Original Research Article

Interaction effect of land use systems and depths on organic carbon storage and some texture related properties of a humid tropical soil of South Eastern Nigeria

Abstract

Soil condition as influenced by land use systems and depths is relevant in the efforts to optimize crop production. A research was conducted to examine the interaction effect of land use systems and depths on organic carbon storage and some texture related properties of a humid tropical soil. It was a 2-factor factorial experiment laid out in RCBD. The factors were land use systems at four levels [arable farm land (AFL), 3 – years fallowed grassland (FGL), forest land (FL) and oil palm plantation (OP)] and depths at five levels (0 – 20, 20 – 40, 40 – 60, 60 – 80 and 80 – 100 cm). There were twenty (4X5) treatments combinations with nine (9) replications which gave 180 sampling units. Soils were collected in a simple random sampling technic. The samples were prepared and analysed in the laboratory. The data generated was subjected to ANOVA using GenStat software package. The results showed that the lowest bulk density (BD) in range of 1.26 – 1.60 mg/kg were obtained under OP at 0 – 100 cm. The most rapid hydraulic conductivity (K_{sat}) in range of 3.62 – 1.90 cm/hr was obtained under AFL at 0 – 60 cm. The oil palm plantation had the highest range of organic carbon (OC) storage of 51.92 – 30.81 ton/ha at 0 – 40 cm, while at 40 – 100 cm, FL had the highest range of OC storage of 22.33 – 13.42 ton/ha. The undisturbed soils had higher OC storage and reduced BD at the various depths. Minimum tillage, cover cropping and shifting cultivation should be encouraged to enhance better soil conditions for optimal crop productivity.

Keywords: land use systems, depths, organic carbon, bulk density, hydraulic conductivity.

Introduction

The quality of agricultural soils as influenced by land use systems at varying rooting depths is of paramount concern in the effort to optimizing crop productivity while ensuring food security amidst climate change (Lei *et al*., 2022). The Bulk density (BD), hydraulic conductivity (K_{sat}),

Comment [NS1]: **Title**: The title needs to be revised to be made more succinct to coax readers. Kindly reduce it to 15-17 words.

Comment [NS2]: **Abstract**:
-The wording in the abstract needs to be reduced to less than or at most 250 words.
-The abstract must be devoid of unstandardized theories like RCBD. Please state the full meaning before using the abbreviated format. Please ensure uniformity throughout the manuscript.

Comment [NS3]: **Introduction:**
Overall, the introduction is okay and well-written. However, authors can enrich or improve the study's rationale and scope by integrating some standardized theories linked to the main subjects (land use, soil, forests and so on) of the study. Authors can refer to a recent study conducted by Sarfo et al. (2022) for such theories and linkages.
-Sarfo, I., Shuoben, B., Beibei, L. *et al.* (2022). Spatiotemporal development of land use systems, influences and climate variability in Southwestern Ghana (1970–2020). *Environ Dev Sustain* **24**, 9851–9883 (2022). https://doi.org/10.1007/s10668-021-01848-5

-Kindly integrate the study's contribution or relevance briefly in the last paragraph of the introduction.

clay content and organic carbon (OC) storage are among the soil quality indicators influencing crop production through their impacts on nutrients and water retention capacity of soils, roots and air permeability, roots growth and ramification, soil biological population and activities (Melissa and Raymond, 2002).

The report of Adugna and Abegaz (2015) showed that there were significant changes in organic carbon and clay contents of a soil at varying depths, and these changes were extrapolated to influence changes in bulk density and hydraulic conductivity. Amanze et al. (2017) confirmed that changes in soil management practices and land use systems greatly influenced the physicochemical properties of soils including BD, K_{sat}, and OC storage. Martins *et al.* (1991) observed that bush fallow increased SOC content. Cropping systems that produce and return biomass to the soil surface enhance SOC content (Lal, 1995). Deep-rooted crops with capacity to produce biomass in large quantities may enhance SOC content of the sub-soil horizons where it is not easily mineralized and decomposed (Kemper and Derpsch, 1981). Agricultural practices with drastic impact on organic carbon storage include deforestation, burning, plowing, and continuous cropping (Lal and Logan, 1995).

Grassland and forest soils have reduced bulk density and improved hydraulic conductivity compared to land cultivated to arable crops (Dilip, 2012). Roots exudates from different plants in a forest land may also act as cementing agents in binding the soil particles together and therefore help in the formation of good soil structure that impacts positively on bulk density and hydraulic conductivity (Dilip, 2012). Good land use systems promoted intense microbial activities as a result of organic matter accumulation (Dilip, 2012). This also engendered good soil environment through adequate soil cover by plant canopy and litter falls. Moreover, the activities of earthworm and soil arthropods which were enhanced by these conditions helped in improving soil bulk density and permeability (Dilip, 2012). Continuous cultivation results in increase in sand fraction and bulk density while reducing aggregation as against bush fallow land use (Malgwi and Abu, 2011).

There is therefore appreciable level of documented information on the changes in soil properties among different land use systems, but more studies are required to reveal the extent at which these land use systems affect soil parameters down the soil profile (residing depths) and the trend of such changes among the selected land use systems at the varying depths. Thus, the objective 'of this study is to ascertain the interaction effects of selected agricultural land use systems and depths on soil organic carbon storage, bulk density, hydraulic conductivity and clay content of soil of the same parent material.

Materials and methods

Description of study area

The study was conducted in Abia State, within the humid tropical region of Southeastern Nigeria. The area lies within latitude $5^{o}29^{''}$N to $5^{o}31$'N and longitude $7^{o}30^{'}$E to $7^{o}32$'E with mean annual rainfall of 2200 mm (NiMet, 2019). The rainy season usually starts from March to October with bimodal peaks in July and September. The dry season usually starts in November to February. The mean annual temperature is about $28^{o}C$ (NiMet, 2019). The landscape is flat to gently undulating slope, dominated with the Coastal plain sand parent material with localized patches of alluvial deposits. The soil of the area is an "Ultisol" according to the USDA soil taxonomy (Soil Survey Staff, 2010).

Land use types

Four (4) land use types were studied viz: Arable farmland (AFL), Oil palm plantation (OP), Forested land (FL), and fallow land (FA). The FL was on the upper slope, the FA was on the mid slope, while the OP and CC were both on the lower slope. Table 1 shows the summary of the history of the land use types.

Soil Sample Collection and preparation

The soil sampling was done by partitioning each land use type into nine blocks (replicate) of equal area. Auger and undisturbed soils were sampled randomly in each block at 0 – 20, 20 – 40, 40 – 6-, 60 – 80, and 80 - 100 cm depths. The auger soil samples in each block were bulked to obtain a representative sample for the block at the various depths. The disturbed soil samples were air-dried and passed through a 2mm mesh for laboratory analysis. The core samples were trimmed, the bases fastened with cheese cloth and placed in a trough of water to saturate before determination of the required soil physical properties.

Laboratory analyses

Particle size distribution was determined by the hydrometer method as described by Gee and Or (2002). Saturated hydraulic conductivity (K_{sat}) was determined by the constant head method of Klute (1986), and calculated using Darcy's equation (Youngs, 2001) as:

$$Ksat = \frac{QL}{AT\Delta H} \quad (1)$$

where Q is quantity of water drained (cm^3), L is length of soil column (cm), A is the interior cross – sectional area of the soil column (cm^2), ΔH is the pressure difference causing the flow (hydraulic gradient) and T is time elapse. Bulk density (BD) was determined using the core method as described by Anderson and Ingram (1993).

Organic carbon was determined by the dichromate oxidation procedure of Walkley and Black as modified by Nelson and Sommers (1982).Total carbon stored in the soil was calculated according to the procedure explained by Peter (2013) as shown below:

$$C_T = C_F \text{ x BD x D x 1 ha} \quad (2)$$

where C_T is total organic carbon stock for the layer (ton/ha), C_F is organic carbon concentration (percentage carbon divided by 100), D is bulk density of the soil layer (mg/m^3), D is thickness of soil layer (m).

Comment [NS4]: **Methods:**
-All equations given in the manuscript must be entered using Math Type or insert equation function. Please ensure the variables in the given equation as given their respective connotations.

Data analysis

Data obtained were subjected to analysis of variance (ANOVA) using GenStat software package while significant means were separated using Fisher's Least Significant Difference at 5% probability level ($LSD_{0.05}$).

Comment [NS5]: -Kindly state the specific GenStat software package or version used.

Table 1: Summary of land use history of the sites used for the study

Site	Land area covered	Land use history
Oil palm plantation	4259.5 m^2	The Oil palm plantation was established for over 20 years, and has undergrowth of siam weed (*Chromolaena odorata*), mimosa plant (*Mimosa pudica*) among others. The alleys are not cultivated to crops but are slashed Periodically to clear the undergrowth and the biomass left at the ground to decay
Forest land	3560.0 m^2	The forest was secondary vegetation regenerated for over 20 years, and was dominated by trees like Oil bean (*Pentaclethra macrophyllum*), African breadfruit (*Treculia africana*), and bush mango (*Irvingia gabonensis*), with shrubs and herbs such as "siam weed" (*Chromolaena odorata*), sun flower (*Aspillia africana*), goat weed (*Sida acuta*) as under growth..
Arable farmland	1865.7 m^2	The land was continuously cultivated to cassava (*Manihot* planting season. Soil tillage was by the use of simple farm manure (such as poultry droppings and pig waste) and mineral fertilizer (such as NPK). Weeding was done periodically.
3 – years Fallow land	6147.0 m^2	The fallow land was a 3 – year fallow dominated by elephant grass (*Panicum maximum*), and was previously cultivated to cassava (*Manihot esculentus*), while heavy machinery was used previously for the land preparation before the land was fallowed.

Results and Discussion

Comment [NS6]: Results and discussion
-The results section is well-written. Please try and crosscheck if you can find current literature that align with the scope of the study for comparisons in the current literature. Though the old literature used may aid such analysis due to information scarcity, try to update the old literature with new ones if possible.

Organic carbon storage

Table 2 shows that there was significant interaction effect (P≤0.05) of land use systems and depths on organic carbon (OC) storage. The generally observation was that there was decrease in OC storage down the depth at the various land use systems, yet the quantity of OC stored at each depth varied among the land use systems. The oil palm plantation (OP) had the highest OC storage of 51.92 tons/ha and 30.81 tons/ha at 0 – 20 cm and 20 – 40 cm depths, respectively; the forest land (FL) had the highest OC storage of 22.33 tons/ha to 13.42 tons/ha at 40 – 60 to 80 – 100 cm depths, respectively; while the lowest OC storage of 22.98 tons/ha to 6.83 tons/ha were observed at Arable farmland (AFL) across 0 – 20 cm to 80 - 100 cm depth, respectively.

Table 2. Interaction effect of land use systems and depths on soil organic carbon storage

	Depths (cm)				
Land use systems	0 – 20	20 - 40	40- 60	60 - 80	80 - 100
AFL	22.98	17.18	13.78	10.34	6.83
FL	43.61	29.40	22.33	14.70	13.42
FGL	34.62	25.74	16.76	11.41	9.86
OP	51.92	30.81	22.28	12.27	11.40
LSD (LxD) = 2.97					

The OC storage of soils at the various land use systems across depths was significantly influenced by the rate of residue turnover, frequency of soil disturbance by tillage, and degree of ground cover as conditioned by the land use systems. The increased storage of soil OC at the various depths of OP and FL relative to the other land use systems could be attributed to the increased rate of residue turnover via litter falls and their accumulation over extended period of time with little or no disturbance to the soil. Consequently, the accumulated organic materials at the top soil were possibly translocated to the lower depths of the soils at increasing quantity resulting to the significant accumulation of organic carbon at the residing depths of OP and FL compared to those of AFL and FGL. Conversely, the relatively low storage of OC at AFL and FGL was possibly a resultant effect of low rate of residue turnover resulting from continuous soil disturbance, crop removal and low residue turnover as in the case of the AFL while the short period of fallow may have caused this effect in FGL as the soil had not appreciably recovered its lost OC after the previous cropping. These findings agreed with the reports of Amanze *et al*., (2022) and Balesdent *et al*., (2000) that organic carbon storage increased with increase in residue turnover via litter accumulation in undisturbed soils with effective ground cover whereas in the disturbed soils, the organic carbon storage significantly decreased due to increased oxidation and decomposition of the organic materials leading to organic carbon loss. There reports also added that low turnover of plant residues to the soil due to frequent crop removal as in arable farmlands contributed to low OC storage, and this statement corroborated the findings of this research. In another report, Holland (2004) showed that little or no disturbance to soils was effective in conserving soil OC and therefore served as a measure to sequester carbon in the soil. Consequently, it could be deduced from the foregoing that the higher OC storage at the various depths under OP, FL and FGL relative to the AFL that was under continuous was probably the result of allowing the soils under them to stay undisturbed for a period of time; thus, soils under OP and FL that had remained undisturbed and covered for a longer period of time accumulated more organic carbon at the various depths than FGL. Also, the increased rooting depths of plants under OP, FL and FGL may have provided for the presence of more organic materials at the residing depths through roots exudates (organic compounds), root hairs and other extended components of the roots in the soil compared to the plants cultivated at the AFL (Balesdent *et al*., 2000). The general decrease in soil OC storage with depth could be attributed to the gradual translocation of humus down the profile, gradual decrease in the presence of roots and microbial population with increasing depth (Balesdent *et al*., 2000).

Clay content

There was significant interaction effect ($P \leq 0.05$) of land use systems and depths on the clay content of the soils as shown in Table 3. There was a general increase in clay content with depth at the various land use systems studied. The highest clay content of 160.4 g/kg was observed under arable farmland at 0 – 20 cm depth, while at 20 – 40 cm to 80 – 100 cm depths the highest clay contents of 175.3 g/kg to 284.2 g/kg, respectively, were observed under OP. The lowest clay contents of 71.3 g/kg to 145.8 g/kg at 0 – 20 cm to 80 – 100 cm depths, respectively, were observed under FL. The positions of the land use systems on the landscape largely influenced the quantity of clay contained in the respective soils. However, comparing clay contents of the land use systems at the same landscape (OP and AFL), it was observed that despite the highest clay content (160.4 g/kg) at the top 0 – 20 cm depth under AFL, there was increased accumulation of clay at the residing depths of the soil under OP (142, 175.3, 205.3, 234.2, 284.2 g/kg) than that of AFL (160.4, 174.9, 189.3, 214.9, 230.4 g/kg); thus indicative of the effect of land use systems on clay content at the residing depths of a soil.

Table 3. Interaction effect of land use systems and depths on clay content

	Depth (cm)				
Land use systems	0 - 20	20 – 40	40- 60	60 - 80	80 – 100
AFL	160.40	174.90	189.30	214.90	230.40
FL	71.30	88.00	103.60	118.00	145.80
FGL	117.00	123.80	142.70	156.00	189.30
OP	142.00	175.30	205.30	234.20	284.20
LSD (LxD) = 1.66					

The increased clay content at the OP and AFL could be predicted on their position on the landscape which was the lower slope. The lower slope is the depositional surface; hence the detached and transported clay particles from the erosional surfaces were deposited at this surface to form the soils of the OP and AFL thereby giving them the characteristic property of increased clay content. On the contrary, the FL and FGL were located at the upper slope and mid slope, respectively, and such positions are considered the erosional surfaces; therefore, considerable clay particles were washed off from the soils under FL and FGL resulting in the decreased amount of clay content in the soils especially at FL. This finding agreed with the reports that the landscape of an area is comprised of two geomorphic surfaces which are; the erosional surface (upper elevation) and depositional surface (lower elevation) (Ojanuga, 2003), and that materials such as clay particles are moved from the erosional surfaces and settled at the depositional surfaces (Amanze *et al*., 2022). The general increase in clay content with depth could be as a result of the translocation of clay particles from the top layer to the residing layers of the soil via the eluviation and illuviation processes (Ojanuga, 2003). Therefore, it could be predicted that the increased differences in the clay contents at the respective depths of the soil under OP compared to the other land use systems was probably the resultant effect of the increased eluviation of clay particles across the depths of the soil under OP compared to that of the other land use types. This effect may have been facilitated by the increased dispersion of aggregated clay particles by some organic compounds in the soil under OP and the subsequent vertical transportation of the clay particles by drainage. Stevenson (1992) had earlier reported that some organic materials are known to increase clay dispersivity by increasing the negative charge density of soil colloidal fraction. Nelson and Oades (1998) also reported the influence of organic compounds on increasing the colloid fraction charge of various clay minerals, thus increasing their susceptibility to dispersion and subsequent translocation down the soil profile.

Bulk density

The significant interaction effect ($P \leq 0.05$) of land use systems and depths on bulk density (BD) was shown in Table 4. There was general increase in BD with depth at the various land use systems. The lowest bulk densities of 1.26 mg/kg to 1.60 mg/kg across all the depths from 0 – 20 cm to 80 – 100 cm depths, respectively, were observed under OP; and the highest bulk densities of 1.55 mg/kg to 1.73 mg/kg across all the depths from 0 – 20 cm to 80 – 100 cm depths, respectively, were observed under the 3 – years fallowed grassland (FGL).

Table 4. Interaction effect of land use systems and depths on bulk density

	Depth (cm)				
Land use systems	0 - 20	20 - 40	40- 60	60 - 80	80 – 100
AFL	1.36	1.41	1.61	1.59	1.69
FL	1.41	1.44	1.48	1.53	1.6
FGL	1.55	1.59	1.64	1.69	1.73
OP	1.26	1.36	1.41	1.5	1.6
LSD ($LxD_{0.05}$) = 0.05					

The lowest BD observed at OP across the depths compared to the other land use systems could be attributed to its highest OC storage at the various depths relative to the other land use systems, and this confirmed the reports of Mbagwu (1992) and Amanze *et al*., (2017) that BD of soils decreased with increase in OC content. Onweremadu (2007) further revealed that the decrease in

BD with increase in OC was as a result of the increased aggregation and aggregate stability of the soils leading to improved macroporosity and the resultant decrease in mass per unit volume of the soils. The decrease in BD of soil under AFL at 0 – 20 and 20 – 40 cm depths compared to FGL and FL was probably the result of its higher clay content which gave the soil a characteristic fine texture compared to soils at FL and FGL. This report corroborates the findings of Johan (1998) that fine textured soils have lower BD than coarse textured soils. Conversely, the high BD across the depths of soil under FL relative to AFL and OP could be inferred on its lowest clay content across the depths relative to the other land use systems; thus was considered as coarse texture soil which confirmed the report of Johan (1998) that coarse textured soils are prone to high BD. This report of Johan (1998) further explains the reason for the highest BD observed at the various depths of the soil under FGL compared to the other land use systems; this is because the soil under FGL was next to the FL in coarse texture but the BD was probably accentuated by the compaction of the soil during the previous tillage operation done with heavy machineries prior to the fallow period, thus confirming the report of Kutilek (2005) that long use of farm machinery during tillage caused irreversible soil compaction leading to increased BD. Therefore, the variation in BD among the land use systems at the various depths could be attributed to variation in OC storage, aggregation, compaction, and clay content as conditioned by the land use systems (Kutilek, 2005).

Hydraulic conductivity

Table 5 shows the significant interaction effect ($P \leq 0.05$) of land use systems and depths on hydraulic conductivity (K_{sat}). There was a general decrease in K_{sat} with depth in each of the land use systems. The most rapid K_{sat} of 3.62 cm/hr to 1.90 cm/hr at 0 – 20 cm through 40 – 60 cm depths, respectively, were observed under AFL, while FL had the most rapid K_{sat} of 0.92 cm/hr through 0.61 cm/hr at 60 – 80 cm and 80 – 100 cm depths, respectively. The slowest K_{sat} of 1.67 cm/hr through 0.60 cm/hr across 0 – 20 cm through 60 – 80 cm depths, respectively, were observed under FGL, while at 80 – 100 cm depth, the slowest K_{sat} of 0.32 cm/hr was observed under OP.

Table 5. Interaction effect of land use systems and depths on hydraulic conductivity

	Depth (cm)				
Land use systems	0 - 20	20 - 40	40- 60	60 - 80	80 - 100
AFL	3.62	2.81	1.90	0.80	0.47
FL	3.38	2.52	1.76	0.92	0.61
FGL	1.67	1.38	0.84	0.60	0.36
OP	2.87	2.09	1.12	0.62	0.32
LSD (LxD) = 0.32					

The most rapid K_{sat} observed at the soil under AFL at 0 – 60 cm depth could be attributed to the loosening of the soil in the recent tillage operation prior planting of crops unlike the other land use systems whose soils have stabilized after remaining undisturbed for a prolonged period relative to AFL. The loosening of the soil via pulverisation may have created increased number of continuous vertical macropores that facilitated the transmission of water down the profile. However, the sharp decrease in K_{sat} at 60 – 100 cm depth of the soil under AFL was probably the consequence of the compacted layer at the interface between the tilled and untilled layers of the soil caused by the pressure from the tillage implement. The compaction may have resulted to the disruption of the continuity of the pores, and possibly caused the sealing of most pores at that layer; and this is possibly the reason for the slowest K_{sat} at FGL. This finding corroborates the report of Kutilek (2005) that the pulverized layer of a soil had increased water transmission and that the water flow significantly decreased at the untilled layers beneath due to soil compaction. The relatively high OC content of the soil at FL and OP may have helped to improve the structure of the soils that improved the water conductivity at the various depths. Also, the increased rooting depths of plants under FL may have created large biopores and macropores that improved water transmission capacity of the soil at higher depths compared to the soils under the other land use systems. This finding confirms the report of Nathalie (2014) that increase in macroaggregation and aggregates stability by the active soil organic matter resulted in improved permeability of the soil to water. The general decrease in K_{sat} with increase in depth was possibly a result of reduced macroporosity and increased compaction down the depths. Schaetzi and Anderson (2005) earlier reported in support of this finding that increased microporosity with limited macroporosity decreased infiltration and percolation of water in the soil.

Conclusion and Recommendation

Changes in land use systems significantly influenced the organic carbon storage, clay content, bulk density and hydraulic conductivity of soil at varying depths of the soil profile. The undisturbed soils being soils under OP and FL had the best quality in terms of organic carbon storage, bulk density and water transmission capacity. The use of heavy farm machineries in tillage operation can cause a prolonged increase in bulk density and reduced permeability even when the soil is left undisturbed for a significant period of time. Therefore, bush fallow with shifting cultivation, maintenance of adequate ground cover in a cultivated soil, increased residue turnover, and reduced tillage can be very effective in improving the organic carbon storage, bulk density and hydraulic conductivity of soils.

Comment [NS7]: Conclusion:
-Kindly introduce the section by restating the main aim/objective of the study. I suggest the main findings are summarized or presented in bulletin format.
-Authors should improve the conclusion by integrating some study limitations or gaps and opportunities that could drive further studies briefly.

Other comments:
-Minor to moderate grammatical defects and syntax errors were spotted throughout the manuscript. I suggest authors revise or check for proficiency errors before resubmission.

References

Amanze, C. T., Oguike, P. C., Eneje, R. C., Ukabiala, M.E., Omatule, L.A., Ozomata, A.S., Kolo J. (2022). Changes in some physical properties of soils and spatial variation of organic carbon storage of soils under contrasting land use systems in Southeastern Nigeria. *International Journal of Agric. and Rural Development.* Vol. 25(2): 6504-6511 2022

Adugna A. and Abegaz A. (2015). Effects of soil depth on the dynamics of selected soil properties among the highlands resources of Northeast Wollega, Ethiopia: are these sign of degradation? *Solis Earth Discuss*, 7: 2011 – 2035. Doi:10.5194/sed-7-2011-2015

Anderson, J. M. and Ingram, J.S.I. (1993). Tropical Soil biology and fertility. A handbook of methods. 2nd Edn., CAB International, Wallingford UK., Pp. 221.

Balesdent, J., Chenu, C., and Balabane, M. (2000). Relationship of soil organic matter dynamics to physical protection and tillage. *Soil & Tillage Research* 53: 215-230.

Chikamnele T. Amanze, Paul C. Oguike and Roseta C. Eneje (2017). Land use effect on some Physicochemical properties of Ultisol at Ndume Ibeku, Southeastern Nigeria. *International Journal of Scientific and Research Publication.* Vol. 7(9): 2250 – 3153

Dilip, K. D. (2012). Introductory to Soil Science, kalyani Publishers Pp 49 – 57

Holland, J.M. (2004). The Environmental Consequences of Adopting Conservation Tillage in Europe: Reviewing the Evidence. *Agriculture Ecosystems & Environment* 103: 1-25.

Johan A. (1998). Influence of soil texture and organic matter on bulk density, air content, compression index, and crop yield in field and laboratory experiments. *Soil and Tillage Research*, 49: 1 - 2

Kemper, B. and Derpsch, R. (1981). Results of studies made in 1978 and 1979 to control erosion by cover crops and no-tillage techniques in Parana, Brazil. *Soil and Tillage Res.* 1: 253–267.

Klute, A. (1986), Method of soil analysis. Physical and mineralogical analysis. *American society of Agronomy*. 9: 23 - 41

Kutilek, M. (2005). Change of Soil Porous system due to Landuse. Unpublished lecture notes. College of soil Physics, International Centre for Theoritical Physics, trieste, Italy.

Lal, R. (1995). The role of residues management in sustainable agricultural systems. *J. Sustainable Agric*. 5: 51–78.

Lekwa, G. and Whiteside, E.P. (1986). Coastal Plain Sands of South Eastern Nigeria; Morphological, Classification and Genetic Relationship. *SSSA Journal*, 50: 154 – 160.

Lei Q., Xuhui W., Pete S., and Mingsheng F. (2022). Soil quality both increases production and improves resilience to climate change. *Nature climate change,* 12: 574 – 580

Malgwi, W. B. and Abu, S. T. (2011). Variation in some Physical properties of Soils formed on a hilly terrain under different landuse types in Nigeria savanna. *International Journal of Soil Science*, 6: 150 – 163.

Martins, P.F., Cerri, C.C., Volkoff, Andreux, B. E., and Chauvel, A. (1991). Consequency of clearing and tillage on the soil of a natural Amazonian ecosystem. *Forest Ecol. Manage*. 38: 273–282.

Mbagwu, J.S.C. (1992). Improving the productivity of degraded Ultisols in Nig. Using organic and inorganic amendments, chemical properties and yield of maize. *Bioresources Tech*. 4: 149 – 154.

Melissa A. S. and Raymond R. W. (2002). The relationship between soil quality and crop productivity across three tillage systems in South Central Hunduras. *American Journal of Alternative Agriculture*, 17 (01): 2 – 8.

Nathalie S. (2014). *What is soil structure and why is it important.* deepRoot Blog.

Nelson, D.W.M. and Sommers, L.E. (1982). *Total carbon, organic carbon and organic matter*. In: Pg. A.L, Miller, R.H. and Keeny, D.R (eds.) Methods of soil Analysis, Part 2, Amer. Soci. Of Agro., Madison, WI,pp. 539 - 580

Nigeria Meteorological Agency (NiMet) (2019). Seasonal rainfall prediction for 2015 Nigeria meteorological publication. Maitama, FCT Abuja.

Ojanuga, A.G, (2003), *Soil Survey and Landuse.* Proceeding of the Annual Conference of the Soil Science Society of Nigeria, Umudike; 4th – 7th Nov., 2003

Onweremadu, E.U., Onyia, V.N. and Anikwe, M.A.N. (2007). Carbon and nitrogen distribution in water-stable aggregates under two tillage techniques in Fluvisols of Owerri area, southeastern Nigeria. *Soil & Tillage Research* 97, 195–206.

Peter, D. (2013). *Measuring soil carbon change*. A Flexible, Practical, Local Method. Soil carbon coalition.org/measuring soil C. Pp. 12 and 33.

Soil survey staff (2010). Keys to soil taxonomy (eleventh edition). United Department of Agriculture (USDA) and natural resources conservation service (NRCS)

Youngs, E. G.,2001. *Hyraulic conductivity of saturated soils*. In : Soil and environmental Analysis. Smith, K. A. and C. E. Mullins (Eds). Physical Methods. 2nd Ed. Marcel Decker Inc. NY., Pp. 637.

Schaetzi, R. J. and Anderson, S. (2005). Soils: Genesis and geomorphology. Cambridge university Press, Cambridge, UK. Pp. 353 – 365

Stevenson, F. J. (1992). Humus chemistry: genesis, composition and reactions. 2nd edn. John Wiley and sons, New York.