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Original Article

Assessment of carbon and nitrogen stock in soils of cassava and rice farms in the Derived Savanna of Anambra State, Southeastern Nigeria

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Maduabuchi Johnbosco OKAFOR[1]*, Emmanuel Chibuikem NNABUIHE[1], Chike Onyeka MADUEKE[1], Thaddeus Nzubechukwu EGBOKA[2], Oluropo Ayotunde APALOWO[3], Chinelo Jennifer NWAIWU[1], Chidozie Iheanyi ERNEST[2] & Chukwuemeka Joseph EZEONU[1]

[1]*Department of Soil Science and Land Resources Management Nnamdi Azikiwe University, Awka, Nigeria*
[2]*Department of Soil Science and Technology. Federal University of Technology, Owerri, Nigeria*
[3]*Department of Crop Science and Horticulture, Nnamdi Azikiwe University, Awka, Nigeria*

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ABSTRACT

The study assessed the carbon and nitrogen stocks in the soil solum of cassava and rice farms in the derived savanna of Anambra state southeast Nigeria. Soil samples were collected from two depths (0 -15 cm and 15 – 30 cm), at two land utilization types, and two locations, using random sampling techniques. Particle size distribution, bulk density, organic carbon, total nitrogen, pH, and soil structural stability index were analysed. The results indicated significant variations in soil properties and carbon-nitrogen stocks between land utilization types and depths. Rice fields demonstrated higher organic carbon (up to 4.72 C. $Mgha^{-1}$) and nitrogen stocks (up to 0.41 N. $Mgha^{-1}$) compared to cassava fields (up to 3.27 C. Mgh^{-1}) and (up to 0.26 N. $Mgha^{-1}$). The study highlighted the influence of soil texture, bulk density, and pH on carbon and nitrogen distribution. These findings emphasize the importance of adopting sustainable agricultural practices to enhance soil health, improve crop yields, and mitigate greenhouse gas emissions. The research provides a crucial baseline for further studies and informs soil management strategies in the derived savanna ecosystem.

KEYWORDS: *Carbon sequestration, Nitrogen retention dynamics, Organic matter distribution, Sustainable land management, Agricultural soil health*

INTRODUCTION

Soil organic carbon and nitrogen are critical components that influences soil fertility and health (Obalum *et al*., 2012). The interplay between agricultural practices and carbon-nitrogen dynamics has become a focal point in the global discourse on climate change mitigation and sustainable food production; these elements, carbon and nitrogen play a pivotal role in agricultural productivity and ecosystem function (Onyegbule *et al*., 2023). It is no doubt

*Corresponding Author: buchi.okafor86@gmail.com; +2347032532603

that in developing countries, that continuous exploitation of land for agricultural purposes, has led to a decline in soil organic carbon and nitrogen stocks. As the world is challenged with rising atmospheric carbon dioxide levels, soils emerge as unsung heroes in the carbon sequestration narrative (Okolo *et al*., 2023). Agricultural soils in particular have immense potential as carbon sinks, but heavily affected by lack of management practices (Okafor and Chidozie, 2016). Cassava and rice, two staple crops in sub-Saharan Africa, certainly would have great impact on soil organic carbon and nitrogen stocks. The impact of land-use change, particularly the conversion of natural ecosystems to agricultural fields is also a growing concerning in the region (Chiedozie *et al*., 2019). Understanding the dynamics of soil organic carbon and nitrogen in different land use system is crucial for developing sustainable management practices in developing countries (Ota *et al*., 2024).

The assessment of carbon and nitrogen stocks in cassava and rice fields within the derived savanna holds a very significant value for both agricultural productivity and environmental sustainability (Ernest et al., 2015). By quantifying these essential soil properties, the study would have contributed a better understanding of the soil health status in the area; the findings would have provided insights into the effects of land use change on soils carbon sequestration and nutrient availability. Having no visible published work of carbon and nitrogen stock of the area, this investigation not only bridges a critical knowledge gap but also lays the groundwork for future research on optimizing agricultural practices for enhanced soil health and climate resilience in the derived savanna ecosystem in Ndiokpaleze and Amanuke; this study would also assist the development of appropriate soil management strategies to enhance carbon and nitrogen storage, improve crop yields, and mitigate greenhouse gas emissions. The objective of the study therefore, was to assess the carbon and nitrogen stocks of cassava and rice farms in the derived savanna of Ndiokpaleze and Amanuke, in Anambra state, Nigeria. The specific objectives were to determine the carbon and nitrogen stocks in the soils of cassava and rice farms in the derived savanna; compare the carbon and nitrogen stocks between cassava and rice farms in the study area; assess the relationship between selected soil properties studied and carbon and nitrogen stocks.

MATERIALS AND METHODS

Study Area

The study was carried out in rice fields and adjacent cassava fields at Ndiopkaleze, Orumba South Local government area, and Amanuke, Awka North Local government area, both in Anambra state. The study areas are located in the Southeastern part of Nigeria, within the humid tropical zone; Ndiokpaleze is located within latitude 6.003028 N, 6.003177 N, and 7.17305 E, 7.17313 E, with mean annual temperature of around 27°C, mean rainfall of 1900 mm, and relative humidity of 66 % per annum. The area is characterized by undulating topography with varying altitude, between low to mid altitude.; the geological formation of the study area mainly Imo clay shale, with some evidence of Nanka sands (Ayadiuno *et al*., 2022). The soils of the study area are classified as Oxisols (Soil survey staff, 2022), and Lixisols (World Reference Base, 2022). The study area in Amanuke is located within 6.31195 N, 6.31253N and 7.049545 E, 7.050068 E, with mean annual temperature of 29°C, mean rainfall of 1950mm, with relative humidity of 71% per annum. The geology of the area is mainly Ogwashi-Asaba (Ayadiuno, *et al*., 2022), with tilts of Imo clay shale; the soils in the area are mainly sands/silt stones, and Livisols (WRB, 2022). The rainy season in the areas lasts from mid-April to late October, with the lowland areas, especially Amanuke, still saturated till late January.

Soil Sampling

Soils were sampled at Cassava and adjacent rice fields in each location, each farm area measuring a total of two chains (800m^2 or 0.08 ha). Random sampling technique was employed, where disturbed (auger) samples were randomly collected within the farm at two depths – 0-15 and 15-30cm, and composite samples collected with four replications on each of the farms, making a total of thirty-two (32) disturbed samples for the two locations. Undisturbed (cores) samples were randomly collected at four points (representing four replications), at two depths to determine bulk density, making a total of thirty-two (32) undisturbed samples for the two locations. The core's dimension that was used measured 5cm × 5cm (diameter and height); hammer and flat plank were used to drive the core samplers into the soil. Soils were subsequently airdried and sieved with 2mm sieve, and were well labelled, before taken to the laboratory for analysis.

Laboratory Analysis

Soil properties that were analysed were particle size, bulk density, organic carbon, total nitrogen, and pH. Soil Structural stability index were also calculated, as well as carbon nitrogen ratio. Soil organic carbon and total nitrogen stock were also calculated.

Particle size was determined using Bouyoucos method, as modified by Andres *et al*. (2014).

Bulk density was determined by the core method (Grossman and Reinsch, 2002).

$$Bulk\ density\ (BD) = \frac{\text{oven dry weight of soil}}{\text{Volume}} \ldots\ldots (1)$$

Organic carbon was determined by the modified Walkley–Black wet digestion/oxidation method described by Nelson and Sommers (1996).

Total nitrogen was determined by Micro Kjeldahl digestion method, as described by (Allen, 1989).

Soil pH, 1:2.5 (aqueous suspension) soil and distilled water was determined using a high precision pH meter, as described by (Thomas, 1994).

C/N ratio was obtained by dividing percentage organic carbon with percentage total nitrogen.

Data on organic matter concentration (obtained by multiplying the soil organic C content by the van Bernmelen factor of 1.724) and silt and clay fractions of the soils were used to establish a soil structural stability index for the soils as proposed for mineral tropical soils, especially those found in the West African savanna (Pieri 1992).

$$\mathrm{SSSI}(\%) = \frac{\%\mathrm{C} \times 1.724}{\%\mathrm{Clay} + \%\mathrm{Silt}} \times 100 \text{ …….. (2)}$$

Soil organic carbon/ nitrogen stock was calculated (Anikwe, 2010; Obalum *et al*., 2012) below.

$$SOC\ or\ TN\ Stock\ = \frac{C\ or\ N}{100} \times BD \times A \times D \text{ …….. (3)}$$

where SOC or TN stock are the soil organic C or total nitrogen stock in Mg/ha, C or N is the soil content of organic C or N in %, BD is the soil bulk density in Mgm^{-3}, A is the area of a hectare in m^2, and D is soil depth interval in cm.

Statistical Analysis

Data collected from the study were subjected to Analysis of variance (ANOVA) to determine the variation on land utilization types and soil depths studied; significant difference in the variations were determined using Least significant difference (LSD) at $p \leq 0.05$. Soil parameters were also subjected to Pearson correlation coefficient, to determine the relationship of soil organic carbon and total nitrogen stock to other soil properties studied.

RESULTS AND DISCUSSION

Result

Seleced soil properties

Table 1, showed the selected soil properties of the studied sites. Rice farm at Amanuke, was clay loam at the surface (0-15cm), and sandy loam at 15-30cm depth, while cassava farm was loamy sand at the surface (0-15cm), and sandy loam at 15-30cm depth. It was different at Ndiokpaleze, as rice farm was sandy clay loam at both depths; cassava farm however, was clay loam at the surface (0-15cm), and clay at 15-30cm depth. Bulk density ranged from 1.70 Mg/m^3 to 2.24Mg/m^3, with the lowest being at Amanuke cassava farm (0-15cm), the highest being at Ndiokpaleze rice farm (15 – 30 cm) depth. Soil structural stability index showed that soils at both land utilization types, depths and locations were very unstable, as their values were all below 20 %. pH across the studied soils were strongly acidic to slightly acidic (5.29 to 5.99). percentage organic carbon (% OC) ranged from 0.58 % to 2.14 %, with the highest value being at Ndiokpaleze rice farm (0-15cm), and the lowest value being at Amanuke cassava farm (15 – 30 cm); generally, rice farms in both locations showed higher % OC than cassava farms. Percentage total nitrogen (% TN) was fairly high across the studied soils, however, the highest value (0.186 %) was recorded at Ndiokpaleze rice farm (0 -15 cm), and lowest value (0.052 %) was recorded at Amanuke cassava farm (15 – 30 cm).

Table 1b, showed variation of land utilization types and depth effect on selected soil properties. There was significant variation in % sand at cassava farm in Amanuke between surface (74.05 %) and sub-surface (54.55 %) soil; also, Ndiokpaleze, there was significant variation in sand content between rice farm (40.47 %) and cassava farm (24.90 %) at 0 – 15 cm depth, and between rice farm (52.15 %) and cassava (24.43 %) at 15 – 30 cm depth. % Silt showed significant variation between soil depths at Amanuke cassava farm (Table 1b); also, between rice farm (32.35 %) and cassava farm (16.90 %) at 0 – 15 cm depth. There was also significant variation between depths at Ndiokpaleze rice farm, with the surface soil having more silt content (37.18 %) than the sub-surface soil (21.00 %); same was in cassava farms, and between rice and cassava farm at 0 – 25 cm depth. Clay content showed similar variation pattern; rice farm had more clay content than cassava farm at 0 – 15 cm depth at Amanuke, however, Ndiokpaleze cassava farm had more clay content than rice farm at both soil depths studied. Bulk density showed no significant variation except between depths at Amanuke cassava farm. SSSI showed significant variation between depths at cassava farms at Amanuke, and between rice and cassava farms at 0 – 15 cm depth; also varied significantly between depths at Ndiokpaleze cassava farm, and between rice and cassava farms at both depths. pH showed significant variation between depths and land utilization types across the locations; so was organic carbon and total nitrogen content. Carbon/nitrogen ratio had no significant variation except between rice and cassava farms at both depths.

Soil organic carbon stock

Soil organic carbon stock showed a consistent pattern across depth, at the land utilization types and locations (Fig. 1 & 2). At Amanuke rice farm, SOC stock was 2.59 Mg/ha at the surface soil, and 2.30 Mg/ha at the sub-surface soil (Fig. 1); cassava farm in the same location showed 1.6 Mg/ha at surface soil, and 1.4 Mg/ha at the sub-surface soil. There was decrease in SOC stock with increase in depth at both land utilization types. At Ndiokpaleze rice farm, SOC stock was 4.72 Mg/ha at the surface soil, and 3.92 Mg/ha at the sub-surface soil (Fig. 2); cassava farm on the other hand showed 3.27 Mg/ha at the surface soil, and 1.93 Mg/ha at the sub-surface soil, showing the same decrease in depth across the studied land utilisation. There was significant variation in SOC stock between rice farm and cassava at both locations (Fig.1 &

2), however, there was no significant variation between depths in rice farm at both locations, whereas cassava farm at both locations showed significant variation.

Table 1. Selected soil properties of studied areas

Location	Land utilization types	Depth (cm)	Sand %	Silt%	Clay %	TC	B.D (Mgm-^{3})	SSSI (%)	pH	OC (%)	TN (%)	C/N
Amanuke	Rice	0-15	35.95	32.35	31.7	CL	1.86	3.23	5.29	1.16	0.095	12.91
		15-30	48.35	25.05	26.6	SCL	1.86	4.13	5.57	1.03	0.090	11.90
	Cassava	0-15	74.05	16.9	9.05	LS	1.70	5.98	5.42	0.79	0.067	11.77
		15-30	54.55	25.80	19.65	SL	2.01	2.23	5.96	0.58	0.052	11.13
Ndiokpa leze	Rice	0-15	40.47	37.18	22.35	SCL	1.84	6.32	5.74	2.14	0.186	11.60
		15-30	52.15	21	26.85	SCL	2.24	5.62	5.42	1.47	0.130	11.69
	Cassava	0-15	24.9	32.96	42.14	CL	1.80	3.53	5.99	1.52	0.119	12.78
		15-30	24.43	21.44	53.13	C	2.04	1.80	5.86	0.79	0.071	11.22

TC = Textural class, B.D = Bulk density, SSSI = Soil structural stability index, OC = organic carbon, TN = total nitrogen, C/N = carbon/ nitrogen ration.

Table 1b. Variation of Land utilization types and depth effect on selected Soil Properties

Land utilization types	Depth (cm)	Sand	Silt	Clay	B.D (Mgm^{-3})	SSSI (%)	pH	OC (%)	TN (%)	C/N
Location: Amanuke										
Rice	0-15	35.95	32.35	31.7	1.86	3.23	5.29	1.16	0.095	12.91
	15-30	48.35	25.05	26.6	1.86	4.13	5.57	1.03	0.090	11.90
	LSD (p≤0.05)	NS	NS	NS	NS	NS	0.20	0.11	NS	NS
Cassava	0-15	74.05	16.9	9.05	1.70	5.98	5.42	0.79	0.067	11.77
	15-30	54.55	25.80	19.65	2.01	2.23	5.96	0.58	0.052	11.13
	LSD (p≤0.05)	14.11	8.85	NS	0.18	2.22	0.20	0.11	NS	NS
Depth (cm)	**Land utilization types**									
0-15	Rice	35.95	32.35	31.70	1.86	3.23	5.29	1.16	0.095	12.91
	Cassava	74.05	16.90	9.05	1.70	5.98	5.42	0.79	0.067	11.77
	LSD (p≤0.05)	14.11	8.85	15.32	NS	2.22	NS	0.11	0.019	2.46
15-30	Rice	48.35	25.05	26.6	1.86	4.13	5.57	1.03	0.090	11.90
	Cassava	54.55	25.80	19.65	2.01	2.23	5.96	0.58	0.052	11.13
	LSD (p≤0.05)	NS	NS	NS	NS	NS	0.20	0.11	0.019	2.46
Location:	**Ndiokpaleze**									
Rice	0-15	40.47	37.18	22.35	1.84	6.32	5.74	2.14	0.186	11.60
	15-30	52.15	21.00	26.85	2.24	5.62	5.42	1.47	0.130	11.69
	LSD (p≤0.05)	10.73	5.56	NS	NS	NS	0.10	0.18	0.018	NS
Cassava	0-15	24.90	32.96	42.14	1.80	3.53	5.99	1.52	0.119	12.78
	15-30	24.43	21.44	53.13	2.04	1.80	5.86	0.79	0.071	11.22
	LSD (p≤0.05)	NS	5.56	NS	NS	1.06	0.10	0.18	0.018	NS
Depth (cm)	**Land utilization types**									
0-15	Rice	40.47	37.18	22.35	1.84	6.32	5.74	2.14	0.186	11.60
	Cassava	24.90	32.96	42.14	1.80	3.53	5.99	1.52	0.119	12.78
	LSD (p≤0.05)	10.73	5.56	14.68	NS	1.06	0.10	0.18	0.018	NS
15-30	Rice	52.15	21.00	26.85	2.24	5.62	5.42	1.47	0.130	11.69
	Cassava	24.43	21.44	53.13	2.04	1.80	5.86	0.79	0.071	11.22
	LSD (p≤0.05)	10.73	NS	14.68	NS	1.06	0.10	0.18	0.018	NS

TC = Textural class, B.D = Bulk density, SSSI = Soil structural stability index, OC = organic carbon, TN = total nitrogen, C/N = carbon/ nitrogen ration.

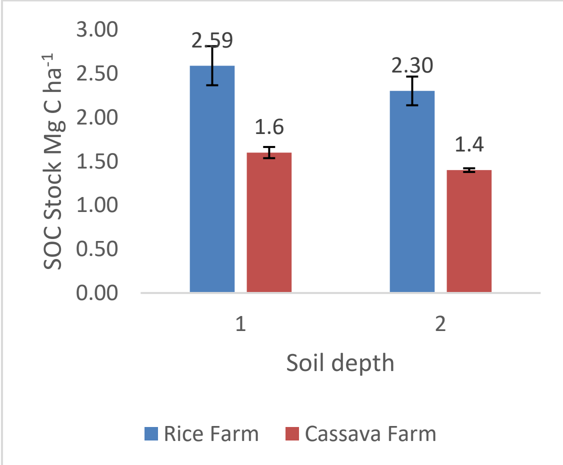

Fig. 1: SOC - Stock variation at depth and different LUT in Amanuke

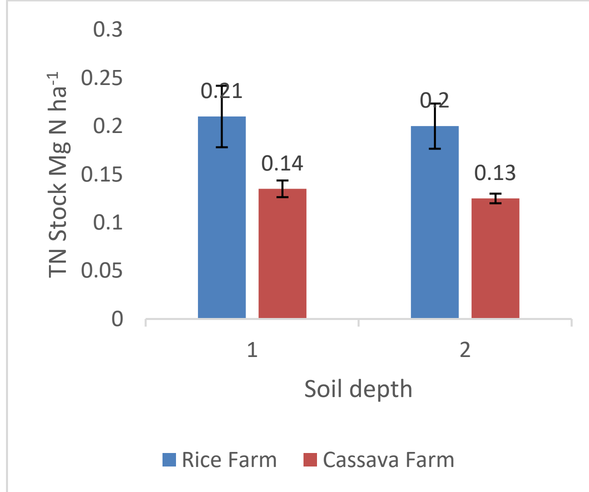

Fig. 1: TN - Stock variation at depth and different LUT in Amanuke

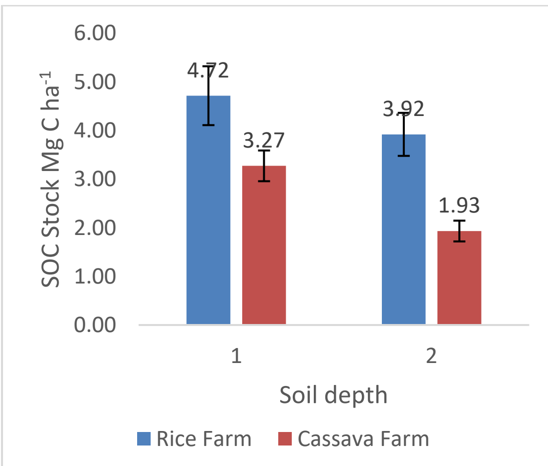

Fig.2: SOC - stock variation at depth and different LUT in Ndiokpalez

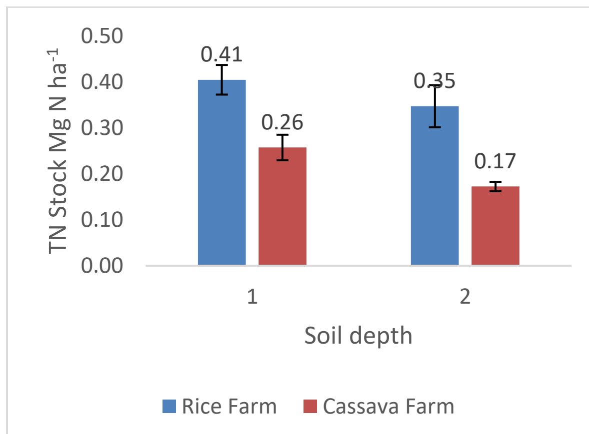

Fig. 1: TN - Stock variation at depth and different LUT in Amanuke

Total nitrogen stock

Total nitrogen stock showed consistent pattern across depths, land utilization types and locations. Amanuke rice farm showed 0.21 Mg/ha nitrogen stock at the surface soil, and 0.2 Mg/ha at the sub-surface (Fig. 3). Cassava farm on the other hand showed 0.14 Mg/ha at the surface, and 0.13 Mg/ha at the sub-surface. Ndiokpaleze rice farm showed 0.41 Mg/ha nitrogen stock at the surface soil, and 0.35 Mg/ha and the sub-surface (Fig. 4); Cassava farm on the other hand showed 0.26 Mg/ha nitrogen stock at the surface soil, and 0.17 Mg/ha nitrogen stock at the sub-surface soil. There was significant variation between rice farm and cassava farm at both depths, at the two locations; and just like carbon stock, nitrogen stock at both rice and cassava farm in Ndiopkaleze was higher than rice and cassava farms at Amanuke.

Relationship between SOC and TN stock and selected soil properties

Correlation of SOC and TN stock with other selected soil properties studied were analyzed separately at 0-15 cm, and 15 – 30 cm depth at Amanuke (Table 2a & 2b); and at Ndiokpaleze (Table 3a & 3b).

Key observations at surface soil (0 – 15 cm) in Amanuke were, strong negative correlation between Sand % and Silt % (-0.68), Sand % and Clay % (-0.89), pH and Clay % (-0.81); very strong positive correlation between SOC stock and OC % (0.92), TN stock and TN % (0.93), OC % and Silt % (0.86) (Table 2a). At the sub-surface (15 -30 cm), key observations were highly negative correlation between Sand % and Clay% (-0.83), strong correlation between OC % and TN % (0.89), Very strong correlation between SOC stock and OC % (0.95), and extremely strong correlation between TN stock and TN % (0.97).

*Corresponding Author: buchi.okafor86@gmail.com; +2347032532603

At surface soil (0 – 15 cm) in Ndiokpaleze, key observations were, strong negative correlation between Sand % and Clay % (-0.97), strong positive correlation between SOC stock and OC % (0.70), TN stock and TN % (0.74), negative correlation between pH and SSSI % (-0.97) (Table 3a). At the sub-surface soil (15 – 30 cm), key observations were, extremely strong negative correlation between Sand % and Clay % (-0.99), strong positive correlation between SOC stock and OC % (0.83), very strong positive correlation between TN stock and TN % (0.84), and negative correlation between pH and SSSI % (-0.92) (Table 3b).

Table 2a. Relationship between studied soil properties at (0-15cm) depth in Amanuke

	Sand %	**Silt %**	**Clay %**	**B.D (Mg/m^3)**	**SSSI %**	**pH**	**OC %**	**TN %**	**C/N**	**SOC Stock (Mg/ha)**	**TN Stock (Mg/ha)**
Sand %	1.00										
Silt %	-0.68	1.00									
Clay %	-0.89	0.27	1.00								
B.D (Mg/m3)	-0.20	0.50	-0.05	1.00							
SSSI %	0.76	-0.55	-0.66	-0.26	1.00						
pH	0.69	-0.15	-0.81	0.34	0.73	1.00					
OC %	-0.71	0.86	0.40	0.26	-0.27	-0.17	1.00				
TN %	-0.46	0.71	0.17	0.11	-0.14	-0.08	0.84	1.00			
C/N	-0.30	-0.02	0.41	0.17	-0.22	-0.19	-0.03	-0.56	1.00		
SOC Stock (Mg/ha)	-0.63	0.90	0.27	0.62	-0.30	0.04	0.92	0.73	0.03	1.00	
TN Stock (Mg/ha)	-0.44	0.80	0.08	0.45	-0.16	0.10	0.84	0.93	-0.44	0.88	1

Table 2b. Relationship between studied soil properties at (15 – 30 cm) depth in Amanuke

	Sand %	***Silt %***	***Clay %***	***B.D (Mg/m^3)***	***SSSI %***	***pH***	***OC %***	***TN %***	***C/N***	***SOC Stock (Mg/ha)***	***TN Stock (Mg/ha)***
Sand %	1.00										
Silt %	-0.30	1.00									
Clay %	-0.83	-0.28	1.00								
B.D (Mg/m3)	0.69	-0.30	-0.53	1.00							
SSSI %	0.64	-0.31	-0.46	0.35	1.00						
pH	-0.03	0.60	-0.32	0.18	-0.63	1.00					
OC %	-0.29	-0.10	0.35	-0.47	0.53	-0.82	1.00				
TN %	-0.44	-0.24	0.58	-0.36	0.36	-0.75	0.89	1.00			
C/N	0.27	0.40	-0.50	-0.32	0.23	-0.05	0.17	-0.29	1.00		
SOC Stock (Mg/ha)	-0.06	-0.22	0.19	-0.17	0.72	-0.85	0.95	0.86	0.08	1.00	
TN Stock (Mg/ha)	-0.26	-0.36	0.47	-0.14	0.51	-0.78	0.83	0.97	-0.37	0.89	1

Table 3a. Relationship between studied soil properties at (0 -15 cm) depth in Ndiokpaleze

	Sand %	*Silt %*	*Clay %*	*B.D (Mg/m^3)*	*SSSI %*	*pH*	*OC %*	*TN %*	*C/N*	*SOC Stock (Mg/ha)*	*TN Stock (Mg/ha)*
Sand %	1										
Silt %	0.78	1.00									
Clay %	-0.97	-0.92	1.00								
B.D (Mg/m3)	0.01	0.12	-0.06	1.00							
SSSI %	0.96	0.80	-0.94	0.00	1.00						
pH	-0.91	-0.77	0.90	-0.22	-0.97	1.00					
OC %	0.84	0.61	-0.79	0.08	0.94	-0.94	1.00				
TN %	0.79	0.54	-0.73	-0.11	0.87	-0.83	0.87	1.00			
C/N	-0.22	-0.16	0.21	0.26	-0.25	0.19	-0.15	-0.61	1.00		
SOC Stock (Mg/ha)	0.54	0.50	-0.55	0.76	0.60	-0.75	0.70	0.47	0.11	1.00	
TN Stock (Mg/ha)	0.64	0.52	-0.63	0.58	0.71	-0.83	0.78	0.74	-0.31	0.90	1

Table 3b. Relationship between studied soil properties at (15 - 30 cm) depth in Ndiokpaleze

	Sand %	*Silt %*	*Clay %*	*B.D (Mg/m^3)*	*SSSI %*	*pH*	*OC %*	*TN %*	*C/N*	*SOC Stock (Mg/ha)*	*TN Stock (Mg/ha)*
Sand %	1.00										
Silt %	0.25	1.00									
Clay %	-0.99	-0.41	1.00								
B.D (Mg/m3)	0.18	0.24	-0.22	1.00							
SSSI %	0.96	-0.01	-0.90	0.09	1.00						
pH	-0.90	0.02	0.85	-0.27	-0.92	1.00					
OC %	0.58	-0.51	-0.46	0.08	0.78	-0.76	1.00				
TN %	0.61	-0.54	-0.48	0.03	0.78	-0.75	0.95	1.00			
C/N	0.02	0.12	-0.04	0.37	0.07	-0.15	0.22	-0.07	1.00		
SOC Stock (Mg/ha)	0.61	-0.26	-0.53	0.59	0.69	-0.79	0.83	0.79	0.33	1.00	
TN Stock (Mg/ha)	0.62	-0.29	-0.54	0.55	0.70	-0.77	0.80	0.84	0.09	0.97	1

Discussion

Soil texture

At rice farms in Amanuke and Ndiokpaleze, sand content increased with depth, while silt and clay content generally decreased. The reason behind that phenomenon could be because of the ecosystem of rice field -wetland or often flooded, leading to finer particles (silt and clay) settling at the surface, while coarser particles (sand) tend to be more prevalent at deeper layers due to water movement and depositions (Nnabuihe *et al*., 2023; Hernanz *et al*., 2000). Cassava farms at Amanuke showed higher sand content at the surface, which decreases with depth, while silt and clay content increase; whereas at Ndiokpaleze, clay content was significantly higher at both depths. The reason could be the aerobic nature of the cassava farm, leading to a higher proportion of sand at the surface. The deep-rooting nature of cassava can influence soil structure and compaction, affecting clay content at various depths (Maduakor, 1993).

Bulk density

Bulk density increased with depth at both land utilization types and locations. The reason is often typical due to compaction and lower organic matter content at greater depths. Topsoil usually contains more organic materials, which reduces bulk density, contrary to the sub surface layers (Salome *et al*., 2009).

Soil structural stability index

SSSI was generally higher in rice farm at Ndiopkaleze, especially at the surface soil (0 – 15 cm), likewise in surface soil (0 – 15 cm) of cassava farm at Amanuke. The reason for this could lie on the influence organic matter content and soil texture have on SSSI; higher organic matter and finer particles at the surface soil contribute to greater stability at the surface. Variations observed could be attributed to differences in organic matter input, root structures, and management practices like tillage (Obalum *et al*., 2013).

pH

Soils studied showed slightly acidity across both land uses and locations, with minor variations between depths. The slightly acidic nature of the soils could be influenced by the nature of south eastern soils (Ultisol), fertilizers used, and water management practices. Rice paddies often have slightly higher pH due to waterlogging, which can lead to anaerobic conditions (Bahmaniar, 2008); cassava farms tend to be more aerated, maintaining slightly lower pH values.

Organic carbon and total nitrogen

OC and TN decreased with depth across both land utilization types and locations. This is could be attributed to the preponderance of plant residues and root biomass on the surface soil (0 -15 cm), as well as decomposition of organic matter and microbial activities near the surface than the sub-surface (Kramer *et al.,* 2013)

Carbon/Nitrogen ratio

C/N ratio was relatively stable across depths, but slightly higher in Amanuke's rice farm at the surface (0 -15 cm). The slight variations could be due to differences in crop residues, root turnover, and microbial activity in the soil (Nicolartdot *et al*., 2001).

Variation in soil carbon stock

In Amanuke, the soil carbon stock showed significant variation with depth and land utilization. In rice farm at Amanuke, carbon stock decreased with depth. This may suggest higher concentration of organic matter in topsoil, which is common in agricultural soils, due to organic inputs like crop residues (Button *et al.,* 2022). The cassava farm showed similar pattern of soil organic carbon stock, the decrease was even pronounced at 15 – 30 cm depth. In Ndiopkaleze, soil organic stock in rice farm showed a similar pattern to that of Amanuke, with high organic carbon stock at the soil surface (0 – 15 cm); the soil organic stock decreased at 15 – 30 cm depth, but remains higher than cassava farm. This trend maintains consistent with Amanuke rice farm, indicating that rice farms generally have higher soil organic carbon stock (Button *et al.,* 2022)

Variation in total nitrogen stock

In Amanuke rice farm, nitrogen stock showed relatively high value at 0 – 15 cm depth, which is typical for topsoil due to nitrogen inputs from fertilizers and organic matter decomposition (Dang *et al.,* 2022). There was decrease in nitrogen stock at 15 – 30 cm, reflecting reduced organic matter and microbial activity at greater depths (Okolo *et al.,* 2023). Cassava on the other hand, had lower nitrogen stock at 0 -15 cm compared to rice farm. In Ndiopkaleze, nitrogen stock was higher at the soil surface, and decreased at 15 – 30 cm, aligning with organic matter distribution observed in the rice farms in Amanuke. Cassava farm had lower nitrogen stock than rice farm.

Comparison of SOC/TN stock between Amanuke and Ndiokpaleze

In both Amanuke and Ndiokpaleze, rice farms exhibited higher SOC stocks compared to cassava farms. The surface soil (0 – 15 cm) had higher SOC stock in both locations, with a decrease observed at 15 – 30 cm depth. Similarly, rice farms in both locations had higher total nitrogen stock compared to cassava farms. The total nitrogen stock was higher in the surface soil (0 – 15 cm), and decreased at 15 – 30 cm depth in both locations. These phenomena suggest that the significant nitrogen accumulation at the surface soil in rice farms could be attributed to higher organic matter input and fertilizer use (Okolo et al., 2023).

Relationship between soil properties studied

At 0 -15 cm soil depth in Amanuke, the inverse relationships in soil particle size distribution are typical in soils where soil particle size distribution dictates that increase in one fraction result in decrease of another (Bittelli *et al.*,1999). Positive correlation between organic carbon (OC) and total nitrogen (TN) was expected as higher organic matter and nitrogen directly contribute to higher stock in the soil (Yang *et al.,* 2011). Negative relationship between pH and clay affirms the suggestion that lower pH can lead to more acidic soils, which often have higher clay content due to weathering processes that break down larger particles (Kome *et al.,* 2019). At 15 – 30 cm depth in same location, the relationship between sand, clay, and silt remained consistent, reflecting the particle size distribution's influence throughout the two depths studied; so was the positive correlation between organic carbon and total nitrogen.

In the surface soil at Ndiokpaleze, the inverse relationship between clay and sand contents was typical as in other depths and locations. The negative correlation between pH and SSSI may suggest that acidic conditions may lead to higher soil structural stability due to the precipitation of certain minerals that bind soil particles together (Jiang-Ming, 2014; Xu *et al.*,2024).

CONCLUSION AND RECOMMENDATION

The result of the study revealed significant differences in soil properties and carbon-nitrogen stocks between the two land utilization types and soil depths. Rice farms across the studied locations had higher carbon and nitrogen stocks compared to cassava farms, with the surface soil (0 – 15 cm) showing the greatest accumulation The comparison of the two land utilization types highlighted significant difference in soil properties, with higher levels of organic carbon and nitrogen at the rice farms across the locations. Additionally, the study found that soil texture, bulk density, and pH significantly influenced the distribution of carbon and nitrogen stocks, emphasising the importance of these soil properties in managing soil health and fertility. The study recommends that:

Use of organic amendments should be intensified in farming practices, to enhance soil organic carbon and nitrogen stocks, especially in cassava farms, where lower levels were observed.

Adoption of soil management practices that maintain optimal pH and soil texture, such as conservation tillage and balanced fertilization, to improve carbon and nitrogen retention in agricultural soils.

Further research and monitoring should be carried out, to better understand the long-term effects of different agricultural practices on soil carbon and nitrogen dynamics, and to develop more effective soil management strategies for the derived savanna region of Anambra state.

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Authors'contribution

Authors: ECN, CJN, OAA, helped with the field work, sample collection, methodology and laboratory analysis. COM, NTE, contributed immensely in literature review, and data analysis All authors read and approved final manuscript.

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