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Research Article

Interactive effect of land use types and depth on selected physicochemical properties of soils: A case study

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Abstract

Inappropriate land use management usually upsets soil nutrient status, leading to unsustainable crop and soil productivity. This study investigated the interactive effect of land use types and soil depth on selected soil properties, based on a case study in Ifite Ogwari, Anambra State, Nigeria. Three land use types (grassland, cassava and rice farms) were selected and mapped for the study. Auger and core soil samples were collected from each of the land use types in three replicates at 0-20 cm, 20-40 cm and 40-60 cm depths, after which the collected samples were subjected to laboratory analysis. From the results obtained, the soils belonged to clay textural class. Bulk density ranged from 1.60 to 2.10 g/cm^3 and increased down the depth. Total porosity was highest at 0-20 cm depth under land use types. Saturated hydraulic conductivity (Ksat) of the soil was generally low and fell in the range of 0.01-0.09 cm/hr. The pH of the soil ranged from 4.84 to 5.87 signifying very strongly to moderately acidic soils. Organic carbon was generally low (0.26-1.32%) and was highest at 0-20 cm depth under cassava farm, which decreased down the depth. The values of sodium adsorption ratio (SAR) ranged from 0.07 to 0.13 meq/l, reflecting a non-sodic soil. The effective cation exchange capacity (ECEC) of soils under land use types and across the depths ranged from 3.53 to 8.33 cmol/kg, with higher concentrations observed at the topsoil. The interaction between land use types and depths revealed significant differences ($P<0.05$) in total porosity, saturated hydraulic conductivity, organic carbon, sodium adsorption ratio, pH, and effective cation exchange capacity of the soil. This underscores the importance of considering land use and soil depth as critical factors in soil nutrient availability and distribution, which are essential for enhancing soil productivity and supporting plant growth.

Keywords: degradation; cultivation; land utilisation; pedons; texture; soil management

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Introduction

Land use is any human driven activities on land which could be determined by the need of the producer, the environmental condition, socio economic status, political and cultural manners of the given area (Lambin *et al.* 2003; Duguma *et al.*, 2010). Among the factors that could influence the user's preference is the soil condition of the field and can be identified by analyzing the soil properties and comparing with the standards. These soil properties combine to determine the type of plants that will grow in a soil or in a particular region. It is believed that soils within the tropical and subtropical regions are well-drained, weathered and low in the major soil nutrients (Yerima and Van Ranst, 2005; Lal, 2019).

As the population increases natural forest and grassland are converted into cultivated farmland thereby affecting soil properties (Tesfahunegn, 2016). These changes in land use and soil carbon have strongly affected soil structure and other soil properties which in turn have implying effects on the soil microbial activity as well as on the soil organic carbon dynamics (Bhattacharyya *et al.*, 2022).

The intensified agricultural land expansion on the expense of loss of the natural environment could also lead to severe land degradation. Soil can rapidly lose both quality and quantity over a brief duration. Effective agriculture necessitates the sustainable utilization of soil resources and fundamental understanding of sustainable land use for proficient agricultural production management (Kiflu and Beyene, 2013; Takele *et al.*, 2014; Agan and Bayrak, 2024). These requirements are particularly essential as rural farmers in the research area lack sufficient knowledge regarding agricultural practices.

Empirical data on the effect of land use and soil depth on soil properties is lacking in the study area especially with the increasing food demand that requires harnessing the fertility of the available soil resources, agricultural sustainability and livelihood of these farmers therefore better understanding of the distribution of soil nutrients in profile of diverse land use types is essential hence the study evaluated the interactive effect of land use and soil depth on selected soil properties for effective soil management in Ifite Ogwari area of Anambra State, Nigeria.

Materials and Methods

Description of the Studied Area

The study was conducted in Ifite Ogwari area of Anambra State, Nigeria, and lies within latitude 06°4'N and 06°60'N and longitudes 06°57'E and 06°95'E. It is among the major agricultural producing towns of Anambra State with cassava, yam, plantain, rice and okro among the major food crops grown in the area. According to FDALR (1990), Ifite Ogwari soils are of Imo shale geologic formation (Figure 1) and belonged to clay textural class (Nwosu and Nweke, 2024). The area falls within the transition zone which according to Chukwu (2007) is derived savannah with some patches of rainforest. Two main seasons of dry and wet seasons prevail in this area with an average annual rainfall of 2737.4 mm based on 2022 data by Nigeria meteorological Agency though rainfall onset and cessation period have varied recently. The average temperature and relative humidity of the area 35 °C and 74% respectively.

Selection and History of Land Use Types Studied

The selection of studied area was due to land degradation challenges impacting the soil properties in the area hence three most common land use types (cassava farm, rice farm and grassland) were used for the study. Features of the studied land use types are presented in Table 1.

On each of the land use types an area of about 200 sqm was mapped for a detailed study after interviewing the land owners on the land utilisation history which were recorded as follows: (a) Rice farm – The farm has been under lowland rice cultivation for over 10 years and is usually rain fed; Planting is usually done through broadcasting method while chemical fertilizer is heavily used in the cultivation process. (b)

Grassland – This area of land has been under grass cover for an estimated period of 3 years having spear grass, Bahamas grass and couch grass as the dominant grass species. (c) Cassava Farm – The land has been under continuous cassava cultivation which sometimes is mixed with maize and yam for over 6 years.

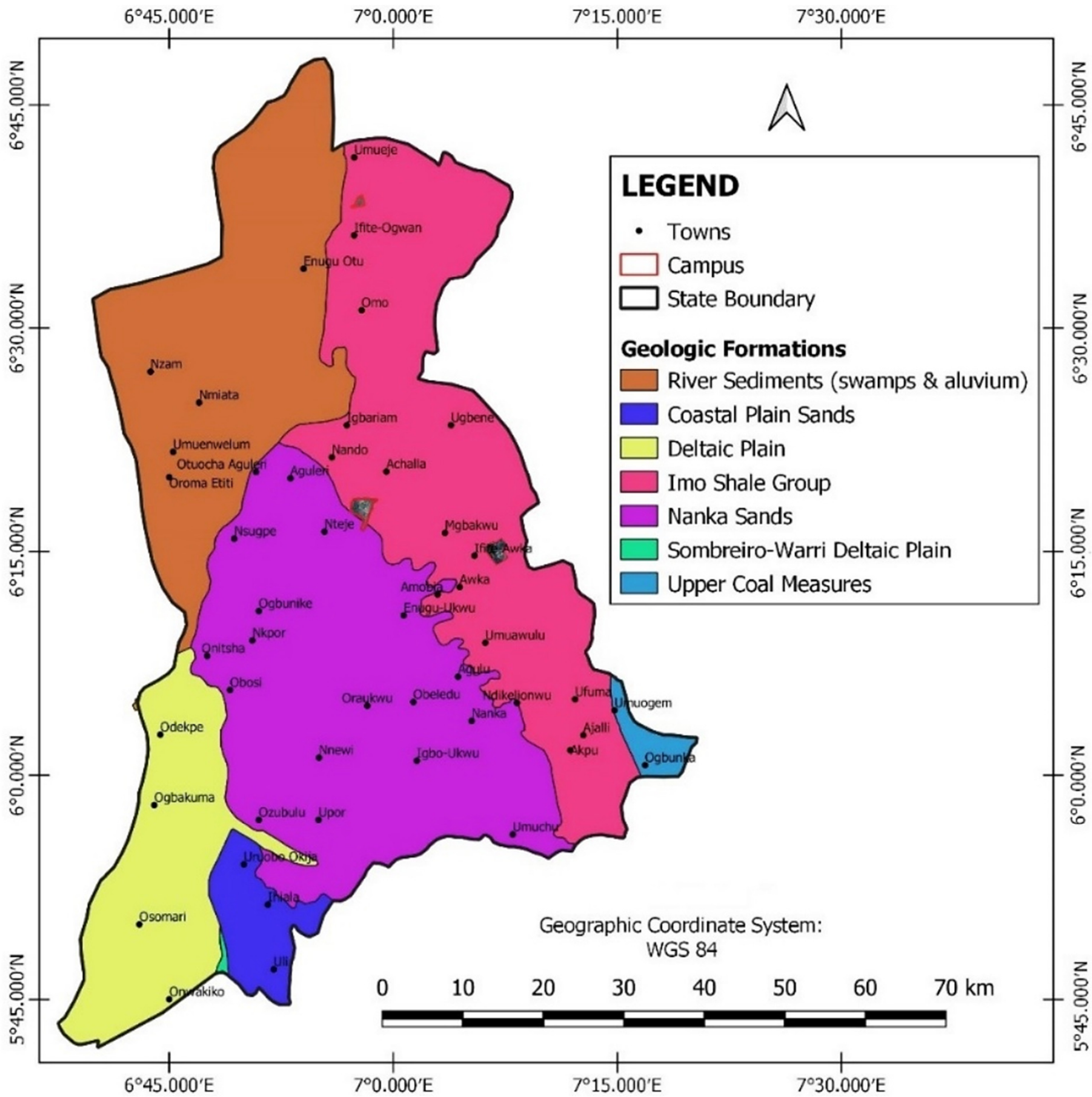

Figure 1. Geological map of Anambra State

Soil Sample Collection

Auger and core soil samples were randomly collected from each of the land use types in three replicates at 0-20 cm, 20-40 cm and 40-60 cm depths. The core sampler measured 5 cm by 5 cm in both diameter and height. The collected soil samples were bagged, properly labelled, air dried for laboratory analysis. Auger soil samples were used to determine the particle size distribution and selected chemical properties of the soil while the core soil samples were used to determine selected physical properties of soil.

Table 1. Features of the studied land use types

Land use	Longitude (°E)	Latitude (°N)	Elevation (m)	Elevation Class	Slope	Slope Class
Rice farm	6.964627815	6.638649932	54	Lowland (<60 m)	4.04	Gentle Slope <5
Cassava farm	6.954165859	6.636870969	64	Midslope (60-70 m)	3.20	Gentle Slope <5
Grassland	6.9592472	6.639056404	73	Upland (>70 m)	5.89	Moderate Slope >5

Laboratory Soil Analysis

i. Particle Size Distribution: The hydrometer method as described by Gee and Or (2002) was used to determine the particle size distribution while the soil texture was determined using the USDA textural triangle.

ii. Bulk Density was determined by core method as described by Grossman and Reinsch (2002).

iii. Soil Total Porosity was calculated from the bulk density as shown in this equation:

$$\text{Total porosity (\%)} = 1 - \frac{\text{Bd}}{\text{pd}} \times 100$$

where Bd =Bulk density, Pd =particle density (2.65 g/cm^3).

iv. Saturated Hydraulic Conductivity (k_{sat}) was determined by the constant head permeability procedure according to Youngs (2000). Darcy's equation for vertical flow of liquid was used for the computation of K as shown in the equation:

$$K_{sat} = \frac{QL}{AT\triangle H}$$

where, Q is water discharge (cm), L is length of soil column, A is the interior cross-sectional area of the volume of soil not occupied by soil column (cm), H is the head pressure difference causing the flow and it is dimensionless, T is the time of flow measured in seconds.

v. Soil pH was measured electrometrically by glass electrode in pH meter in both KCI (1 N) and distilled water suspension using a soil: liquid ratio of 1:2.5 (International Institute for Tropical Agriculture, 1979).

vi. Soil Organic Carbon was determined using the wet dichromate oxidation method of Walkley and Black (1934).

vii. Total Nitrogen (TN) was determined by the Kjeldahl digestion method (Jackson, 1958).

viii. Effective Cation Exchange Capacity (ECEC) determined by summation of basic and acidic cations.

ix. Sodium Adsorption Ratio (SAR) was calculated using the formula below:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Statistical Data Analysis

Data collected was subjected to ANOVA using SPSS 13.0 (SPSS Inc., Chicago, IL, USA). Separation of means for statistical difference was done by the least significance difference (LSD) at 5% probability level.

Results

Particle Size Distribution

The result obtained showed that soils under grassland, cassava farm and rice farm had the highest sand, silt and clay contents with respective values of 349 g/kg, 235 g/kg and 466 g/kg (Table 2). Clay particle was the most dominant soil particle with the highest value hence the soils under land use types belonged to clay textural class. As regards soil depth (Table 3), the highest sand and clay contents were obtained at 20-40 cm depth while 0-20 cm depth recorded the highest silt content. The interaction results of land use types and depth showed a significant difference (P< 0.05%) (Table 4).

Table 2. Main effect of land use types on particle size distribution

Land use	Sand	Silt	Clay	Textural class	SCR
	(g/kg)				
Cassava farm	308	235	457	Clay	0.53
Grassland	349	229	422	Clay	0.53
Rice farm	300	234	466	Clay	0.48
LSD (P<0.05)	*	*	*		ns

Note: SCR – Silt clay ratio; * – significant; ns – not significant (P>5%).

Silt Clay Ratio (SCR)

SCR indicates the weathering stage of the soil and further helps in the classification of tropical soils. The lower the SCR the more weathered the soils are. The result obtained showed that SCR under land use types ranged from 0.48-0.53 with the highest value obtained under cassava farm. SCR had non constant decrease as the depth increased however highest and lowest SCR was obtained at 0-20 and 20-40 cm depths (Table 3).

Table 3. Main effect of depth on particle size distribution

Soil depth (cm)	Sand	Silt	Clay	SCR
	(g/kg)			
0-20	318	248	436	0.56
20-40	343	194	458	0.42
40-60	301	245	454	0.54
LSD (P<0.05)	*	*	*	ns

Note: SCR – Silt clay ratio; * – significant; ns – not significant (P>5%).

Table 4. Combined effect of land use and depth on particle size distribution

Land Use	Depth (cm)	Sand	Silt	Clay	SCR
		(g/kg)			
Cassava	0-20	321	280	392	0.81
	20-40	315	215	495	0.80
	40-60	288	227	485	0.74
Grassland	0-20	307	207	487	0.71
	20-40	327	174	473	0.41
	40-60	267	294	441	0.56
Rice Farm	0-20	325	247	428	0.74
	20-40	388	194	405	0.57
	40-60	335	214	435	0.48
LSD (P<0.05) L×D		*	*	*	ns

Note: SCR – Silt clay ratio; * – significant; ns – not significant (P>5%).

Bulk Density

As per land use types, the results showed that the soils of cassava farm had the highest BD with a value of 1.90 gcm^{-3} while the soils of rice farm had the lowest BD with a value of 1.73 gcm^{-3} (Table 5). The bulk density of soil under cassava farm was significantly higher when compared to other land use types and may be attributed to the continuous cultivation of the cassava farm. As regards soil depth (Table 6), the values obtained increased with an increased depth of which 40-60 cm depth recorded the highest value of 1.90 gcm^{-3} while 0-20 cm depth recorded the lowest with a value of 1.62 gcm^{-3}; the lower BD observed at the upper layer could be as a result of organic matter deposits usually observed at the surface soil.

Total Porosity

Total porosity was highest under rice farm with a value of 34.57% and lowest under cassava farm with a value of 29.47 % (Table 5). Highest total porosity was obtained at 0-20 cm depth with a value of 38.78% and lowest at 40-60 cm depth with a value of 28.40% (Table 6). The lowest total porosity value obtained under cassava farm could suggest reduction in the soil's ability to store water and air exchange due to associated high density. Significant differences (P<0.05%) were observed in total porosity of soil amongst the land use types, depth and their interaction (Tables 5, 6 and 7) and probably may be associated to variations in soil management practices.

Hydraulic Conductivity (Ksat)

From the result obtained, hydraulic conductivity was 0.04 $cmhr^{-1}$ under cassava farm, 0.01 $cmhr^{-1}$ under grassland and 0.01 $cmhr^{-1}$ under rice farm (Table 5). Cassava farm had the highest hydraulic conductivity with a value of 0.04 $cmhr^{-1}$, grassland and rice farm had the lowest hydraulic conductivity with equal values of 0.01 $cmhr^{-1}$. Significant differences were observed in hydraulic conductivity of soil across the depths; the study further observed an increase in Ksat value down the depth with 40-60 cm recording the highest value of 0.04 $cmhr^{-1}$. (Table 6)

Soil pH

The pH of soil under land use types ranged from 5.16-5.79 and was in the order cassava farm> grassland>rice farm while it ranged from 5.44-5.72 across the depths (Tables 5 and 6). The interaction of land use and depth showed significant differences (P<0.05%) as seen in Table 7. Based on the level of acidity, the pH falls in the range of strongly to moderately acidic.

Soil Organic Carbon

The results showed that organic carbon was highest under cassava farm with a value of 1.12% followed by grassland with a value of 1.00% while rice farm had the lowest organic carbon content with a value of 0.36 % (Table 5). Cassava farm had 12% more of organic carbon when compared with grassland. Significant differences were observed in organic carbon contents under land use types and across the depths (Tables 5 and 6). There was a significant difference (P<0.05) in the interaction of land use types and depth (Table 7)

Total Nitrogen

For total nitrogen, cassava farm had 0.09%, grassland had 0.08% while rice farm had 0.03%. Cassava farm recorded the highest total nitrogen content while rice farm recorded the lowest (Table 5). With regards to soil depth, the result showed a significant difference across the depths which decreased as the depth increased with the highest value of 0.09 % obtained at 0-20 cm depth (Table 6)

Sodium Adsorption Ratio (SAR)

The result of SAR under land use types showed 0.09 meq/l, 0.09 meq/l, and 0.08 meq/l respectively under cassava farm, grassland and rice farm (Table 5). The values of SAR under land use types and across the depths were statistically similar (Table 6). SAR usually indicate soil structural stability to dispersion as well describes the tendency for sodium cations to be adsorbed at the cation exchange sites in soil at the expense of other cations.

Effective Cation Exchange Capacity (ECEC)

The results showed ECEC values of 7.24 cmol/kg, 6.59 cmol/kg and 5.00 cmol/kg under cassava, grassland and rice farm. ECEC value under cassava farm was significantly higher compared to other land use types (Table 5). Based on depth, the highest ECEC value of 6.40 cmol/kg was recorded at 0-20 cm depth, which decreased down the soil depth with a value of 4.51 cmol/kg being the lowest obtained at 40-60 cm depth (Table 6). ECEC of a soil shows how well a soil can hold onto and store cations, so a soil with a high ECEC would be able to hold more nutrients than a soil with low ECEC. Furthermore, low ECEC soils are more likely to develop potassium and magnesium deficiencies while high ECEC soils are less susceptible to leaching losses of these cations.

Table 5. Main effect of land use types on selected soil properties

Land use	BD (g/cm^3)	TP (%)	Ksat (cm/hr)	pH	OC (%)	TN (%)	SAR (meq/l)	ECEC (cmol/kg)
Cassava farm	1.90	29.47	0.04	5.79	1.12	0.09	0.09	7.24
Grassland	1.74	34.27	0.01	5.65	1.00	0.08	0.09	6.59
Rice farm	1.73	34.57	0.01	5.16	0.36	0.03	0.08	5.00
LSD (P<0.05)	*	*	*	*	*	*	ns	*

Note: BD – Bulk density; TP – Total porosity; Ksat – Saturated hydraulic conductivity; OC – organic carbon; TN – Total nitrogen; SAR – Sodium sorption ratio; ECEC – Effective cation exchange capacity; * – significant; ns – not significant (P>5%).

Table 6. Main effect of depth on selected soil properties

Depth (cm)	BD (g/cm^3)	TP (%)	Ksat (cm/hr)	pH	OC (%)	TN (%)	SAR (meq/l)	ECEC (cmol/kg)
0-20	1.62	38.78	0.02	5.72	1.00	0.09	0.08	6.40
20-40	1.86	31.14	0.02	5.44	0.89	0.06	0.10	5.71
40-60	1.90	28.40	0.04	5.45	0.59	0.05	0.09	4.51
LSD (P<0.05)	*	*	*	*	*	*	ns	*

Note: BD – Bulk density; TP – Total porosity; Ksat – Saturated hydraulic conductivity; OC – organic carbon; TN – Total nitrogen; SAR – Sodium sorption ratio; ECEC – Effective cation exchange capacity; * – significant; ns – not significant (P>5%).

Table 7. Combined effect land use and depth on selected soil properties

Land use	Depth (cm)	BD (g/cm^3)	TP (%)	Ksat (cm/hr)	pH	OC (%)	TN	SAR (meq/l)	ECEC (cmol/kg)
Cassava	0-20	1.68	36.73	0.02	5.77	1.32	0.11	0.07	8.33
	20-40	1.94	30.81	0.03	5.87	1.25	0.10	0.13	6.81
	40-60	2.10	20.88	0.09	5.75	0.80	0.07	0.09	4.66
Grassland	0-20	1.60	39.81	0.01	5.71	0.49	0.06	0.12	3.54
	20-40	1.82	31.31	0.02	4.84	0.40	0.00	0.07	0.86
	40-60	1.79	32.61	0.01	4.94	0.20	0.03	0.11	0.63
Rice Farm	0-20	1.60	39.81	0.01	5.68	1.21	0.11	0.07	6.67
	20-40	1.82	31.31	0.01	5.61	1.04	0.09	0.10	5.95
	40-60	1.82	31.70	0.01	5.66	0.78	0.06	0.09	3.53
LSD (P<0.05) L×D		ns	*	*	*	*	ns	*	*

Note: BD – Bulk density; TP – Total porosity; Ksat – Saturated hydraulic conductivity; OC – organic carbon; TN – Total nitrogen; SAR – Sodium sorption ratio; ECEC – Effective cation exchange capacity; * – significant; ns – not significant (P>5%).

Discussion

The results of particle size distribution showed significant differences (P<0.05) under land use types and across soil depths (Table 4). Clay fraction was the most dominant soil particle which was irregularly distributed under land use types and across soil depths. The higher clay particle observed at the sub surface soil could be as a result of the translocation of clay particles from the top soil layer down the depth through the eluviation and illuviation processes (Cornu *et al.*, 2014; Pereira *et al.*, 2024). The increased clay fraction in all the soil depths could be associated to erosion, rate of fine particle deposition, farm management practices and biological activities taking place in the studied area.

Studies have proven that clay dispersion is sometimes influenced by humidity and amount of water percolation which is evident in the studied location as it is prone to less water percolation thus the nature of the clay value obtained. The relative alike in the values of silt fraction across soil depths and land use types could be associated to the degree of weathering. High values of silt indicate the formation of young soil. Silt clay ratio showed higher value at the soil surface which decreased with attendant increase in soil depths. The decrease is an indication that the sub soil surface is more weathered than the surface soil. Furthermore, the decrease in values of SCR as the depth increased in this study corroborates with an earlier study by Lal (2000) who stated that SCR for a majority of tropical soils decline with depth and that the ratio may range widely from soil to soil even within the same toposequence.

Generally, SCR values under land use types and at different depths were statistically similar and could suggest the young age of the soils of the studied area; this was in agreement with the report of Nweke *et al.,* (2021) who opined that young parent material usually have SCR greater than 0.26. The nature of SCR value (> 0.38) obtained in this study probably showed that the studied soils have not been subjected to severe weathering and may still have some weatherable minerals (Nweke *et al.*, 2021). The result of bulk density as obtained in this study might be associated with the depth of tillage operations, texture, and organic matter content of the soils however the observed high BD especially under cassava farm (Table 5) could be related to soil compaction due to textural characteristics of the soil as well as structural breakdown. Nweke (2018) asserted that organic matter content influenced bulk density and is likely to be observed in a shallow soil depth tillage practice especially in tropical soil like Nigerian soil where the major implement for tillage operations is wooden hoe that does not cut deeper into the soil layer hence leading to hard pan in some cases. The interaction of land use and depth showed no significant difference (P>0.05) on the bulk density (Table 7). The result of total porosity showed a relatively alike values which decreased as soil bulk density increased. The study observed total porosity values in the range of 20.88-39.81% under land use types and across soil depths. According to Landon (1991) the favourable total porosity of clay content soil is about 50% and above to sustain and regulate the activities of soil biota, enhance good water infiltration and aeration. However, this submission was in contrast with the findings of this study with values of total porosity less than 50% which could suggest soils with water logging problem. The interaction of land use and depth showed a saturated hydraulic conductivity (Ksat) in the range of 0.01-0.09 cm/hr among the pedons and could be termed low (Table 7).

The reduced hydraulic conductivity observed in rice farms can be attributed to the soils used in paddy rice cultivation, which often exhibit low hydraulic conductivity due to puddling and the formation of traffic pans (Kalita *et al.*, 2020; Priyadharshini *et al.*, 2024). The nature of Ksat values observed in this study is an indication of the soil's inability to transmit water due to water logging and associated textural characteristics; similar observation was reported by Nweke and Nsoanya (2015). The pH of soils under land use types and across the depths ranged from 4.84-5.87 and was in the order cassava farm> rice farm> grassland, while organic carbon ranged from 0.20-1.32%.

The acidic nature of soils under the land use types studied could be a natural reflection of the parent material as reported by Nwosu *et al.* (2020) as well as the very high annual rainfall recorded in the region which facilitates extensive leaching of basic cations leaving behind an impoverished soil predominated by acidic cations (Onweremadu, 2007). Higher values of organic carbon were observed at the surface soil which decreased as the soil depth increased; this may be attributed to the position of the topsoil in the profile to have direct organic matter input. The organic carbon content under land use types ranged from 0.36-1.12%. Soil organic carbon has the ability to disperse or aggregate the soil but it is dependent on the threshold level of the organic carbon in the soil as well as the ratio at which it occurs with other aggregating agents. As regards soil depth, organic carbon was highest with a value of 1.00 % at 0-20 cm depth and lowest at 40-60 cm depth with a value of 0.59 %. The obtained results showed a decrease of organic carbon content down the soil depth; similar observation was made by Nnabude *et al.* (2016). The higher organic carbon at the topsoil against the sub soil could be due to its position in the soil profile; which allows for direct input of organic litter (Sahrawat, 2004).

The interaction of land use and depth showed significant difference ($P<0.05$) in organic carbon contents and could be associated to variation in residue management, tillage methods, continuous cropping as well as cultivation with different tillage implements as collaborated by the report of Nweke and Ilo (2019). The organic carbon content of soil in this study was generally low and according to the report of Fullen and Catt (2004) soils with <5% organic matter content are highly erodible. Total nitrogen content was low and statistically similar which decreased proportionately down the soil depth; however higher values were obtained at the surface soil than the sub soils and could be attributed to decomposition process at the surface layer. The obtained result of total nitrogen across the depths showed close relationship with the recorded value of organic carbon; this observation is in line with Ubuoh *et al.* (2013) who reported that the highest total nitrogen available at the topsoil is a confirmation of structural relationship with organic matter with more than 75% of total nitrogen derived from organic matter.

Based on this study, the total nitrogen content of soils was generally low. Nweke (2015) and Nwosu *et al.* (2020) found low soil total nitrogen content in their study which they partly attributed to loss of nutrient at the epipedon. Landon (1991) rated total nitrogen content of <0.1% to be very low and 0.1-0.2% to be low. The SAR values under land use types and across the depths were not fairly distributed; high SAR value is an indication of soil instability while low value show resistance to erosion. Using the general classification for sodium hazard based on SAR values, soils under the studied land use types had very low SAR values which reflects a non sodic soil as collaborated by the report of Ejikeme *et al.* (2021) who made similar observations in soils of Obosi south eastern, Nigeria. The ECEC values under land use types and across soil depths followed a definite trend; here surface soils had higher ECEC values compared to sub surface soil which could be attributed to high litter accumulation and decomposition/mineralisation at the surface soil. There were significant differences($P<0.05$) in ECEC under land use types and across soil depths which may be attributed to the leaching process as well as proportion of clay content; this observation is in line with the findings of Muche *et al.* (2015).

Conclusions

The interaction of land use types and depth in this study showed significant differences in total porosity, saturated hydraulic conductivity, soil pH, organic carbon, sodium adsorption ratio and effective cation exchange capacity. Therefore, for effective soil management, consideration should be given to the combined factors of land use and depth since they could influence nutrient cycling, distribution and availability in soils.

Authors' Contributions

Conceptualization: TN; Supervision: IN; formal analysis: CI, CA and TC; Writing review and editing: FO and TN. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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