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Soil Carbon Storage as Influenced by Land Use Types in Akure Forest Reserve, Ondo State, Nigeria

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ABSTRACT

The study aimed to investigate the effect of land use on carbon storage in Akure forest reserve. The study site was stratified into three different land uses (Natural forest, Arable land and Cocoa agroforest). One hectare was marked out in each land use. Sixteen (16) sample plots of 25 m by 25 m was established randomly in each of the land use. Three (3) plots were randomly selected within each stratum. Soil samples were collected at three points diagonally on each plot along three different soil depths (0-15 cm, 15-30 cm and 30-45 cm) using soil auger. The samples were analyzed using standard laboratory procedures. Result on soil type of the study sites were loamy sand except for Cocoa agroforestry land which was sandy loam at 30-45 cm soil depth. At 0-15 cm depth, arable land has the highest organic carbon (3.58 %) and organic matter content (6.18 %); followed by cocoa agroforest land, with 1.95 % organic carbon and 3.37 % organic matter content. Results at 15-30 cm and 30-45 cm depths followed similar pattern with the results obtained for 0-15 cm soil depth. At 0-15 cm soil depth, total carbon stock under arable land was 20394.00kg/ha followed by cocoa agroforest (17419.00kg/ha) and natural forest (6342.50kg/ha) respectively, while natural forest soil has the least value along the soil profile. The study therefore concluded that it is important to manage the different land uses such that they remain a carbon sink than a carbon source.

Keywords: carbon storage; land use; Akure forest reserve; Ondo State; Nigeria

INTRODUCTION

Humanity's interest in soil quality and functionality dates back to the dawn of civilization [1]. In the presence of climate change, land degradation and biodiversity loss, soils have become one of the most vulnerable resources in the world [2]. Soil organic carbon (SOC) is the main component of soil organic matter (SOM) and it an indicator for soil health. SOC is important for its contributions to food production, mitigation and adaptation to climate change for achieving sustainable development goals (SDGs). Soils host the largest terrestrial carbon pool as it contains about twice more carbon than the atmosphere and two and a half times more than all living things [3].

Soils have the unique ability to sequester and store large amounts of carbon (C). Soil organic carbon is one part in the much larger global carbon cycle that involves the cycling of carbon through the soil, vegetation, ocean and the atmosphere [4]. Soils host the largest terrestrial carbon pool and play a crucial role in the global carbon balance by regulating dynamic bio-geochemical processes and the exchange of greenhouse gases (GHG) with the atmosphere [5]. Most soil C is in the form of organic C derived from living organisms and has been stored for hundreds to thousands of years in deeper soil layers below 20 cm [6, 7]. The loss of even relatively small amounts of this soil organic carbon could exacerbate global climate change by releasing substantial amounts of greenhouse gases, such as carbon dioxide (CO2) and methane (CH4), to the atmosphere.

Land-use has been defined as the arrangement, activity and input people undertake on a particular land [8]. Many natural land systems such as native forests, grasslands, and wetlands have relatively high carbon stocks. The soil pool is highly reactive and dynamic, and the cultivation of virgin soils or conversion of natural ecosystems to agricultural ecosystems has led to depletion of the soil C pool and emission of greenhouse gases into the atmosphere [9]. Land use change causes perturbation of the ecosystem and can influence the carbon stocks and fluxes. The two most important anthropogenic processes responsible for the release of carbon dioxide into the atmosphere are burning of fossil fuels (coal, oil, and natural gas) and land use. Land use change has been reported to alter the soil physico-chemical properties, soil microbial composition [10].

The dynamics of soil aggregation and SOC are greatly influenced by land use changes and management practices. These changes may affect soil structural stability SOC storage and nutrient turnover in soils [11]. Many studies have reported that conversion of forest land into other land use type such as agricultural ecosystems, affects several soil properties especially soil organic carbon concentration and stock.

As a result, SOC vary considerably both along with land-use types and land-use patterns. There is dearth of information on the organic carbon stock of the soil in Akure Forest Reserve (Queens' Plot). little monitoring has been conducted to make it possible to know their true medium and long-term evolutions, especially under the influence of changes in forestry practices. Therefore, this study was conducted to investigate the effect of land use on carbon storage in Akure forest reserve.

MATERIAL AND METHODS

Study Area

The study was carried out in Akure Forest Reserve. It is geographically located in a humid rainforest zone of Akure South local government area of Ondo State, Nigeria. It lies between latitudes 7°10'0" and 7°27'30" N of the Equator and longitudes 4° 52'30" and 5°12'30" E of the Greenwich Meridian with a total land area covered of 6993 ha. It shares border with Osun State in the Northeast [12] (Figure 1).

The climate of the study area is characterized by dry season which lasts from November to March while the wet season commences from April and ends in October with the highest rainfall records between July and August. Average annual temperature is 27°C. The mean annual rainfall is about 4000mm with relative humidity of 80–85% annually [13]. The soils are predominantly ferruginous tropical soils and are typical of the variety found in the intensively weathered areas of basement complex formations in the rainforest zone of southwest in Nigeria [14]. It is slightly neutral; pH of 6.7–7.3 and sandy-loam in nature. The soils are of high agricultural value for both tree and arable crops.

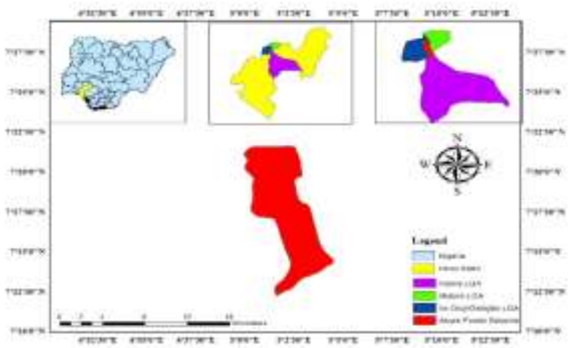

FIGURE 1: Map of Ondo State showing the location of the study area

Procedure of the Experiment

• *Collection of soil samples*

The study area was stratified into three based on land use namely; Natural forest land (NFL), Arable land (ARL) and Agroforestry land (AFL). Three (3) plots of 25m×25m were established in each of the land use type. Soil samples were collected at three different points diagonally on each plot at three different soil depths (0-15 cm, 15-30 cm and 30-45 cm) using soil auger. Soil samples from the same soil depth in each plot were then bulked and collected into labeled sample bottle for laboratory analysis.

• *Soil analysis*

The soil particle size distributions were determined using hydrometer method. Percentage sand, silt and clay were calculated and the textural class of the soils was determined by using the USDA textural triangle. Bulk Density (Bd) was determined using the core method [15], while organic carbon was determined using the wet oxidation method [16]. The SOC stocks at each soil depths were estimated using the equation;

SOC stock = (OC) × Bd × Soil depth [17].

Where,

SOC stock is the stock of the organic carbon (kg/ha)

OC is organic carbon (g/kg soil)

Bd is bulk density (g/cm^3)

Soil depth is the depth of the respective soil layer (cm)

Data Analysis

Data obtained were subjected to analysis of variance (ANOVA) at α= 0.05 and the means were separated using the Duncan multiple range test (DMRT).

RESULTS

Physical Properties of the Soils of the Study Area

Result in table 1 shows the particle size distribution and textural class for the three land uses at different soil depth. At 0-15cm soil depth (surface soil), the result shows that sand has the highest value ranging from 71.24 % to 75.00 % followed by silt (15.49 % to 17.89 %) and clay (9.51 % to 10.87 %) with textural class of loamy sand for the three land uses. At 15-30cm soil depth (sub-surface soil), the result followed the same pattern as obtained for the surface soil. Result on particle size distribution at 30-45cm soil depth (sub-soil) shows that percentage sand was significantly highest ($p < 0.05$) in arable land while silt and clay were highest in agroforestry land and natural forest land respectively. However, the textural class for agroforestry land was sandy loam.

TABLE 1: Particle size distribution and textural class of the sampled soils

Soil separates	Natural forest	Arable land	Agroforestry land
0-15 cm			
Sand (%)	71.24± 1.00^{c}	72.40±2.42^{b}	75.00±2.47^{a}
Silt (%)	17.89±0.67^{a}	17.49±2.43^{a}	15.49±1.64^{b}
Clay (%)	10.87±0.33^{a}	10.08±0.00^{a}	9.51±0.87^{a}
Textural class	Loamy sand	Loamy sand	Loamy sand
15-30 cm			
Sand (%)	70.24±0.32^{b}	74.07±3.29^{a}	74.35±2.05^{a}
Silt (%)	18.56±0.00^{a}	16.48±2.92^{b}	16.49±1.53^{b}
Clay (%)	11.32±0.12^{a}	9.45±0.63^{b}	9.56±0.52^{b}
Textural class	Loamy sand	Loamy sand	Loamy sand
30-45 cm			
Sand (%)	70.24±0.00^{a}	72.95±2.23^{a}	69.68±3.36^{a}
Silt (%)	19.11±0.29^{a}	17.36±1.72^{a}	19.79±2.77^{a}
Clay (%)	10.65±0.29^{a}	9.69±0.53^{a}	10.59±0.61^{a}
Textural class	Loamy sand	Loamy sand	Sandy loam

Means with the same superscript along the rows are not significantly different ($p < 0.05$)

Mean Bulk Density of the Sampled Soil

Figure 2 shows the results for bulk density of the soils in the study area. The result shows that the bulk density is not significantly different ($p < 0.05$) for all the land use at 0-15cm soil depth. The bulk density is significantly higher in agroforestry land at 15-30cm and 30-45cm soil depth with 0.74 ± 0.32g/cm3 and 0.70 ± 0.30g/cm3 respectively.

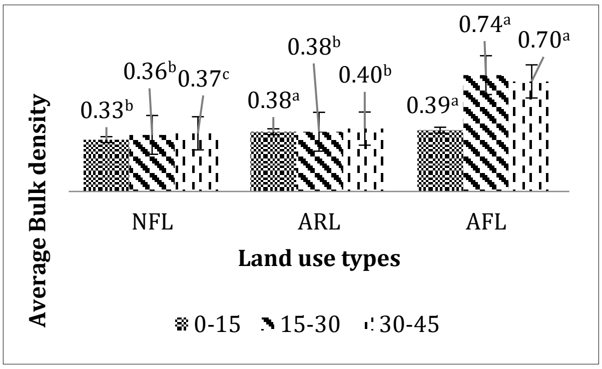

FIGURE 2: Mean bulk density of the sampled soil

Means with the same superscript on the same bar across the land use are not significantly different (p <0.05)

Organic Matter and Organic Carbon Contents of the Soils of the Study Area

Table 2 present results on distribution of soil organic matter and soil organic carbon contents in the study area. The result shows that arable soil at 0-15 cm soil depth has the highest organic matter (6.18 %) and organic carbon content (3.58 %), followed by agroforestry soil with 3.37 % organic matter and 1.95 % organic carbon content. The result at 15-30 cm and 30-45 cm soil depth followed the same trend as obtained for 0-15 cm soil depth in all the land use. Results on carbon stock show that arable soil has the highest carbon stock value of 20394.00kg/ha, 16846.00kg/ha and 14066.00kg/ha at 0-15cm, 15-30 cm and 30-45 cm soil depth respectively while natural forest soil has the least value along the soil profile.

TABLE 2: Organic matter and organic carbon contents of the sampled soil

Variables	Natural forest	Arable land	Agroforestry land
0-15 cm			
Organic matter (%)	2.31±1.15^{b}	6.18±0.56^{a}	3.37±0.54^{b}
Organic carbon (%)	1.34±0.67^{b}	3.58±0.33^{a}	1.95±0.31^{b}
Carbon stock (kg/ha)	6342.50±2900.61^{c}	20394.00±2319.69^{a}	17419.00±6316.57^{b}
15-30 cm			
Organic matter (%)	1.66±0.15^{b}	5.22±0.51^{a}	2.10±0.77^{b}
Organic carbon (%)	0.96±0.09^{b}	3.03±0.30^{a}	1.21±0.44^{b}
Carbon stock (kg/ha)	5251.00±720.88^{c}	16846.00±615.91^{a}	14199.00±7440.59^{b}
30-45 cm			
Organic matter (%)	1.39±0.67^{b}	4.03±0.44^{a}	3.21±0.28^{ab}
Organic carbon (%)	0.81±0.39^{b}	2.33±0.26^{a}	1.86±0.45^{ab}
Carbon stock (kg/ha)	4710.50±2413.95^{c}	14066.00±1298.02^{a}	11605.50±2124.44^{b}

Note: means with the same letter along the rows are not significantly different (p < 0.05)

DISCUSSION

The observed improvement in soil texture from sand to loamy sand at the sub-soil (30-45cm) depth in agroforestry land might be due to addition of humus into the soil from organic matter contents at that sub-soil depth compare to the value obtained at the sub-surface soil level in agroforestry land. This observation is in agreement with the submission of [10], who reported improvement in soil texture from sand to loamy sand in a study involving four land use practices. This high organic matter content observed at this level could have resulted from dead decaying roots of trees that were killed in-situ by the farmers to allow for reforestation program through taungya system. Also, the increase in the percentage silt and clay along the soil depth indicates possible clay translocation from the top layer to the layer below this will reduced the porosity and air spaces of the soil below which consequently results in heaver soil. This assertion has similarly been reported by [18] and [19].

The observed increase in bulk density along the soil depth in all the three land uses could be attributed to decrease in organic matter with increase in soil depth. This assertion is in line with the findings of [20] who reported that soil bulk density is inversely correlated to organic matter content. In addition, the tillage activities of farmers on both arable and agroforestry land compare to natural forest with zero cultivation results into compaction of the soil thereby increase the bulk density. However, the observed mean bulk densities in this study are desirable as they were less than 1.40 g/cm3 which is the allowable optimum soils bulk density for effective movement of air and water through the soil [21].

The significant ($p < 0.05$) highest SOM and SOC contents obtained in the surface soil compared to the sub-soil and sub-surface soil level (Table 2) might be due to high input from decaying and decomposing leaf litter which results from human and microbial activity at that soil level especially in the arable and agroforestry land. At this soil surface level, the soil is well exposed to solar radiation resulting in higher temperature and consequently higher microbial activity which aid decomposition and consequent fast carbon turnover rate in the soils. This assertion is in consonance with the earlier report by [22] and [10].

Observed greater soil carbon stock in arable and agroforestry lands compared to what is obtained in natural forest land could probably be attributed to frequent cultivation of the soils which has brought about finer textured especially at the surface soil level thereby making the soil to be well aerated. This condition coupled with favorable soil temperature gives room for more microbial activities for decomposition and mineralization of organic matter and consequently increase carbon sequestration in the soil. This assertion is in consonance with the earlier report by [23]. On the other hand, the significantly least carbon stock value obtained in natural forest despite high litter accumulation could probably be due to ever green nature of the forest with damp forest floor and low soil temperature which inhibit microbial activities and consequent low rate of litter decomposition to release carbon for storage in the soil.

CONCLUSION AND RECOMMENDATION

The result from this study has revealed an improvement in soil texture from loamy sand to sandy loam at the sub-soil level (30-45cm) in agroforestry land. The study also revealed an increase in soil bulk density with increasing soil depth in all the three land uses. The study further revealed that soil organic carbon accumulation in all the land use in the study area decrease as the organic substrate quality and quantity decreases along the soil depth. It was also revealed in this study that carbon stock accumulation increases with increasing SOC and SOM but decreases with increasing soil depth. In conclusion, observation from this study generally shows that carbon accumulation in the soil of the study area increases with exposure of the soil to human activities. In view of the above results and observations, it was recommended that for optimum below-ground carbon accumulation and storage, land users especially foresters and agriculturist should embrace land use practices that will enhancing litter and organic matter decomposition and mineralization to increase carbon storage in the soil for overall sustainable land use management and improved soil health.

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