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Carbon and Nitrogen Sequestration Potential of Various Land Use Types in Tai Area, Rivers State

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ABSTRACT

Sequestering Organic Carbon in soil is an important way of mitigating climate change. However, soil Organic Carbon (SOC) sequestration without appropriate check on soil Nitrogen (N) and C: N ratio can offset greenhouse gas (GHG) mitigation balance through N mineralization and Nitrous oxide (N_2O) emission. This study assessed the impact of land utilization types (LTUs) on Carbon and Nitrogen sequestration and C:N ratio. The LUTs included secondary forested land, monocropped land (Oil palm Plantation), farmland (under continuous cassava cultivation for over 5 Years) and grassland. Soil samples were collected in seven replicates from each LUTs at depths 0-30 and 30-60 cm and analyzed for soil attributes. Soil organic carbon was analyzed using wet dichromate oxidation method. Fixed depth method was used to determine C and N sequestration. Findings: The LUTs and management practices had significant influence on CS, NS and C:N ratio. At depth 0-30 cm, CS in farmland was highest and varied significantly ($P<0.05$) from the other LUTs which were statistically the same. In the subsoil, monocroped land recorded the highest and followed the trend: monocropped land (97.42 kg/m ^{2})> grassland (91.88kg/m ^{2})> farm land (75.06 kg/m ^{2}) > forest land (41.30 kg/m ^{2}). NS was highest in farmland (11.92kg/m^2) in the top soil. But in the sub soil, monocopped land showed the highest with the trend: monocropped land (13.41kg/m ^{2})> grassland (10.93/m ^{2})> farmland (10.3 kg/m ^{2}) > forest land (6.56 kg/m ^{2}). The CN ratio at depth 0-30 cm was lowest (6.79) in farmland and was highest in monocropped soil (8.76). At 30-60 cm depth, monocropped land still showed the highest. CN followed the trend: monocropped land (8.30) > grassland (7.56) > farmland (7.26) > forest land (652). From the result obtained, monocropped and grassland should be considered tor stabilizing and retaining C and N in deeper soils. Farmland LUT showed higher potential to sequester C in top soil but the lower CN ratio in farm land indicates possible net mineralization of N which can cause emission of N_2O and thereby offset (GHG) mitigation balance.

KEY WORDS: CS, SOC, LUT, GHG, C/N, N_2O

Introduction

Global climate change has had recognizable effects on the environment. Scientists have high opinion that global temperatures will continue to rise for years to come, mainly due to GHGs (CO_2, CH_4, N_2O etc) produced by anthropogenic activities (NASA, 2021). According to Rosenberg (2020), even in best-case scenario, the disadvantages of global warming outweigh any possible advantages. Climate change mitigation strategies therefore include approaches to decarbonize or reduce CO_2 and other GHGs emission and proposal to sequester them and store them in geologic formations (Fawzy et al., 2021). Soil, plants and ocean represent Carbon sinks that absorbs CO_2 from the atmosphere (NRDC, 2019). Soil sits at the centre of global dynamics in the Carbon and Nitrogen cycles between the atmosphere, vegetation and oceans.

Soils are, in fact, the main compartment of climate regulation and the primary source of Greenhouse gases emissions. According to Jobgg and Jackson (2010) and Bisbo et al. (2017), the soil contains huge volumes of carbon budgets. Mineral soils contain between 1500 and 2400Pg of organic carbon (org.-C), which is nearly three to four times greater than the amount of C in biomass (450-650 Pg) and between twice and three times the amount found in the atmosphere (approximately ~829 G tC) (Ciais et al 2013). Soil organic carbon (SOC) pools are extremely sensitive to changes in land-use/land cover, with soils potentially becoming either sources or sinks of atmospheric CO2 depending on land-use management practices (Al-Kaisi et al., 2005; Chen et al., 2009; Zanatta and Salton, 2010).

The use of fossil fuels leads to land use changes, which affect the dynamics of soil organic carbon (SOC) and total nitrogen (STN) (Lozano-García and Parras-Alcántara, 2013; Olorunfemi 2020). Changes in land use and cover (LULC) are critical to the operation and longevity of natural ecosystems (Zhang et al., 2017; Olorunfemi et al., 2020). Various practices related to land use that are supportive of carbon storage (carbon sequestration) have remarkable potential in combating climate change. Nevertheless, land management practices that are capable of both storing carbon and releasing Nitrogen oxides (NOx) could offset the overall greenhouse gas (GHG) mitigation balance! The capacity of soils to absorb and retain carbon, as well as the duration of its storage, are location-specific and dependent on land management practices (Cho, 2018). Moreover, the distribution of SOC is affected by soil pedogenic characteristics such as clay content and depth (Okebalama 2017, Udom et al., 2015), nitrogen input from deposition or application, soil carbon-to-nitrogen ratio (C:N) (Signor et al 2011; Nave et al., 2009) among other factors. C:N ratio is a critical parameter that influences soil behavior, crop yield, and the mineralization process leading to the production of nitrogen oxides.

MATERIAL AND METHODS

Description of Study Area

The study was carried out in Tai Local Government Area of Rivers State, Nigeria. The area is bounded by Oyigbo Local Government Area (North), Ogu /Bolo and Gokana Local Government Area. Such as (South), Khana Local Government Area (East) and Eleme Local Government Area. To the West. The area lies on Latitude 4043’0” N and longitude 7018’ 0” E. Some different communities in Tai Local Government Area where the soil samples were collected from are such as Bunu, Nonwa, Ban Ogoi. All of them and Koroma. Some additional information about The annual rainfall is over 2000mm with biomodal distributions. Wet season starts from in March to October with peaks in June/July. It also includes and September. The soil in the area is derived from the Coastal Plain Sands of the Niger Delta and it is predominantly Ultisols. The Land use practice in the area includes agriculture, fishing, lumbering and different other non-agricultural activities which may have exposed the area to pollution.

Field Work and Soil Sampling

Four sampling communities were constructed based on four distinct land use categories (grassland, arable farm land, mono crop land, and forest), with soil samples collected at random in seven separate repetitions at two depths (0-30 and 30-60cm). The soil sample was gathered during the peak of the rainy season. Seven disturbed and seven undisturbed samples were obtained at 0-30 and 30-60 cm depths from each land use type using a soil augur and metal cores. A total of 56 disturbed and undisturbed soil samples were collected, correctly marked for easy identification, and delivered to the laboratory for examination.

Table 1. Soil Sample Locations, Coordinates and Land Use Histories of the Study Area

Land-use	Coordinates	Land use Histories
Forested land	4^0 45’59.76” N, 7^0 16’ 20.9994” E (Koroma Tai)	The forest site is more than 20 years. The land is covered with trees, wild oil palms, bamboos, shrubs and undergrowth (creepers and thickets). Vegetation is more or less of a secondary type and very tall wild oil palms scantly distributed.
Mono cropped land	4^0 44’ 46.6794” N, 7^0 13’ 9754” E (Bunu Tai)	The oil palm plantation has been in existence for more than twenty years and the land is covered with shrubs and undergrowth. The fronds are incorporated in to the soil yearly as a source of manure to the palm tree
Grassland	4^0 74’ 49.4794” N, 7^0 23’ 8754” E (Nonwa Tai)	The grass land has been fallow for four years with elephant grass and shrubsdominating
Arable farm land	4^0 50’ 58.9914” N, 7^0 13’ 8.9754” E (Ban Ogoi Tai)	The farmland has been under cassava cultivation and is being used for continuous cultivation for five years. Crop residues are usually incorporated into the soil during harvesting and mulching is done during weeding.

Photos of land use covers

Plate 1 shows the Monocropped Land cultivated with oil palm only for over 20 years

Plate 2 showing the Arable Farm Land under continuous cassava cultivation over the past 5years

Plate 3 shows the Grass Land with elephant grass being dominant

Plate 4 shows the Forest land which is of secondary type

Laboratory Analysis

The samples underwent significant disturbance and were air-dried naturally before being crushed using wooden rollers and passed through a series of sieves with varying mesh sizes to separate aggregate classes ranging from 4.75mm to 2.0mm, 2.0mm to 1.0mm, 1.0mm to 0.5mm, 0.5mm to 0.25mm, and less than 0.25mm. The entire soil was utilized for thorough analysis. The undisturbed core samples were carefully prepared, saturated to field capacity, to ensure accurate examination.

Determination of Saturated Hydraulic Conductivity, Moisture Content and Bulk Density

Identifying Saturated Hydraulic Conductivity was carried out using the constant head permeability method outlined in Klute and Dirkson's (1986) work. This technique involved measuring the drainage of water from soil core samples that had been fully saturated for an extended period until a consistent flow rate was achieved. At this critical juncture, the flow rate was determined using a specific equation.

The determination of Saturated Hydraulic Conductivity plays a vital role in soil analysis, providing essential insights into water movement within the soil profile. While the constant head permeability method has its challenges, it yields valuable information for enhancing our understanding of soil properties and behavior.

$$K_{sat} = \frac{Q}{AT} \times \frac{L}{\Delta H}$$

Where; K_{sat}= Saturated hydraulic conductivity (cm hr^{-1})

Q = Volume of water that flows through a cross section area (cm^2)

T = Time elapses (s)

L = Length of core (cm)

ΔH = Hydraulic Head (cm)

Bulk density was determined using the core method as described by Anderson and Ingram (Anderson and Ingram 1993)

Bulk Density $(gcm-3) = \frac{Mass\ of\ dry\ soil\ (g)}{volume\ of\ bulk\ (cm3)}$

Moisture Content was determined at field capacity using the formulae:

MC=Ww_f-OD

Where Wwf =Wet weight at field capacity

OD= Oven dry weight

Soil pH and particle size analysis

A Bechman's zeromatic pH metre was used to assess soil pH at a soil water ratio of 1:2.5 (Thomas, 1996). The modified hydrometer technique (Gee and Or, 2002) was used to examine particle size distribution, with sodium hexametaphosphate (calgon) serving as a dispersant. Gravitational sedimentation in accordance with Stoke's Law was used to establish the percentages of sand, silt, and clay. The soil texture was assessed using a typical textural triangle. The total nitrogen content of the soil was calculated using Macro Kjeldahl techniques (Bremner Mulvancy, 1982). Total organic carbon levels were determined using the Walkley and Black Wet dichromate oxidation Method (Nelson and Sommes, 1996).

Determination of soil Organic Carbon Stock, Nitrogen stock, CN Ratio and Total Carbon

Soil organic carbon stock had been calculated using the technique of fixed depth volume. The technique by Are et al. (2018) assessed the proportional input of small earth material (<0.2mm) towards the whole soil mass, layer thickness, and concentration of soil carbon employing the subsequent formula.

SOC Stock (kgm^2)= $\frac{Organic\ Carbon\ concentration\ x\ BD\ x\ Soil\ layer\ thickness\ x\ fine\ earth\ content}{100}$

Where BD = $\frac{Total\ Soil\ Mass\ (mg)}{Sample\ Volume\ (m3)}$

Soil organic Nitrogen stock was obtained from bulk density using total Nitrogen concentration with the following equation.

Total Nitrogen Stock (kgm^{-2}) = $\frac{total\ nitrogen\ concentration\ x\ BD\ x\ Soil\ layer\ thickness\ x\ fine\ earth\ content}{100}$

Carbon to Nitrogen ratio was calculated using the equation

C:N= $\frac{Total\ carbon}{Total\ Nitrogen}$

ANOVA, known as Analysis of Variance, involves examining data collected from four distinct land use categories at different depths (0-30cm and 30-60cm). This analysis focuses on carbon and nitrogen levels across diverse land types to determine average discrepancies using Fisher's protected test. The study by Gomez and Gomez (1984) is referenced here with a 5% significance level. Pearson's correlation analysis was used to identify key factors influencing the CN ratio and the process of Carbon Sequestration.

RESULT

The characteristics of the top and sub soils of the four land use categories are detailed in Table 2. The distribution of particle sizes in the soils indicates a prevalence of sand particles in all land uses at depths of 0-30 cm and 30-60 cm. Specifically, the particle size distribution ranges from 843.14 to 878.86 g/kg, 45.14 to 76.86 g/kg, and 76.00 to 87.14 g/kg for sand, silt, and clay fractions, respectively, at 0-30 cm depth. At depths of 30-60 cm, the distribution ranges from 673.4 to 824.57 g/kg, 61.71 to 88.00 g/kg, and 113.71 to 248.57 g/kg for sand, silt, and clay, respectively.

In the upper soil layers, there was a significant variation ($P<0.05$) in the sand and silt fractions across the different land use types, while the clay fractions did not exhibit significant differences ($P>0.05$) among the four land uses. The farmland's topsoil contained the highest sand fraction, followed by forest soil (878.86 g/kg and 872.00 g/kg, respectively), with the monocropped soil showing the lowest sand fraction (843.14g/kg). Moving to the lower soil layers, the forest soil displayed the highest sand fraction (824.57 g/kg), followed by farmland (774.29 g/kg), while monocropped soil maintained the lowest sand fractions (673.14 g/kg).

Monocropped soils had the highest silt content (76.86 g/kg) followed by grassland (52.57 g/kg) while farmland showed the highest least fraction (45.14 g/kg) in the top soil. At 30-60 cm soil depth, farmland showed the highest silt content of 88.00 g/kg followed by monocropped soil (78.29 g/kg) while forest showed the least silt fraction (61.71 g/kg). The clay content of the four land use types increased with depth. While farmland and forest showed the same values (76.00 g/kg) as the highest, they were not significantly different ($P>0.05$) from grassland and monocropped soils that had 87.14 g/kg and 80.00 g/kg at 0-30 cm depth. In the subsoil, there was significant difference ($P<0.05$) among the clay contents of the four land uses. The clay content of monocropped and grassland soils were significantly highest (248.57 g/kg and 194.24 g/kg) respectively. Forest showed the least clay content of 113.7 g/kg.

The textural classes were mainly loamy sand for 0-30 cm depth and sandy clay loam for monocropped and grassland at 30-60 cm while farmland soil at 30-60 cm depth was sandy loam, forest soil at this depth was loamy sand.

Table 2. Particle density and textural class of soils under the different land uses studied

Land use types	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Textural class
Grassland	860.29ab	52.57cd	87.14e	Loamy sand
Farm land	878.86b	45.14d	76.00e	Loamy sand
Forest land	872.00a	52.00dc	76.00e	Loamy sand
Moncropped land	843.14bc	76.86ab	80.00e	Loamy sand
30-60cm				
Grass land	729.43[e]	66.77b[c]	194.29b	Sandy clay loam
Farm land	774.29d	88.00a	137.71c	Sandy loam
Forest land	824.57c	61.71c	113.71d	Loamy sand
Moncropped land	673.14f	78.29ab	248.57a	Sandy clay loam

Means with the same alphabet are not significantly ($P<0.05$) different

Table 2 shows the effect of different land use types on soil bulk density, hydraulic conductivity, and moisture content descriptions. The bulk density ranged broadly from 1.37 to 1.54 g/cm3 in the topsoil and subsoil, 1.46 to 1.71 g/cm3 respectively.

Saturated hydraulic conductivity overview

Ranged equivalently from 14.33 to 50.31 cm/hr (topsoil) and 2.96 to 16.90 cm/hr (subsoil). Moisture Content showed a variance between 40.29 to 53.91 % and 30.87 to 58.27 % at different soil depths for context purposes.

Bulk density was significantly noticeable for farmland (pectin < 0.05) marking the highest among all land uses. Cornering different results at 0-30 cm and 30-60 cm depths (1.54 g/cm3 and 1.79 g/cm3). Other entities showed no noticeable difference (pleasing pectin > 0.05).

Detailed bulk density analysis

The lowest bulk density encountered in forest soils (1.37 g/cm3) at 0-30 cm depth. While monocropped soils revealed (1.46 g/cm3) density at 30-60 cm depths. It's essential to acknowledge the solid relationship between bulk density and depth.

Hydraulic conductivity surfaced with distinctions at $P<0.05$ in the topsoil, with a stagnant result in the subsoil. Grassland taking a lead in saturated hydraulic conductivity, preceding forest soils (50.31 cm/hr and 46.83 cm/hr) in the topsoil. While monocropped densely placed in hydraulic performance in the subsoil alongside forest (16.90 cm/hr and 12.19 cm/hr) respectively.

Farmland observer noted critically through the session recording the least result (18.71 cm/hr and 2.96 cm/hr) at 0-30 cm and 30-60 cm depths.

Moisture content of the soil increased with depth except in farmland where it decreased with depth. Forest soil showed the highest moisture content (53.91%) followed by grassland (42.84%) at both 0-30 cm and at 30-60 cm. the lowest moisture content was recorded in monocrpped (39.69%) and farmland (30.87%) at depths 0-30 and 30-60cm depths.

Table 3 Some physical properties of the four land use types

Land use types	BD (g/cm3)			Ksat (cm/hr)	Moisture C(%)
		0-30 cm			
Grassland	1.44^{c}			50.31^{a}	42.84^{bcd}
Farmland	1.54^{bc}			18.71^{b}	40.29^{bcd}
Forest land	1.37^{c}			46.83^{a}	53.91^{ab}
Monocropped land	1.45^{c}			14.33^{b}	39.69^{cd}
		30-60 cm			
Grassland	1.71^{ab}			3.46^{b}	50.41^{abc}
Farm land	1.78^{a}			2.96^{b}	30.87^{d}
Forest land	1.49^{bc}			12.19^{b}	58.27^{a}
Monocropped land	1.46^{c}			16.90^{b}	41.13^{bcd}

Means with the same alphabet are not significantly (P<0.05) different

BD= Bulk density, Ksat= Saturated Hydraulic Conductivity and MC= Moisture Content

Chemical characteristics

Chemical characteristics of the soils under the four land uses are shown in Table 4. pH values of the soils indicate that they were slightly acidic. The values ranged from 4.93 (monocropped soil) to 6.63 (farmland) in the top soil and 4.96 (forest soils) to 5.89 (farmland) at 30-60 cm depth. The soils pH values decreased slightly with depth except for monocropped soil which increased slightly with depth though not significant, while farmland showed the highest pH value (6.63), monocropped soil showed the lowest pH (6.63) in the top soil and forest soil showed the least(4.96) in the sub soil.

The total nitrogen concentration of soils from various land uses ranged from 0.23 to 0.34% and 0.10 to 0.14% at depths of 0-30 and 30-60 cm, respectively. Farmland had the greatest TN concentration in both the top and subsoil (0.34 and 0.14%, respectively) and did not differ substantially from the other land use groups at 0-30 cm (P>0.05). Grassland has the lowest TN content (0.23%). In the subsoil, monocropped soil had the lowest TN content (0.10%). Only farming had a significant difference (P<0.05) in TN compared to the other land use groups. TN content in grassland and farms was statistically equivalent (P>0.05). Percentage TN was found to decrease with depth.

Total Carbon (TC), Soil Organic Carbon (SOC) are shown in Table 5. The total carbon (TC) ranged from 1.97 to 2.46 % and 0.96 to 1.19 % for the surface and subsurface soils respectively. Farmland showed the highest total carbon (2.46 %) followed by monocrpped soil (2.21 %). Grassland had the least total carbon in the surface soil in the soil surface. In the subsurface soil, farmland still showed the highest TC (1.19 %) followed by grassland (1.12 %). Although the TC content of the four land uses were statistically the same at P>0.05 in the subsoil, forest and monocropped soils showed the least.

Soil organic carbon (SOC) ranged from 1.83 to 2.31 % and 0.82 to 1.02 % for top and sub soil respectively. SOC was highest in farmland (2.31%) and significantly different from other land use types in the surface soil. Grassland showed the lowest SOC (1.83%) in the top soil. at depth 30-60 cm Farmland still showed the highest organic carbon (1.02%) while forest showed the least (0.82%) organic carbon content; at this depth, there was no significant difference (P>0.05) in SOC concentration among the four land use types. SOC was observed to show decrease with depth.

Land use types	**SOC (%)**	**TC (%)**	**pH**	**TN (%)**
		0-30cm		
Grassland	1.83^{b}	1.97^{b}	5.61^{c}	0.23^{b}
Farmland	2.31^{a}	2.46^{a}	6.63^{a}	0.34^{a}
Forest land	2.07^{ab}	2.20^{b}	5.00^{e}	0.25^{b}
Monocropped land	2.07^{ab}	2.21^{b}	4.93^{e}	0.24^{b}
	30-60cm			
Grassland	0.98^{c}	1.12^{c}	5.39^{d}	0.14^{c}
Farmland	1.02^{c}	1.19^{c}	5.89^{b}	0.14^{c}
Forest	0.82^{c}	0.96^{c}	4.96^{e}	0.13^{cd}
Monocropped land	0.85^{c}	0.99^{c}	5.03^{e}	0.10^{d}

Table 4. Influence of land use types on soil SOC and TC

Means with the same alphabet are not significantly (P<0.05) different

SOC= Soil Organic Carbon and TC= Total Carbon

The result of the Carbon sequestration (CS) Nitrogen sequestration (NS) and Carbon to Nitrogen (C;N) ratio are shown in Table 4. CS ranged from 64.97 to 80.65 kg C/m^2 for the top. Considering the land use types, soil organic carbon sequestration at 0-30 cm depth followed this trend: farmland (80.66kgC/m^2) > monocopped land (71.30 kgC/m^2)>grassland (68.56 kgC/m^2)>forest (64.97 kgC/m^2) and at depth 30-60cm, CS ranged from 41.29 to 97.42 kgC/m^2 and followed the trend: monocropped land(97.42 kgC/m^2), grass land (91.88 kgC/m^2) > farmland (75.06 kgC/m^2) and forest (41.30 kgC/m^2). CS followed no definite trend with depth. CS at 0-30 cm depth was statistically the same while at 30-60 cm, it varied greatly (P<0.05). Forest soil sequestered the least soil organic carbon (64.97 kgC/m^2) at both 0-30 and 30-60cm depths. In the sub soil, monocropped land had the highest significant carbon stock of 97.42 kgC/m^2 followed by grassland soil (91.88 kgC/m^2).

The result of Nitrogen sequestered varied significantly (P<0.05) among the four land use types. NS was significantly high in farmland (11.92 kgC/m^2) followed by grassland 8.56 kgC/m2 in the top soil. in the sub soil, monocopped land showed the highest with the trend: monocropped land (13.41kg/m ^{2})> grassland (10.93/m ^{2})> farm land (10.3 kg/m ^{2}) > forest land (6.56 kg/m ^{2}).

The C:N ratio ranged from 6.79 to 6.75 and 8.76 to 8.30 at 0-30 cm and 30-60 cm depth. The highest CN ratio of 8.75 and 8.31 were obtained in monocropped and forest soil respectively and the least of 6.52 was obtained in farmland at depth 0-30cm. in the subsoil, monocropped and grassland soils showed the highest CN (8.30 and 7.56) respectively farmland and forest showed the least (6.52 and 7.26). The C:N ratio decreased with depth except for farmland where it increased with depth.

Table 4.5. Impact of land use types on Carbon Sequestration, CN Ratio and Nitrogen Stock

Land use	**Carbon stock (kg/m^2)**	**Nitrogen stock (kg/m^2)**	**CN Ratio**	
		0-30cm		
Grassland	68.56^{c}	8.56^{cd}	8.14^{ab}	
Farmland	80.66b^{c}	11.92^{ab}	6.79^{c}	
Forest	64.97^{c}	7.78^{d}	8.33^{ab}	
Monocropped	71.30^{c}	8.15^{d}	8.76^{a}	
		30-60 cm		
Grassland	91.88^{ab}	10.93^{a}	7.56^{abc}	
Farmland	75.06^{c}	10.36^{bc}	7.26^{bc}	

Forest	41.30[d]	6.56d	6.52[c]	
Monocropped	97.42[a]	13.41[b]	8.30[ab]	

Means with the same alphabet are not significantly (P<0.05) different

Discussion

Soil physical characteristics

The sand content decreased as depth increased across the four land uses, while the silt and clay fractions showed an increase in concentration with depth. The rise in clay content at deeper levels across all land use categories is potentially a result of the movement of clay particles from the surface to lower soil layers, consequently elevating the amount of sand content in the uppermost soil strata. Soil clay content is relatively low compared to the overall sand fractions, with sand dominating and silt being the least prevalent among the various particle sizes. This pattern is commonly observed in soils in southern Nigeria, influenced by the mineral composition and the origin of the soils in the region. Similar observations were made by Okebalama (2017) in a study investigating soil organic carbon levels in diverse land uses in South Eastern Nigeria. These outcomes are consistent with findings by Okon (2018) who noted higher sand proportions in soils within the Ogoni region, attributing it to the soil formation processes and characteristics of the study area. Therefore, the prevalence of sand fractions in different land uses may be ascribed to the soil's origin rather than the specific land use practices. The texture of a soil has early been considered as a permanent soil attribute since it does not readily subject to change (Ngowari 2018) due to land use, management or conservation (Ahukaemere 2019).

Bulk density range (1.37-1.54g/cm3) in top soil and (1.46-1.79g/cm3) in sub soil was in the range for fair bulk density (<1.6-1.8g/cm3) for sandy soil texture (Soil Quality and Environmental Health 2011) this bulk density pose no threat to plant root development and soil organic carbon accumulation. However, the lowest bulk density recorded under forest and monocropped soils may be due to absence of tilling as the soils have not been disturbed over many years. Highest bulk density was obtained in farmland which is cultivated soil and where tiling (conservational tillaging) is often carried out. High bulk density under farmland could be attributed to cultivation, tilling and tramping during farm activities such as harvesting and management practices. The result is contrary to Udom et al (2015) findings where he reported lower bulk density in top soil of cassava cultivated land use and attributed it to the organic litter falls from cassava. However this result agrees with Are et al (2018) findings where he reported that bulk density increased with depths and was higher in farmland and grassland than in forest soils.

The amount of moisture in the soil increased as you dug deeper, while the saturated hydraulic conductivity decreased with depth. The grassland and forest land showed high moisture levels possibly due to stable structures from minimal disturbance and rich organic matter. The dense vegetation present in these areas like creepers and thickets helped retain moisture. On the other hand, farmland soil had low moisture levels because of poor structural aggregates, limiting available water content. Yihenew and Ayanna (2013) had similar findings, noting that continuous cultivation harmed soil structure, leading to the lowest water content.

The acidity levels in the different land usage areas could be linked to the parent materials like Coastal Plain Sands and their highly weathered state. This aligns with Okon (2018) who also found similar pH levels in the sampled soils. The acidic conditions may stem from excessive precipitation washing away basic cations. Conversely, the farmland's high pH might be due to increased organic matter content from farming practices, in line with Bot and Berries (2005) mentioning that organic matter boost can elevate pH levels in acidic soils.

The SOC content within the topsoil met the required threshold (2%) for sustaining soil quality across all land use types except for grassland, which recorded 1.83%. SOC decreased with depth mainly due to litter fall reduction. At 30-60cm depth, farmland had the highest SOC, likely influenced by bioturbation transfer and root biomass.

Organic carbon trends in surface and subsurface soils followed distinct patterns based on land usage. Farmland exhibited the highest organic matter content both in top and subsoil levels. The contribution of land use systems to organic matter addition markedly affected the organic carbon content levels. Though cultivating farmlands generally leads to lower soil organic carbon, this study suggests that sound soil management practices such as mulching and conservation tillaging play a crucial role in preserving and improving soil organic matter while mitigating reductions from cultivation.

Plant litters and their ease of decomposition may also have been a contributing factor to this observation. Robertson (2014) stated that biomass with a lower CN ratio and lignin decomposes faster and affects the rate of carbon input to the soil and this is observed with the cassava farmland which recorded the lowest CN ratio. The continuous addition of soil organic matter (SOM) in the form of mulching and subsequent mineralization of the added SOM may have also caused the higher OM content recorded in farmlands. The high SOC content in forest and moncropped soils could be attributed to the plant materials and the fact that soils under those land use types were always covered with plant liters. This result corroborate with Yeasmin (2020) studies where he found that OC contents were in line with the native OM status of different land uses. The result also shows that the OC decreased with depth. The decrease with depth could be due to plant litters deposition on the top soil and the low activities of microorganisms beneath the top soils.

SOC values contributed over 80% to the values of the Total C. The SIC content of the soils under the four land uses were far much lower than the OC content of the soils. This indicate that the soils are not calcareous as typical of soils found in humid environment (Suarez 2006., Monger 2014) due to high leaching and elevated moisture content near the surface of the soils. These factors result in elevated CO_2 and thus increase carbonate dissolution (Suarez, 2006). This observation by Suarez (2006) is agreeing with this result of SIC under forest being the lowest (0.13%) with highest moisture content of 53.92% and 58.26% at depths 0-30 and 30-60. The highest SIC content recorded in farm land soil could be attributed to the low saturated hydraulic conductivity of the soil. Land clearing and soil disturbance decreases soil water infiltration and this favors less dissociation of carbonates (Suarez, 2006).

CS range (64.91-80.60kgC/m2) in the topsoil and (41.30-97.42kgC/m2) in the subsoil was less than 30tC/ha across the four land utilization types. As per Minasny et al (2017), the initial 30tC/ha in the topsoil is considered low and can be augmented by 10 per mille to achieve equilibrium within the first twenty years post implementation of optimal management strategies. This emphasizes the need for attention towards enhancing four per mille soils to address food security and climate change in the study area.

The four per mille goal aims to elevate SC stock by 4 per 1000 (or 0.4%) annually to offset global greenhouse gas emissions resulting from human activities (Minasny et al 2017). Soil organic carbon (SOC) tends to have longer residence times in subsoil layers compared to topsoil, where soil organic matter (SOM) may be less prone to biodegradation (Zohra et al 2017). Monocropped land and grassland display promising potential in sequestering carbon in deeper soil layers compared to other land use types.

No significant differences were noted in carbon stocks among the four land uses at depths of 0-30cm, but significant variations were observed at 30-60cm depths. Unlike SOC and nitrogen content of the soils, carbon stocks and nitrogen storage did not exhibit a clear trend with soil depth. Among the land uses, the study revealed no substantial differences at $P<0.05$ in carbon stocks among grassland, monocropped, and forest soils in the surface layer, whereas significant differences existed in carbon stocks at 30-60cm depths among the various land uses. This discrepancy can be linked to the clay content trend in the land utilization types at different depths.

The quantities of clay content showed non-significant differences at $P>0.05$ in the topsoil, while substantial variations were observed in the subsoil clay content among the different land uses at depths of 30-60cm. Udom et al (2015) reached similar conclusions, suggesting that finer particle sizes store greater SOC and TN compared to coarser soil particles. This underscores the significant positive correlation (0.541**) between percentage clay and carbon sequestration.

Clay content exerts a strong influence on the spatial distribution of soil organic carbon sequestration in monocropped and grassland soils. At 30-60cm depth, carbon stocks of these land uses see an increase, with higher clay content soils such as sandy clay loam displaying the highest carbon stocks (91.88kgC/m2 and 75.66kgC/m2) compared to loamy sand and sandy loam soils. The elevated carbon sequestration in grassland and monocropped soils may be attributed to their higher clay content, with a significant increase observed at this depth (19.2% and 16.8%) relative to farmland (4.17%) and forest (1.77%).

Deep soil carbon stabilization is likely influenced by mineral retention (Rumpes and Kogel-Knabner 2011) and is principally stored in silt size aggregates and/or clay fractions based on the soil depths (Zohra et al 2015). This aligns with Obakelema's (2017) observations that clay content boosts soil carbon pools in Okikwe and Nsuka II soils due to the attachment of negatively charged soil organic matter to positively charged clay particles.

The notably lower carbon sequestration in forest soil may indicate the presence of vegetation types such as creepers and thickets that resist degradation and mineralization. Additionally, the age of plants in the forest may contribute to the reduced carbon sequestration, as older plants tend to store less carbon (Ahukaemere 2018). Conversion of forest to well-managed grassland and cropland to grassland has been linked to enhanced soil carbon storage compared to native forest conditions. Studies have also highlighted increased soil organic carbon storage post conversion of cropland to grassland (Poeplau et al 2013, Akpa, 2021).

The carbon-to-nitrogen (CN) ratio plays a crucial role in nitrogen mineralization and potential N2O emissions, which can offset greenhouse gas mitigation efforts. The low nitrogen content contributes to a narrow CN ratio (<20:1) in the soils, promoting rapid decomposition and SOM mineralization. This implies that nitrogen availability in the surface layers is not a key factor in reducing carbon losses and enhancing SOC content. CN ratio variation across land use types likely reflects differences in organic residue decomposition entering the soil organic matter pool and is influenced by varying vegetation covers.

The CN ratio generally remains low across land use types, indicating net mineralization in the four land uses. Farmland soil surfaces display the narrowest CN ratio, possibly due to increased mineralization and organic matter oxidation. These findings are consistent with Yimer et al (2007), reporting CN ratios below 10:1 in agricultural soils and attributing it to enhanced oxygenation and higher soil temperatures from tillage. Monocropped soils exhibit higher CN ratios compared to their respective farmlands, as they experience less annual disruption than farmland.

The elevated mineralization in farmland can also be linked to pH levels, a major factor influencing mineralization rates. When pH drops below 5.5, bacterial activity diminishes, affecting organic matter nitrification (Okebalama et al., 2017). The considerably high pH levels noted in farmland could be associated with heightened microbial activities, nitrification, and subsequent mineralization.

Conclusion

The result of this study showed that land use types influenced C and N sequestration in the study area. C:N ratio range (6.79-8.76) in top soil and (6.52-8.30) in sub soil is generally low compared to 20:1(Klemedttson 2007) and 30:1(Signor et al 2005) for reduced N_2O emission. Farmland LUT showed high potential to sequester C and N but the lower CN ratio in farm land indicates possible net mineralization of N which can cause emission of N_2O and thereby offset (GHG) mitigation balance. In the sub soil, monocopped land showed the highest potential to sequester C and N with higher CN ratio. Hence, monocropped land and grassland soils could be helpful in retention and stabilization of SOC and N in deep soil depth in these and similar soils.

In addition, SOC level in soil is not the sole determinant of CS; % clay content, C:N, OM are important determinants of SOC and its sequestration. Therefore, carbon sequestration could be function of O.M and its CN ratio, land use management practices, and soil texture.

Land use type and land use management practices that encourage the addition of organic matter and crop residue to the soil such as monocropped land and grassland are important in enhancing C and N sequestration. Also, since a change in bulk density between sampling times in land use types can affect the estimation of differences in CS when comparing fixed soil depths, CS in future studies should be calculated for Equivalent Soil Mass (ESM)

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