GOUNI Journal of Interdisciplinary Research (GJIR)
Volume 5; Issue 1, 2026
Official Publication of Interdisciplinary Research Department
Godfrey Okoye University, Ugwuomu- Nike, Enugu-Nigeria
Published by K-Injo | Kobia Data Limited

INFLUENCE OF PARENT MATERIALS AND LAND USE ON SOIL CARBON SEQUESTRATION IN SOUTHERN NIGERIA

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DOI: https://doi.org/10.5281/zenodo.18505496

Abstract: A study was conducted to determine the effect of parent materials and land use on C sequestration in southern Nigeria. The experimental design used for the study was a 2 x 5 x 3 factorial in RCBD. The factors were land use (managed tree croplands (MTC) and continuously cultivated croplands (CCC), parent material (coastal plain sands at the Forestry Research Institute of Nigeria (FRIN), Isieke; Shale at the National Horticultural Research Institute (NIHORT), Okigwe, Imo Clay Shale at the Anambra-Imo River Basin Development Authority (AIRBDA), Agbala; Coastal Plain sands at the Niger Delta Basin Development Authority (NDBDA), Kpong and Alluvium at the Niger Delta Basin Development Authority (NDBDA), Isiokolo and soil horizon depths (0-19, 20-39 and 40-100 cm). Physical properties ranged from 49-85 %, 9-40 %, 4-22 % and 1.35-2.15 gcm-3 for sand, clay, silt and bulk density in MTC and 60-81 %, 9-30 %, 5-13 % and 1.38-2.15 gcm-3 for sand, clay, silt and bulk density in CCC. The textural class ranged from loamy sand to sandy loam at the surface and sandy clay loam to sandy clay at the subsurface. Soil reaction were extremely acid to strongly acid (pH 4.4-5.5) for MTC and very strongly acid to moderately acid (pH 4.5-5.6) for CCC. Soils under MTC sequestered higher ($p<0.05$) amount of C across the soil depths relative to arable croplands. SOC pool in MTC soil was within the ideal range for mitigating climate change and environmental quality control, whereas CCC land utilization type was below the threshold level. Coastal plain sands of FRIN- Isieke had highest ($p<0.05$) amount of SOC pool (575.80 $MgCha^{-1}$), while the alluvial soils of NDBDA- Isiokolo gave the lowest (409. 50 $MgCha^{-1}$). The study revealed that SOC sequestration is a function of land use, parent material and depth. Therefore, the soil conservation practices associated with CCC under the different parent materials in the studied area should be re-evaluated, this is because reduction of SOC in CCC increased oxidation of SOM, thereby leading to SOC losses to the atmosphere and this may also accelerate global warming.

Keywords: Soil organic carbon sequestration, Land use systems, Parent material, Soil depth, Southern Nigeria soils

Introduction

Agricultural soils are among the planet's largest reservoirs of carbon and hold potential for expanded carbon sequestration, and this, provide prospective way of enhancing aggregate stability and mitigate the increasing atmospheric concentration of CO2 (Ibe, 2021). But, the development of Agriculture during the past centuries and particularly in last decades has entailed depletion of substantive soil carbon stocks (Nnaji, 2008; Ibe, 2014; Lal, 2017).

The impact of organic carbon (OC) losses in soils may have a variety of serious environmental consequences. Abah and Petja (2017) reported that several depletion of SOC degrades soil quality, reduces biomass productivity and adversely impacts water quality. Salako (2015) observed that organic matter (OM) losses from soil worldwide contribute to increased atmospheric CO_2 concentration. Ibe (2021) indicated that the net losses of SOC due to land use changes may occur as a result of decreased organic residue inputs and changes in litter composition, and increased rates of soil organic decomposition and soil erosion. The contribution of soil erosion to global C emission has also been recognized by Abdres *et al.* (2016) as equally important to that of deforestation and fossil fuel burning. It was estimated that the total SOC displaced by water erosion globally is 57 $PgCyr^{-1}$ (Aliero, 2018; Lal, 2004; and Li *et al.*, (2010). It was predicted by Lal (1996) that CO_2 emission to the atmosphere would increase from 7.4 $GtCyr^{-1}$ in 1997 to approximately 26 $Gtcyr^{-1}$ by 2010. Furthermore, the annual CO_2 flux from the soil to the atmosphere (68 $PgCyr^{-1}$) is 11.3 times the emission from fossil fuel combustion (6 $PgCyr^{-1}$) (An *et al.*, 2010; and Abdullahi *et al.*, 2018). The intergovernmental panel on climate change (IPCC, 2016) recognized three main options for the mitigation of atmospheric CO_2 concentration by the agricultural sector:

i) Reduction of agriculture-related emissions
ii) Creation and strengthening of C sinks in the soil and
iii) Production of bio-fuels to replace fossil fuels

There is need to evaluate the role of parent material and land use in the distribution of organic C and N among labile and stable pools with kinetically different turnover rates. This will help in the enhancement of soil fertility and stability of soil micro aggregates. It is with this background that several attempts have been made to assess the potential of coastal plain sands, alluvium and Imo clay shale under managed tree croplands (Ibe, 2021), sandstones under arable cropping (Salako, 2015; Ibe, 2014), shale under mixed cropping system (Anikwe, 2010) and Alluvium, Coastal plain sands and upper coal measure under cassava/maize long term cultivation (Lal and Okigbo, 1990) to sequester C as possible strategies to curtail the rate of increase of atmospheric concentration of CO_2.

According to Abdullahi *et al.* (2018), biomass production which is an important determination of C pool and fluxes depends on parent material, land use and cultural practices. Consequently, conservation of natural (TRF and TS) ecosystems to agricultural land use (plantation, pastoral and crop land) under a given parent material, has a drastic impact on C pool and emissions of GHGs to the atmosphere. Awelewa and Ogban (2017) showed that parent material and land use influence soil moisture status, soil temperature, oxygen supply (drainage), soil acidity, soil nutrient supply and clay content which are the major environmental factors that control the behaviour of OM in the soil. Govers *et al.* (2013) also remarked that the soil forming factors, notably parent material as well as local biological activity in which human are often a predominating factor, control the amount of SOM that corresponds with equilibrium conditions in a certain natural ecosystem. Different factors influence different SOC pools. Free OM particles and microbial biomass in soils are controlled by residue inputs (management of crop residue and mulching) and climate for example, the microbial populations and activities in pasture tends to be higher compared to the corresponding agricultural soils due to the positive impacts of the surface cover, vegetation, below ground C allocation via roots and lack of tillage of pasture (FAO, 2017).

More so, soil aggregation, texture and parent material control OM in microaggregates. The other pools are less influence by agronomic factors but mainly by pedological factors-microaggregates, clay composition (IUSS Working Group WRB, 2015). Furthermore, the turnover and cycling of SOC is more rapid in the tropics than in temperate regions (Salako, 2015).

Lal (2017) reported high SOC pool in soils formed from shale with its associated increased clay contents relative to coastal plain sands with its associated low clay content. Li *et al.* (2010) recorded that soils with high activity clay have more SOC content than those with low activity clay based on the differences in their pedology.

Quantification of the impacts of parent material, land use and soil cultural/management practices on carbon stocks in southern Nigeria is challenging because of the spatial heterogeneity of soil, climate, cultural/management conditions and due to the lack of data on soil carbon pools of most common agroecosystems. Some available statistics are generally based on extrapolation. Lal (2005) and FAO (2017) reported that the rates of SOC sequestration in agricultural and restored ecosystems range from 0 to 150 kg Cha^{-1} yr^{-1} in dry and warm regions and 100-1000 $kgCha^{-1}yr^{-1}$ in humid and cool climates. They also estimated the total potential of C sequestration in world soils as 0.4-1.2 $GtCyr^{-1}$, all of which were derived from natural resource inventory without special consideration of specific geological materials as a soil forming factor.

Improvement in the data base on the concentration of SOC needed to be validated with ground truth measurement/assessment, as the use of reliable data is essential for developing technique of soil management and identifying policy options needed for promoting appropriate measures. Despite several studies carried out on the quantification of soil sequestered C in different geographical and geological regions of the world (Hamed *et al.*, 2019; Bhunia *et al.*, 2016; FAO, 2017 and IUSS Working Group WRB, 2015), there are limited knowledge about SOC pool dynamics in the tropical humid agroecosystem of southern Nigeria. It is important to generate information which is essential for developing techniques of C sequestration for sustainable agriculture and erosion control leading to advancement in food security and consequently, mitigate global warming using five (5) locations in the southern agro-ecological zones of Nigeria. The aim of this study is to evaluate the influence of parent materials and land use on soil carbon sequestration in Southern Nigeria. This aim will be achieved through the following specific objectives: to:

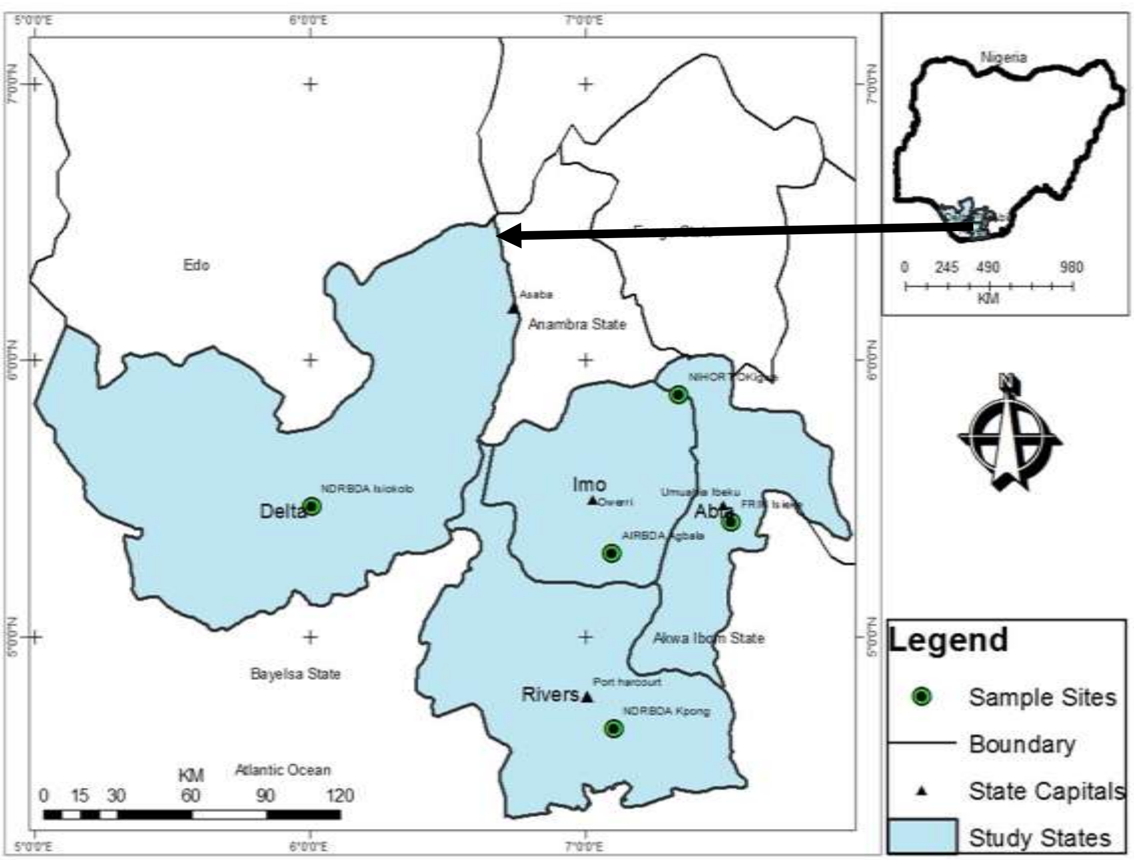
i) determine the effect of parent material and land use on selected soil physico-chemical properties

ii) determine the effect of parent materials and land use on soil organic C pool.

Materials and methods

Description of the Study Area

Geographically, southern Nigeria refers to the area bounded within latitudes $10^{0}28$ north of the equator and longitude $5^{0}25^{|}$ and $8^{0}51^{|}$ east of the greenwish meridian, occupying a land area of about 282,672.48 km^2 or about 30.6 % of the total land area of Nigeria. It represents about 75.02 million or 39.3% of the population of Nigeria (Monanu, 1975, and Ofomata, 1975, Lal and Okigbo, 1990; Abia State Official Gazette, 1992). The study was conducted at the Forestry Research Institute of Nigeria (FRIN) Isieke, National Horticultural Research Institute (NIHORT) Okigwe, Anambra-Imo River Basin Development Authority (AIRBDA) Agbala, Niger Delta Basin Development Authority (NDBDA) Kpong and Niger Delta Basin Development Authority (NDBDA) Isiokolo, in the States of Abia, Imo, Rivers and Delta, southern Nigeria (Figure 1).



Map of southern Nigeria showing the study location

Geology, climate and natural vegetation of the study area

The soils of FRIN-Isieke are derived from coastal plain sands of Bende Ameki formation (Lekwa and Whiteside, 1986; Nuga and Akinbola, 2011). Soils of NIHORT-Okigwe are derived from shale of Ajali formation (Jungerius, 1964; Ojanuga, 1977). While soils of AIRBDA-Agbala are underlain by Imo Clay Shale of Imo formation of the tertiary period. The residuum of this shale formation is the parent material of the soils (Asadu et. al., 1997: Ojanuga, 1998). Soils of NDBDA-Kpong are derived from coastal plain sands of Benin formation. The coastal plain sands are connected with the sea with a large number of creeks. The general geology of the area essentially reflects the influence of movement of rivers in the Niger Delta, in their search for lines of flow to the sea with consequent deposition of transported sediments (Lekwa and Whiteside, 1986; FDALR, 1990). Whereas, the soils of NDBDA-Isiokolo are derived from Alluvium. The geology of the area is quaternary to recent alluvium known as the sombreiro (Deltaic plain sands, clayey/silty sand) (Jungerius, 1964; Ojanuga *et al.*, 1981; FDALR, 1990). The geomorphology of the five (5) locations is nearly level to gently undulating (0-3 %) and the altitude ranged from 14 masl to 182 masl (Lal and Okigbo, 1990: FDALR, 1990: Ojanuga, 1998; Ibe, 2021). The drainage of the area encompasses the entire land surface dissected and drained by many streams and creeks that flow in southerly direction into one another and eventually into the Atlantic coastal mashes (Lekwa and Whiteside, 1986; Ibe, 2014; Nwagbara and Ibe, 2015; Osodeke, 2017).

The southern Nigeria has a tropical humid climate with bimodal rainfall distribution pattern but with less intensity and clear distribution between wet and dry seasons in the tropical rainforest (Abia and Imo State). The freshwater swamp and the tropical rainforest have average rainfall of 2500 mm and 2350 mm, respectively (Nwagbara and Ibe, 2015; NIMET, 2018). Air temperature in southern Nigeria are generally high all year round. Mean minimum temperature of the area is 35°C while the mean minimum is 21°C, given an annual range of about 11°C (Nuga and Akinbola, 2011; NIMET, 2018). The study area is endowed with an annual average daily sunshine hours of 6.25 hours ranging from 3.5 hours at the coastal area to 9.0 hours at the far northern boundary. The minimum and maximum hours of sunshine amount to 0.1 and 9.9 hours, respectively (Uguru et. al., 2011; NIMET, 2018). Similarly, it has an annual daily solar radiation of about 2.25 Kwh/m²/day varying between 3.5 Kwh/m²/day at the coastal areas and 7.0 Kwh/m²/day at the northern boundary. Relative humidity over the study ranged from 65 % to 92 % at the coastal area through 82 % in the central area (Chikezie et. al., 2016; NIMET, 2018).

The vegetation of the experimental area is typical of tropical rainforest vegetation. The secondary bush which dominates the area are the remnants of the tropical rainforests which are fast disappearing in the area. Some of the forest species found in the area especially in the ally crop portion include: oil bean (*Pentaclethra marcophyllum),* oil pam (*Elaesis guinensis)*, plaintain/ banana (*Musa spp)*, raffia palm (*Raphia spp).* Grasses and broadleaf weeds that dominate the entire area include *Panicum maximum, Pennisetum purprerium, Cyperus spp, Axonopus compressus, Elusime indica, Chromolaena adoratum,* *Centrocema pubescence, Culapgonium mucunoides and Aspillia africana.*

The experimental sites had been cropped continuously for more than ten years for arable crops with mechanical clearing done in February/March followed by panting in April/May. During these years, there were intercropping systems in some areas. Inorganic fertilizer were used. Weeding were done manually with hoes, cutlass and trowels. Also, there were herbicides applications. There were longer stand rotation in the horticultural and managed forest tree plantations.

Stratified random sampling as modified by Smith (1976), was used in the collection of soil sample. Six (6) mini-pits of the same dimensions (0.5 m x 0.5 m x 1 m) were dug in sample locations and sample collected at depths 0 -19, 20- 39, 40-100 cm. The mini-pits were dug to represent landscapes occupied by different tree and arable crops under define management and cultural practices over a long period of time. Within each sampling location, soils of similar textures were collected from intensive arable cropland adjacent to the tree cropland (horticultural tree crops, plantations and managed forest ecosystem) in each location. In general, soils under 8 (LUTs) were studied. Three sites (replicates) in each location were chosen for collection of soil samples to represent each of the LUTs. A total of 90 soil samples were collected from the five locations at three depths from each sample site. The land utilization types were: (1) *Pinus carribean* plantation (PPF-PCP) at FRIN-Isieke (2) *Irvingia wombulu* Plantation (MTC-IWPN) NIHORT- Okigwe (3) *Elias guineensis* plantation (MTC-OPP) at AIRBDA-Agbala (4) *Musa paradisica* plantation (MTC-PPk) at NDBDA- Kpong and (MTC-PPI) NDBDA-Isiokolo (5) Cassava/Maize/*Telferia* Intercrop (CCC-CMTF) at FRIN-Isieke and (CCC-CMTI) NDBDA-Isiokolo (6) Cassava/Maize/Okra Intercrop (CCC-CMO) at AIRBDA-Agbala (7) Cassava/Maize/Yam Intercrop (CCC-CMY) at NDBDA-Kpong (8) Cassava/Maize/Melon Intercrop (CCC-CMM) at NIHORT-Okigwe.

Information on land use and cultural practices were derived from farm management and crop production reports and cultural practices of AIRBDA- Agbala, forest cultural practice guide of FRIN-Isieke, research collaboration and training reports of NDBDA for Kpong and Isiokolo project sites, and records of farming system research programme of NIHORT-Okigwe were used. Also, information were acquired from interviews with heads of station of the collaborating institutions, heads of units and technical officers.

Laboratory analysis

Particle size distribution was determined by the hydrometer method as described by Gee and Bander (1986). Bulk density was obtained by the cylindrical core method as described by Blacke and Hantge (1986). Soil pH was determined in distilled water and Potassium Chloride solution at ratio 1:1 and 1:2.5 soil/water suspension using pH meter (Mclean, 1982). Soil organic carbon content was quantified by Walkley and Black wet oxidation method as described by Nelson and Sommers (1982). Total nitrogen content was determined by the macrokjeldahl digestion method using CUSO4 and NaSO4 catalyst mixture (Bremmer and Mulvaney, 1982). Cation exchange capacity (CEC) was determined by the NH4OAC (Ammonium acetate) pH method (Thomas, 1982). Available Phosphorus was determined using Bray and Kurtz II solution (Olsen and Sommers, 1982). The SOC pool content was calculated using the equation of Lal *et al.* (1998):

$$MgCha^{-1} = \frac{\underline{(\% C \times Pb \times d \times 10^{-4} m^2 ha^{-1})}}{100}$$

Where; $MgCha^{-1}$ = Megagram carbon per hectare (1 Mg = 10^6g), % C = percentage of C given by laboratory results, Pb = Soil bulk density (Megagram per cubic meters), d = depth in meters

Statistical Analysis

The experimental design used for the study was a 2 x 5 x 3 factorial in randomized complete block design (RCBD). The factors were land use [managed tree croplands (MTC) and continuously cultivated croplands (CCC)], parent material [coastal plain sands at the Forestry Research Institute of Nigeria (FRIN)], Isieke; Shale at the National Horticultural Research Institute (NIHORT), Okigwe; Imo Clay Shale at the Anambra-Imo River Basin Development Authourity (AIRBDA), Agbala; Coastal Plain Sands at the Niger Delta Basin Development Authourity (NDBDA), Kpong and Alluvium at the Niger Delta Basin Development Authority (NDBDA), Isiokolo and depth (0-19, 20-39 and 40-100 cm). The data collected on the various parameters were analyzed using ANOVA. Separation of treatment means for significant difference was performed by the FLSD procedure according to Obi (1986).

Results and Discussion

Soil physico-chemical characterization

The particle size analyses of the soil showed that the sand particles are the dominant size fraction in both major land utilization types ranging from 49-85 % in MTC and 66-81 % in CCC. While clay particles ranged from 9-40 % in MTC and 9-30 % in CCC. Whereas silt fractions were the least with values ranging from 4-22 % and 5-13 % MTC and CCC respectively. The textural class generally ranged from loamy sand to sandy loam at the surface and sandy clay loam to sandy clay at the subsurface horizons. Bulk density values ranged from 1.35-2.15 gcm^{-3} and 1.38-2.15 gcm^{-3} in MTC and CCC respectively. This is in alignment with the findings of Ogumwole *et al.* (2014), who recorded high bulk density in soils with high clay content.

The soils were extremely acid to strongly acid (pH 4.4-5.5) in soils under MTC and very strongly acid to moderately acid (pH 4.5-5.6) in soils under CCC. The organic carbon content ranged from 1.57-3.80 % and 0.37-3.56 % in soils under MTC and CCC respectively. Organic carbon content of the two major LUTS were within the optimal range (3-5 %) as reported by FAO (2017), except in soils under CCC. The depletion of SOC in soils under CCC could be due to long term continuous cultivation, vegetation removal and tillage operation.

Available phosphorus across the major LUTs ranged from moderate to high for MTC (13.80-28.07 mgkg-1) and CCC (9.03-26.67 $mgKg^{-1}$) and varied down the profile. This could be due to prolonged accumulation of SOM resulting from litter fall and debris of organic material in the managed tree croplands and constant application of chemical fertilizer (NPK) in the continuous cultivated croplands. Research findings in confirmation to this abound in literature (Nzegbule, 2018; Asawalam, 2017; Baishya, 2015). However, Osodeke (2017) contradicted this observation. The range for K was very low (0.01-0.19 $cmolkg^{-1}$) and very low to moderate (0.02-0.62 $cmolkg^{-1}$) in soils under MTC and CCC respectively.

Sulieman *et al.* (2019) and Yadav and Arora (2018) reported that soils with underlying clays have much higher levels of cations than surface soils. Whereas Anikwe (2010) recorded that the low level of basic cations in soils are reflection of low pH which affect nutrient solubility and sorption. Cation exchange capacity (CEC) ranged from moderate to high (14.20-26.28 cmolkg^{-1} for MTC and moderate (10.81-18.60 cmolkg^{-1}) for CCC. Total nitrogen ranged from low to very high (0.07-0.51 %) in MTC and very low to very high (0.04-0.40 %) in CCC. Soil organic carbon pool across the LUTs ranged from 33.80-326.80 mgCha^{-1} in soils under MTC and 17.80-197.80MgCha^{-1} in soils under CCC. This is in line with the findings of Eibasiouny *et al.* (2014), Khera and Singh (2008), who recorded higher sequestration of soil organic carbon in soils under managed tree croplands relative to continuously cultivated croplands (Table 1 and 2).

Table 1: Mean values of physico-chemical properties of soil under managed tree croplands (MTC)

			%						%		cmolkg^{-1}			
Parent material	**Land use**	**Depth (cm)**	**Sand**	**Silt**	**Clay**	**Textural Class**	**BD (g/cm^3)**	**pH (H_2O)**	**SOC**	**TN**	**K**	**CEC**	**P (mgKg-1)**	**SOC Pool**
CPS-FRIN-ISIEKE	PPF-PCP	0-19	75	9	16	SL	1.48	5.50	3.63	0.51	0.04	18.01	15.25	133.40
		20-39	71	11	18	SL	1.58	4.90	3.28	0.38	0.02	16.11	19.75	107.60
		40-100	69	3	28	SCL	1.78	4.60	3.28	0.38	0.02	16.11	13.80	334.80
SHL-NIHORT-OKIGWE	MTC-IWP	0-19	75	14	11	SL	1.62	5.0	2.11	0.10	0.05	25.00	18.33	88.00
		20-39	65	22	13	SL	1.81	5.5	3.10	0.20	0.06	22.00	18.33	104.10
		40-100	49	11	40	SC	1.84	5.5	3.06	0.31	0.20	22.00	19.26	326.80
ICS-AIRBDA-AGBALA	MTC-OPP	0-19	75	12	13	LS	1.50	4.9	3.80	0.07	0.62	26.28	28.07	102.10
		20-39	73	10	17	SL	1.63	4.9	3.40	0.08	0.08	23.12	19.10	111.80
		40-100	71	4	25	SCL	1.68	4.8	3.20	0.08	0.06	24.00	17.03	313.80
CPS-NDBDA-KPONG	MTC-PP_K	0-19	77	10	13	SL	1.33	4.702	2.60	0.13	0.06	20.17	19.37	72.50
		20-39	77	6	17	SL	1.33	4.40	2.80	0.13	0.07	17.06	16.07	73.80

		40-100	79	6	15	SL	1.50	4.70	1.80	0.09	0.07	16.89	17.27	172.20
ALV-NDBDA-ISIOKOLO	MTC-PP$_I$	0-19	85	6	9	LS	1.41	4.78	3.56	0.11	0.19	18.56	20.00	95.60
		20-39	75	10	15	SL	1.85	4.79	2.84	0.13	0.19	14.20	17.00	96.00
		40-100	75	4	21	SCL	2.15	4.82	1.57	0.10	0.12	15.20	15.10	217.90

Keys:

BD=Bulk density, CEC=Cation Exchange Capacity, TN=Total Nitrogen, SOC=Soil Organic Carbon, P=Phosphorus, K= Potassium, LUT=Land Utilization type, CPS-FRIN-ISIEKE=Coastal plain sand of forestry research institute of Nigeria, Isieke; SHL-NIHORT-Okigwe=shale of national horticultural research institute, Okigwe; ICS-AIRBDA-AGBALA=Imo clay shale of anambra-imo river basin development authority, Agbala; CPS-NDBDA-KPONG=Coastal plain sands of niger delta basin development authority, Kpong; ALV-NDBDA-ISIOKOLO=alluvium of niger delta basin development authority, Isiokolo; PPF-PCP=Planted pine forest of pinus caribae plantation; MTC-IWP-managed tree cropland of irvingia wombulu plantation; MTC-OPP= managed tree cropland of oil palm plantation; MTC-PPk/MTC-PPi=managed tree cropland of plantain plantation

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Table 2: Mean Values of physico-chemical properties of soils under continuously cultivated croplands (CCC)

			%						%		$cmolkg^{-1}$			
Parent material	**Land use**	**Depth (cm)**	**Sand**	**Silt**	**Clay**	**Textural Class**	**BD (g/cm^3)**	**pH (H_2O)**	**SOC**	**TN**	**K**	**CEC**	**P ($mgKg^{-1}$)**	**SOC Pool**
CPS-FRIN-ISIEKE	CCC-CMT_F	0-19	79	11	10	SL	1.56	5.6	1.31	0.25	0.04	11.12	18.33	33.80
		20-39	75	7	18	SL	1.38	5.2	1.34	0.11	0.08	10.81	20.00	31.70
		40-100	66	5	30	SCL	1.66	4.9	0.80	0.34	0.01	12.15	26.67	58.20
SHL-NIHORT-OKIGWE	CCC-CMM	0-19	77	12	11	SL	1.70	4.7	0.87	0.13	0.05	13.00	26.63	27.80
		20-39	65	7	18	SL	1.88	4.9	0.57	0.40	0.05	16.00	18.54	23.60
		40-100	60	13	27	SCL	2.05	5.1	1.03	0.13	0.04	12.00	16.38	98.70
ICS-AIRBDA-AGBALA	CCC-CMO	0-19	80	5	15	SL	1.68	4.5	1.80	0.04	0.08	18.60	23.83	37.20
		20-39	70	5	21	SCL	1.62	4.8	0.91	0.13	0.07	16.40	21.32	26.60
		40-100	71	8	21	SCL	1.93	4.7	0.80	0.14	0.06	13.68	15.27	87.50
CPS-NDBDA-KPONG	CCC-CMY	0-19	81	8	11	LS	1.56	4.66	0.95	0.18	0.10	16.12	10.37	21.40
		20-39	77	6	17	SL	1.66	4.87	0.59	0.09	0.11	13.18	13.27	17.80
		40-100	78	7	15	SL	1.90	4.53	0.57	0.10	0.09	13.02	9.03	61.80
ALV-NDBDA-ISIOKOLO	CCC-MMT_I	0-19	80	11	9	LS	1.70	4.78	3.56	0.11	0.19	18.00	22.00	56.40
		20-39	80	9	11	SL	1.72	4.95	2.84	0.13	0.19	14.83	15.00	62.60
		40-100	75	8	17	SL	2.15	4.82	1.57	0.10	0.12	13.15	16.00	197.80

Keys:

BD=Bulk density, CEC=Cation Exchange Capacity, TN=Total Nitrogen, SOC=Soil Organic Carbon, P=Phosphorus, K=Potassium, LUT=Land Utilization type; CCC- CMTf/CCC-CMTi= continuously cultivated cropland of cassava/maize/telfetia; CCC-CMM= continuously cultivated cropland of cassava/maiz/melon;CCC-CMY=continuously cultivated cropland of cassava/maize/yam; CPS-FRIN-ISIEKE= coastal plain sands of the forestry research institute of Nigeria, Isieke; SHL-NIHORT-OKIGWE=shale of national institute of horticultural research institute,;Okigwe; ICS-AIRBDA-AGBALA= Imo clay shale of anambra imo river basin development authority, Agbala; CPS-NDBDA-KPONG= coastal plain sands of Niger delta basin development authority, Kong; ALV-NDBDA-ISIOKOLO=Alluvium of Niger delta basin development authority, Isiokolo

Soil Organic Carbon Pool

The effects of parent material, land use and depth on SOC pool under MTC and CCC across the study area are presented in Table 3. Significant ($p<0.05$) influence of parent material on SOC pool was observed across the study area with SOC pool of 111.10 $MgCha^{-1}$, 111.50 $MgCha^{-1}$, 113.20 $MgCha^{-1}$, 69.90 $MgCha^{-1}$ and 11.00 $MgCha^{-1}$ for CPS-FRIN-Isieke, SHL-NIHORT-Okigwe, ICS-AIRBDA-Agbala, CPS-NDBDA-Kpong, ALV-NDBDA-Isiokolo parent materials respectively. This suggests that SOC pool in alluvial soils were within the ideal range in relation to mitigating climate change and for better environmental quality control as postulated by FAO (2017) for surface soil (0-100 cm). Significant ($p<0.05$) influence of land use on SOC pool was observed at the three soil depths across the study area with MTC having higher SOC pool than CCC soils. The mean SOC pool were 154.50 mgCha-1 for MTC and 56.20 MgCha-1 for CCC soil. These results imply that MTC improved SOC pool whereas CCC degraded it. The SOC pool in MTC soil was within the ideal range (≥ 120 mgCha-1) in relation to mitigating climate change and for better environmental quality control. Significant ($p<0.05$) influence of depth on SOC pool were observed at the various depths with SOC pool varying with depth in MTC, CCC and parent materials across the study area. The highest (334.80 $mgCha^{-1}$) SOC Pool was observed at 40-100 cm soil depth under CPS-FRIN-Isieke followed by 326.80 $mgCha^{-1}$ SOC pool under SHL-NIHORT-Okigwe. The least (17.80 $mgCha^{-1}$) was observed at 20-39cm depth under CPS-NDBD-Kpong parent material which has been under >20 years of conventional tillage operation. This study revealed that there was greater soil carbon accumulation in forest soils when compared with arable soil irrespective of lithological differences. This result is in line with Lal (2017) who noted high SOC pool in soils under tropical forest. Significant ($P<0.05$) influence of the interaction of parent material, land use and depth was observed on SOC pool. This suggests that SOC pool is a function of land use, parent material and depth and their interactions. This result is in line with lal (2005) and li *et al.* (2010), who reported that SOC pool depends on land use and depth.

Table 3: Effect of parent materials, land use and depth on SOC pool ($MgCha^{-1}$) under MTC and CCC across the study area

Parent Material	Land Use

	Depth (cm)	MTC	CCC	Mean	Sub mean
CPS-FRIN-ISIEKE	0-19	100.40	33.80	67.10	
	20-39	107.60	31.70	69.60	
	40-100	334.80	58.20	196.50	
Sub mean		**180.90**	**41.20**		**111.10**
S-NIHORT-OKIGWE	0-19	88.00	27.80	57.90	
	20-39	104.10	23.60	63.90	
	40-100	326.80	98.70	212.70	
Sub mean		**172.90**	**50.00**		**111.50**
ICS-AIRBDA-AGBALA	0-19	102.10	37.20	69.70	
	20-39	111-80	26.60	69.20	
	40-100	313.80	87.50	200.70	
Sub mean		**175.90**	**50.40**		**113.20**
CPS-NDBDA-KPONG	0-19	72.50	21.40	46.90	
	20-39	73.80	17.80	45.80	
	40-100	172.20	61.80	117.00	
Sub mean		**106.20**	**33.70**		**69.90**
A-NDBDA-ISIOKOLO	0-19	95.60	56.40	76.00	
	20-39	96.00	62.60	79.30	
	40-100	217.90	197.80	207.80	
Sub mean		**136.50**	**105.60**		**121.00**
Total mean		**154.50**	**56.20**		
$LSD_{(0.05)}$ for parent material					9.85**
$LSD_{(0.05)}$ for land use					17.48*
$LSD_{(0.05)}$ for depth					10.94**
$LSD_{(0.05)}$ for parent material x land use					15.56**
$LSD_{(0.05)}$ for parent material x depth					17.98**
$LSD_{(0.05)}$ for land use x depth					15.51**
$LSD_{(0.05)}$ for parent material x land use x depth					25.53**

Key:

*, ** = Significant at 0.01 and 0.05 alpha level (2 tailed), respectively, NS = Non-significant, MTC = Managed tree croplands, CCC = Continuously cultivated croplands, CPS=FRIN-Isieke =Coastal plain seeds at FRIN-Isieke, S-NIHORT-Okigwe=Shale at NIHORT-Okigwe, ICS-AIRBDA-Agbala=Imo, Clay Shale at AIRBDA-Agbala, CPS-NDBDA-Kpong=Coastal plain seeds at NDBDA-Kpong, A-NDBDA-Isokolo=Alluvium at NDBDA-Isiokolo

Conclusion

The influence of parent materials and land use on soil carbon sequestration was evaluated in southern Nigeria. Soils under managed tree croplands (MTC) sequestered higher ($p<0.05$) amount across the soil depths relative to the continuous cultivated croplands (CCC). Coastal plain sands of FRIN- Isieke had highest amount of SOC pool. While the alluvial soils of NDBDA -Isiokolo gave the lowest. Amongst the managed tree crop LUTs, C sequestration followed this trend: Pine forest > Oil palm plantation > Irvingia Wombulu > Plantain plantation. The SOC pool in MTC soil was within the ideal range for mitigating climate change and environmental quality control, whereas CCC land utilization type was below the threshold level. Pine forest, Oil palm, *Irvingia wombulu* and Plantain plantation soils sequestered more carbon across the soil depths and therefore hold a consideration promise for carbon sequestration in southern Nigeria. The study revealed that SOC sequestration is a function of land use, parent material and depth. Therefore, the conservation practices associated with CCC under the different parent materials in the studied area should be re-evaluated. This is because reduction of SOC in CCC increased oxidation of SOM, thereby leading to SOC losses to the atmosphere and this may also accelerate global warming. Also, they are inadequate to maintain the qualities of the soils on sustainable basis with special emphasis on organic matter content. Some practices such as no-till reduced tillage, use of cover crops, mulching, application of organic and inorganic fertilizers and reduced application of agro-chemicals should be incorporated into the soil management and cultural practices.

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