests had higher values than the disturbed forests. Soil magnesium content was observed to be higher in disturbed than in undisturbed forest. Omo forest reserve (undisturbed) also had the highest soil pH value at 20-35 cm depth. This was however not significantly different from the value recorded for the degraded forest in the same Forest Reserve. Oluwa Forest Reserve (undisturbed) had the highest phosphorus content at 20-35cm depth. Also there was no significant difference between the degraded forest and undisturbed forest.

Soil characteristics at 35 – 50 cm depth under the various forest cover is presented in Table 4. The results of particle size analysis shows that the soil was sandy loam, an indication that there was no textural change as one goes down the soil profile to a depth of 50 cm. As in the upper soil layers values of organic matter content, pH, phosphorus, exchangeable calcium potassium and magnesium were higher in the undisturbed forests. Also, values for Omo Forest Reserve were generally higher than for Eda, Ogbese, and Oluwa forest reserves. There was a general decrease in the soil organic matter content, total nitrogen, phosphorus, exchangeable calcium potassium and magnesium with soil depth.

Soil bulk densities were generally higher under the degraded forests than in undisturbed forests (Figure 1). There were also variations in soil bulk density among the forest types. The lowest bulk density value ($1.07 g/cm^3$) was obtained in the undisturbed forest of Omo Forest Reserve while the highest ($1.18 g/cm^3$) was in the degraded forest of Ogbese Forest Reserve.

Table 2: Soil characteristics (0-20cm depth) as influenced by forest degradation in the various Forest Reserves

Soil Characteristics	Ogbese Forest Reserve (Degraded)	Eda Forest Reserve (Undisturbed)	Oluwa Forest Reserve (Undisturbed)	Oluwa Forest Reserve (Degraded)	Omo Forest Reserve (Undisturbed)	Omo Forest Reserve (Degraded)
Sand (%)	74.19[a]	76.52[a]	71.20[a]	70.53[a]	73.01[a]	71.01[a]
Silt (%)	14.26[a]	8.89[a]	10.24[ab]	9.58[b]	10.56[ab]	8.56[b]
Clay (%)	11.55[a]	14.59[a]	18.56[a]	19.89[a]	16.42[a]	20.42[a]
pH	4.48[b]	4.27[c]	4.42[c]	3.93[c]	7.34[a]	6.83[a]
Mg (meq/100g)	1.83[ab]	1.00[b]	1.73[ab]	2.40[a]	1.73[ab]	2.30[a]
Ca (Meq/100g)	4.00[a]	3.43[ab]	2.77[bc]	2.00[c]	3.83[a]	3.40[ab]
K (Meq/100g)	0.35[a]	0.25[a]	0.23[a]	0.19[a]	0.28[a]	0.70[a]
P (ppm)	7.85[b]	6.56[b]	10.58[a]	9.98[a]	4.91[c]	2.90[c]
Organic matter (%)	3.13[bc]	3.52[b]	2.65[c]	3.13[bc]	5.51[a]	2.10[c]
Organic C (%)	1.82[b]	2.04[ab]	1.54[c]	1.82[b]	3.01[a]	1.22[c]
Total N (%)	0.10[a]	0.19[a]	0.13[a]	0.11[a]	0.19[a]	0.17[a]

Means on the same rows followed by same superscripts are not significantly different ($p < 0.05$)

Table 3: Soil characteristics (20-35cm depth) as influenced by forest degradation in the various Forest Reserves

Soil Characteristics	Ogbese Forest Reserve (Degraded)	Eda Forest Reserve (Undisturbed)	Oluwa Forest Reserve (Undisturbed)	Oluwa Forest Reserve (Degraded)	Omo Forest Reserve (Undisturbed)	Omo Forest Reserve (Degraded)
Sand (%)	74.19[a]	70.85[a]	71.20[a]	70.53[a]	69.78[a]	68.36[a]
Silt (%)	11.89[a]	13.23[a]	10.24[a]	9.58[a]	11.13[a]	11.22[a]
Clay (%)	13.65[b]	15.92[b]	18.56[a]	19.89[a]	19.09[a]	20.42[a]
pH	4.59[c]	5.84[b]	4.57[c]	4.39[c]	7.51[a]	7.25[a]
Mg (Meq/100g)	0.53[b]	0.50[b]	1.20[ab]	1.97[a]	1.17[ab]	2.10[a]
Ca (Meq/100g)	2.17[b]	2.83[a]	1.70[c]	1.50[c]	2.53[ab]	2.37[b]
K (Meq/100g)	0.21[a]	0.19[a]	0.14[a]	0.17[a]	0.23[a]	0.21[a]
P (ppm)	5.08[ab]	3.16[b]	8.87[a]	7.08[a]	1.74[c]	2.69[c]
Organic matter (%)	1.87[bc]	2.16[b]	1.10[c]	0.74[c]	3.32[a]	2.30[b]
Organic C (%)	1.25[b]	1.08[bc]	0.62[cd]	0.43[d]	1.92[a]	1.33[ab]
Total N (%)	0.05[a]	0.07[a]	0.09[a]	0.07[a]	0.19[a]	0.17[a]

Means on the same rows followed by same superscripts are not significantly different ($p < 0.05$)

Table 4: Soil characteristics (35-50cm depth) as influenced by forest degradation in the various Forest Reserves

Soil Characteristics	Ogbese Forest Reserve (Degraded)	Eda Forest Reserve (Undisturbed)	Oluwa Forest Reserve (Undisturbed)	Oluwa Forest Reserve (Degraded)	Omo Forest Reserve (Undisturbed)	Omo Forest Reserve (Degraded)
Sand (%)	72.18^{a}	72.19^{a}	69.01^{a}	71.62^{a}	70.34^{a}	63.01^{a}
Silt (%)	13.25^{a}	10.56^{a}	8.43^{a}	10.49^{a}	9.23^{a}	13.56^{a}
Clay (%)	14.57^{a}	17.25^{a}	22.56^{a}	17.89^{a}	20.43^{a}	23.43^{a}
pH	4.89^{c}	6.27^{b}	4.72^{c}	3.95^{c}	7.25^{a}	7.08^{a}
Mg (Meq/100g)	1.37^{ab}	1.23^{ab}	1.07^{b}	1.57^{a}	1.10^{b}	1.67^{a}
Ca (Meq/100g)	2.40^{ab}	2.90^{ab}	1.67^{bc}	1.43^{c}	3.37^{a}	1.73^{bc}
K (Meq/100g)	0.18^{a}	0.23^{a}	0.15^{a}	0.16^{a}	0.17^{a}	0.14^{a}
P (ppm)	3.81^{bc}	5.44^{b}	7.13^{a}	6.71^{a}	2.45^{c}	3.54^{bc}
Organic matter (%)	2.41^{b}	2.52^{b}	1.18^{bc}	0.79^{c}	3.04^{a}	2.16^{b}
Organic C (%)	1.40^{ab}	1.45^{b}	0.69^{ab}	0.46^{c}	1.76^{a}	1.25^{ab}
Total Nitrogen (%)	0.05^{a}	0.82^{a}	0.10^{a}	0.08^{a}	0.16^{a}	0.11^{a}

Means on the same rows followed by same superscripts are not significantly different ($p < 0.05$)

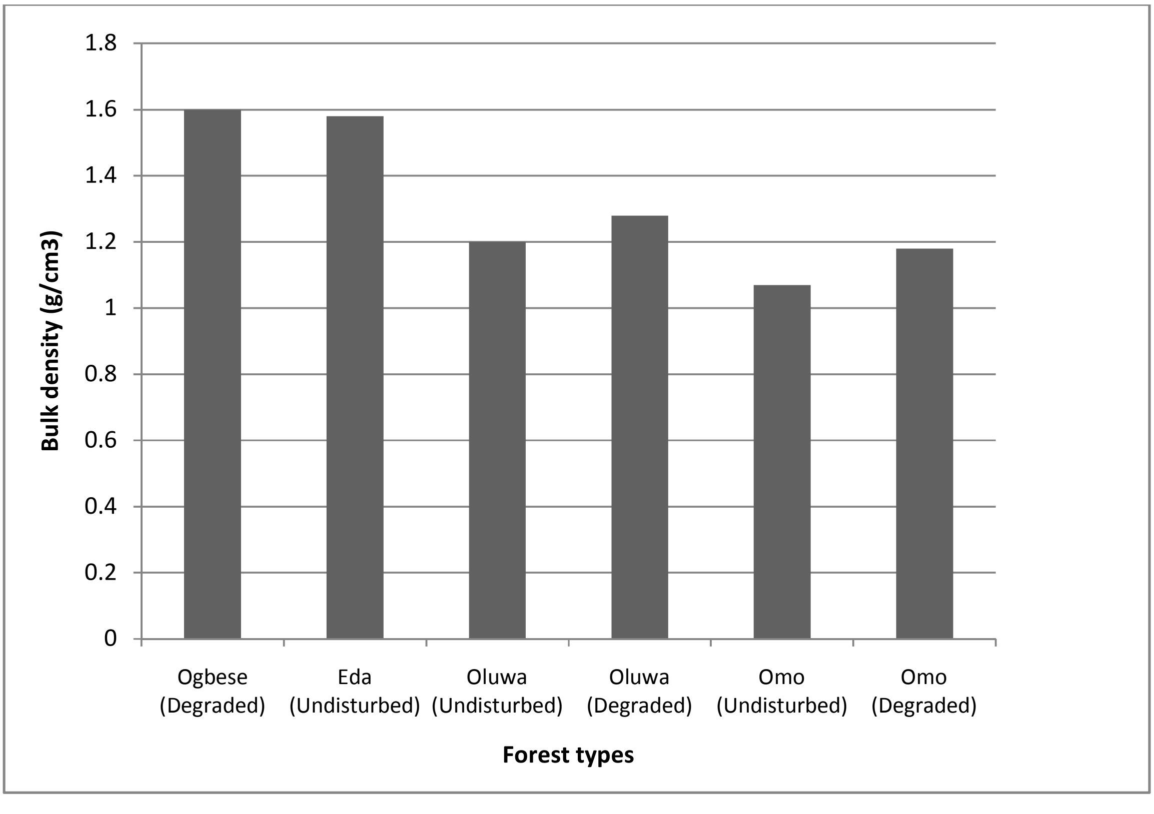

Figure 1: Impact of forest degradation on soil bulk density

Soil organic carbon pool

Figure 2 shows the impacts of forest degradation on soil carbon pool under the various forest reserves. Soil organic carbon pool in Oluwa Forest reserve was generally lower than in the other three Forest Reserves (Omo, Ogbese and Eda). Carbon pool in soils of the degraded forests was also observed to be generally lower than in the undisturbed forests at each of the sites. Highest value of soil organic carbon pool was obtained for Eda Forest Reserve (undisturbed) while the lowest was in Omo Forest Reserve (Degraded). The soil organic carbon pool of Omo Forest reserve was most affected by degradation. A decline of about 55% was observed in the carbon pool of Omo Forest Reserve following forest degradation.

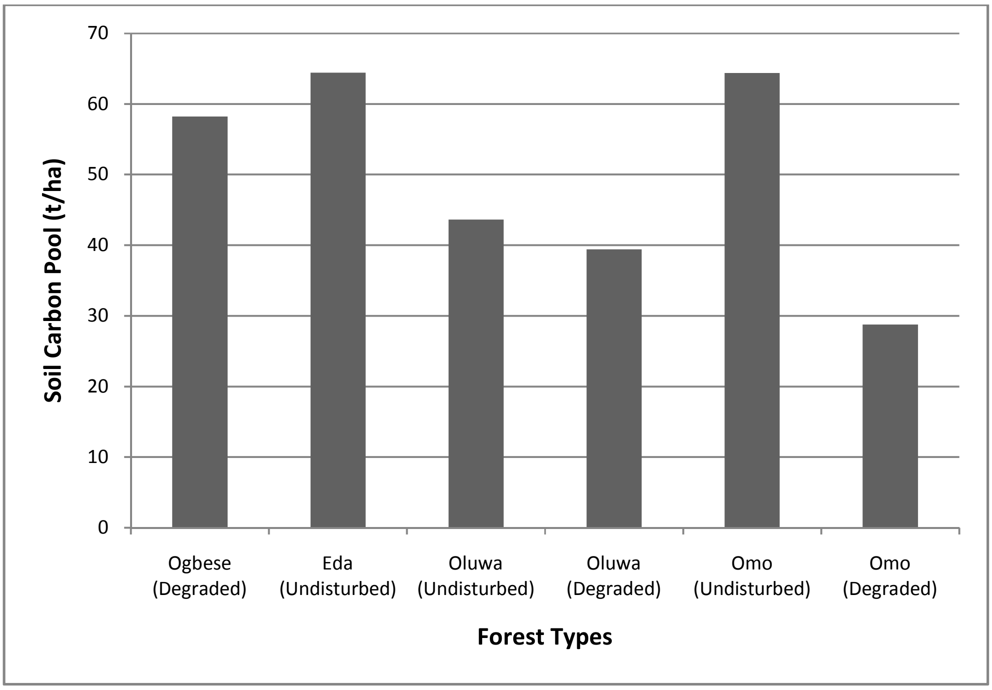

Figure 2: Impact of forest degradation on soil Carbon pool

Discussion

Effects of forest degradation on soil physical and chemical properties

This study has further shown that forest degradation can lead to substantial nutrient losses. Vagen et al, 2006 attributed reduced soil fertility after forest conversion to the removal of nutrients in the harvested timber, burning, increased surface erosion and enhanced leaching.

Generally soil organic matter and nutrient contents in tropical soils are highest in the upper 20 cm of the profile and decrease with depth; while pH varies less but often increases with depth (Brouwer and Riezebos, 1998). A sharp decline in soil organic C and increase in bulk densities of oxisols was found under various cropping systems up to four years after deforestation (Ghuman et al 1991; Ghuman and Lal, 1991). Hartemink et al (2008) noted that conversion from forest to pasture or new forests has smaller dramatic effects on soil organic C and bulk density compared to conversion from forest to cropland. The tendency for the soil pH to decrease due to accumulation of SOC has been reported in long term field experiments on acid soils (Schjonning et al, 1994; Wild, 1994).

Effects of forest degradation on soil organic carbon pool

Soil, especially forest soil, is a major store of organic carbon because they contain higher soil organic matter compared to any other land use. Soil contains (in the form of organic and inorganic C) three times more C than in atmosphere and 3.8 times more C than in biotic pool (Lal and Kimble, 1997). Jha et al.(2003) attributed the high organic carbon content of forest soils to continuous extensive litter fall and its decomposition. Forest degradation is the quantitative and qualitative loss of vegetation cover over a long period of time within the forests (Singh, 2010). It is due to continuous anthropogenic pressures for exploitation of forest products. Soil organic carbon as observed in this study was affected by forest degradation. The lower content of soil organic carbon in the degraded forests may be attributed to logging. Logging practices may have also contributed to the differences between the Forest Reserves. Soil organic carbon is usually impacted not only by the interval of logging but the intensity (Olsen et al., 1996; Jurgensen et al., 1997; Knop and Swank, 1997).

Soil organic carbon dynamics depend upon various biotic and abiotic factors, such as micro-climate, faunal diversity, land use, and management (Shrestha and Singh, 2007). The upper soil layer is generally richer in carbon than the lower layers due to continuous addition of litter which stimulates biological activities. The observed higher carbon pools in the undisturbed forests compared to the degraded forests may also be attributed to the heavier root and litter inputs from the dense forest canopy. Singh (2010) stated that degradation reduces the potential of the forest to function as a regulator of the environment and impacts on carbon dynamics. He reported a decrease in soil carbon with forest degradation. Ordonez et al (2008) analyzed soil carbon contents in 10 land use and land cover classes in Mexico. They reported a higher soil carbon contents (116.4 Mg/ha) in oak forest than in the degraded forest (72.8 Mg/ha).

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