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Effects of land use types on total soil organic carbon and aggregate stability of soils in Lafia and Doma LGAs, Nasarawa State, Nigeria.

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ABSTRACT

The study was conducted to compare total soil organic carbon (TSOC) and aggregate soil stability statues of soils under different land use types (LUT) in Lafia and Doma LGAs of Nasarawa State Nigeria. A free survey technique was used to identify the most representative sampling point for soil profile studies based on LUT. Three mapping units (MU) were identified in each LGAs and profile pits were used in used in their studies. Routine laboratory procedures were carried out on the samples. The preponderance of sand (73.85% - 85.93%) fraction in the particle size distribution may be influenced by its lithology and its type of their utilization. The silt (5.40%) exhibited uniformity in all the horizons. The SCR were >0.15, indicative of young soil with weatherable reserves. Lowest values of bulk density (1.23gcm-3) and higher total porosity (53.31%) recorded in LUT4 which suggests that continuous LUTs have negative effect on soil aggregate stability especially where SOM accumulate under the forest soil. The pH (KCl) in Doma was rated very strong acid (4.84 - 4.14) while at Lafia was rated slightly acid (6.34) to neutral (6.63) in LUT4. The soils had CN ratio <25, found to be favourable to OM mineralization, therefore, implies that LUT4 with the lowest CN ratio had Ca2+ and Mg2+ release than other LUTs. The clay dispersion or micro aggregate stability indices CDR, CDI, TOC, OM and SCR were generally significantly ($p \leq 0.05$) higher in LUT4, while ASC had negative values in all LUTs except LUT1,. Negative ASC values indicate that WDC is higher than total clay determined in calgon. Soils higher in CFI are better aggregated while CDR with higher values is indicative higher ability to disperse. Hydraulic conductivity, Ksat (cm/hr) values obtained were rated moderate, the LUTs have weighted mean range of 3.44 (cm/hr)- 4.95 (cm/hr). The study reveals generally poor aggregate stability, low agricultural soil quality/ health due to acidic soils, low nutrients (N, P, K, Ca, Mg), with high sand content leading to poor water retention while the nexus between LUTs and soil's intrinsic properties degradation. Doma soil mapping units appears to have better aggregate indicators compared to Lafia, obviously the effects higher anthropogenic activities (continuous cultivation) in the later may be a predisposing factor. Doma soils showed stronger soil acidity due to higher precipitation leading to leaching of basic cation (Ca2+, Mg2+, K+) and these influenced the TSOC and SOM in soils.

INTRODUCTION

Soils aggregate stability is one of the most complex and dynamic soil characteristics affecting principal physical and hydraulic soil characteristics, such as infiltration rate, hydraulic conductivity, water holding capacity and erodibility. Supporting plant growth and providing vital ecosystem functions depend heavily on the physical makeup of the soil (Adhikari and Hartemink 2016). However, land use influenced structural stability than soil intrinsic properties and that percolation stability increases as the soil organic matter increases. Total Soil Organic Carbon (TSOC) is the unit for deriving soil organic matter (SOM) according to the procedure of Nelson and Sommers (1982).

Heterogeneity of soils is influenced by its spatial distribution and variations in its properties while crop management practices such as application of organic fertilizers, liming, incorporation of stubble and minimum-till or no-till cultivation can improve aggregate stability. Other researchers opined that cropping may lead to erosion and leaching of nutrient which in turn, affects soil's intrinsic properties (Ogban *et al*., 2022) while Li *et al* (2023) reported that soil stability was significantly affected by land utilization type (LUT) tested at $p < 0.01$ using correlation of aggregate stability with SOC and soil particle composition (texture). Aggregation is essentially the flocculation and cementation of individual soil particles to form aggregates. The primary soil properties influencing aggregation and aggregate stability are texture, clay mineralogy, SOM, cations, sesquioxides and calcium carbonate. Onweremadu *et al*. (2011) had observed that soils with higher clay flocculation promote soil aggregation and structural stability. Igwe and Agbatah (2008) and Oguike and Mbagwu (2009) confirmed that cultivation practice (land utilization types) influences hydraulic conductivity.

The consensus is that the clay fraction and humus (colloidal particles) have a positive effect on structural stability compared to the silt and sand fractions (Donstova and Norton, 2002). Cations such as Fe3+, Al3+, Mg2+ and Ca2+ serve to: (1) stimulate the precipitation of compounds that act as bonding agents for primary soil particles and (2) form bridges between clay and SOM particles resulting in aggregation. Research has shown that Ca2+ ions were more effective than Mg2+ in aggregating soil clays and that if soils are prone to surface sealing, it is beneficial to manage them to high Ca:Mg ratios. High concentrations of Al and Fe oxides and hydroxides, often referred to as cementing agents, have the effect of increasing aggregate stability. The presence of Al and Fe oxide in soils also has a favourable effect on soil structure. Evidence of soil structural improvement is provided by increased aggregate stability, permeability, friability, porosity, and hydraulic conductivity. In general, Al oxides have a greater stabilizing effect than spherical Fe oxides on structure because of their platy morphology. Water is the main cause of aggregate breakdown in most soils, either directly by rainfall or by surface runoff. Water-stable aggregation on the soil surface is therefore important when considering the inherent erodibility of a soil and its susceptibility to soil structural decline. Soils in the study areas have come under intensive and continuous cropping due to a number of factors increase population, land tenure, urbanization and conflict over land resources for arable cropping and grazing. The major objective of this study was to compare TSOC and aggregate soil stability status of soils under different land use types in Lafia and Doma LGAs of Nasarawa State Nigeria.

MATERIALS AND METHODS

Location and field study

The study was conducted in two select locations in Nasarawa state in north central Nigeria. The area lies in the southern guinea savannah 7°23' 35"N to 9°25’38”N and Longitude 7°21' 19’E to 9°37’E 37’E with the mean elevation 151 m above sea level. Nasarawa state is found in the Benue trough in the south and Jos plateau to the north. Mineralogy of the state is composed of basement complex rocks 60% and sedimentary rocks 40%.and geologic materials were sandstone and basement complex with basaltic intrusion giving rise to sandy loamy soil texture. The study area is characterized by tropical climate with two distinct seasons, wet and dry season, the wet season lasts from March to October whereas the dry seasons last from November to February, with mean annual rainfall of 1251 – l500 mm distribution is bimodal with peaks in August and September (NiMet, 2025a). The relative humidity varies as the season (about 40 % in January and 90 % in July) with mean annual temperature of about 29°C and the dry and wet seasons are controlled by the annual migration of the inter-tropical convergence zone (ITCZ) or inter tropical discontinuity (ITD) according to NiMet (2025b). However, Lafia temperature during March and April recorded day temperatures between 39°C to 41°C in the year 2025 (some degrees higher than the predicted 38.9°C by NiMet, 2025). The hydrology of Nasarawa state is governed by Benue River. The vegetation is characterized by tall grasses and scanty tall trees and shrubs of secondary regrowth influence by anthropogenic activities, urbanization in Lafia, through bush burning, tree felling for fuel-wood and other demands on Ohina forest reserve in Doma, land clearing and farming systems. Doma LGA is reputed for the supply of agricultural and forest products to Lafia (capital city of Nasarawa state) due to its proximity (fig. 1) to the capital city while Lafia and its peri-urban soils are under various degree of continuous cultivation. The vegetation is woody savannah characterize by mango (*mangifera indica*), wide palm, *Daniella olivera,* Shea tree (*Vitellaria paradoxa*), Oil-palm and Java plum (black currant). The major farm produce are Yam (*Dioscora spp*), melon (*Citrullus lanatus*), Soy Bean (*Glycine max*), Maize (*Zea mays*), Cassava (*Manihot spp*), Rice (*Oryza sativa*), sorghum and millet. Other common crops are sugarcane production amaranths, eggplant, tomatoes and pepper. Other socioeconomic activities are fishing. Indigenous grasses identified in the fields were *Andropogon gayanus* (Gamba grass), Brachiaria *decumbens* (Signal grass), *Cenchrus ciliaris* (Buffel grass), *Digitaria smutsii* (Finger grass), *Panicum maximum* (Guinea grass), *Hyparrhenia rufa* (Shuchi grass). The abundance of these pasture acts as attractants to cattle herders (Fulani pastoralist).

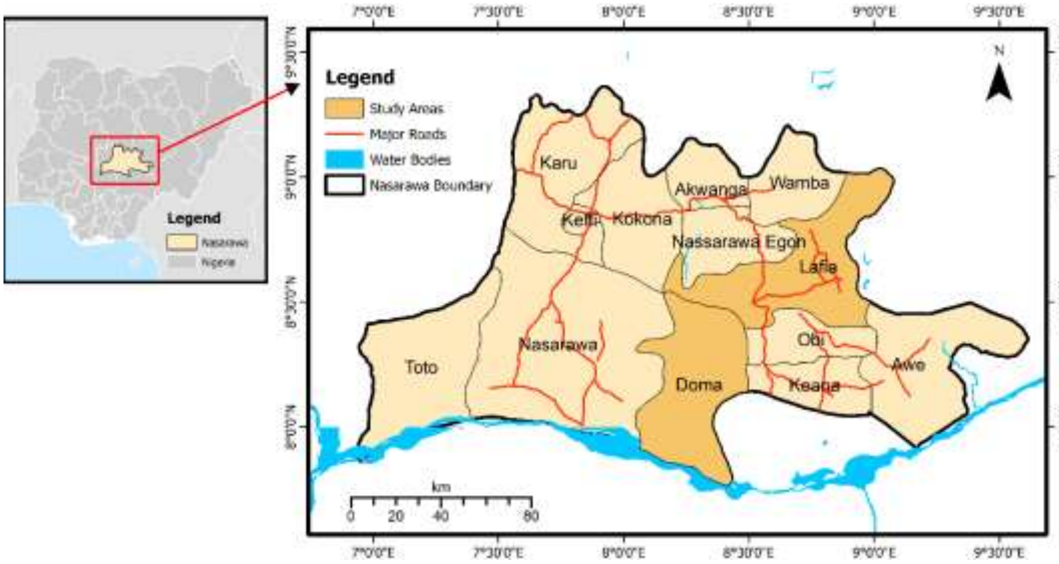

Figure 1: Map of Nasarawa state Nigeria showing the study areas

A reconnaissance survey was conducted in the study areas in order to obtained general information about the study area. A free survey technique was used to identifying the most representative sampling point for soil profile studies based on LUT (table 1) and its heterogeneous landscapes nature. Three mapping units (MU) were identified in each LGA and soil profile pits were used in their *in-situ* morphological studies.

Table 1: LUT description in the study areas

MU	LUT	Coordinate and elevation
Doma		
LUT 1	Arable cropped to upland rice	8°8'43.7"N and 8°15'41.8"E, 193MASL
LUT 2	Arable cropped to maize	8°8'48.7"N and 8°15'41.8"E , 179 MASL
LUT 3	Arable cropped to sugarcane	8°9'15.7"N and 8°15'51.7"E 179 MASL
Lafia		
LUT 4	7 - year old forest	8°28'52.1"N and 8°33'08.0"E, 175MASL
LUT 5	Arable cropped to cowpea	8°33'47.8"N and 8°33'12.4"E, 164MASL
LUT 6	Arable cropped to cassava	8°34'4.20"N and 8°33'05.4"E, 184MASL

*All LUTs are under continuous cultivation except LUT4

Sample Preparation

Each profile pit was described according to the procedure of Soil Survey Staff (2006). The soil samples were air-dried at room temperature (25^0C) for about three days, after which it was sieved using a 2 mm sieve mesh in order to separate the fine earth fraction from the coarse fragments. Some part of the soil sample was passed through 0.5 mm mesh sieve for soil organic carbon (SOC) and total nitrogen determination. Particle Size analysis was determined by use of hydrometer method both in calgon and water as water dispersible clay (WDC) and water dispersible silt (WDS) (Gee and Or, 2002). The soil pH was determined by glass electrode pH meter both in 1:2.5 soil/ liquid suspension of water and KCl (Henderson *et al.,* 1993) Organic carbon was determined by wet dichromate method described by Udo *et al.,* (2009). Total nitrogen was determined by micro-Kjeldahl digestion method as modified by Udo *et al.,* (2009). Extraction of available phosphorus was done using Bray 1 method. Exchangeable cations (K^+, Ca, Mg^{2+}, and Na^+) were extracted by neutral normal ammonium acetate, K^+ and Na^+ in the extraction were determined by flame photometer (Udo *et al.*,, 2009) while Ca^{2+} and Mg^{2+} were by atomic absorption spectrophotometer. Cation exchange capacity was by summation method. Exchangeable acidity was determined in 1NKCl extracting solution with 0.5N NaOH using phenolphthalein indicator by titration method of Mclean as described by Udo *et al.,* (2009). Bulk density was measured by core method (Grossman and Reinsch, 2002). Total porosity (P_o) was obtained from bulk density (ℓp) values with assumed particle density (ℓs) 2.65 g cm^{-3} as follows, Porosity (Po) =100 – (ℓp/ℓs) ×100/1.

Aggregate stability index were mathematically derived as follows:

Dispersion Ratio (DR) $= \frac{\%silt+\%clay(WDC)}{\%silt+\%clay\ (calgon)} \times 100$ (1)

(Oguike and Mbagwu, 2009)

Clay dispersion index (CDI) = $\frac{\%WDC}{\%clay\ (calgon)} \times 100$ (2)

(Oguike and Mbagwu, 2009)

Aggregated silt + clay (ASC) = [(%clay (calgon) + %silt (calgon)]– [%clay (calgon+ %silt(WDS)] (3)

(Oguike and Mbagwu, 2009)

Clay Flocculation Index (CFI) = $\frac{\%clay\ (calgon)-(WDC)}{\%\ clay(calgon)} \times 100$ (4);

(Oguike and Mbagwu, 2009)

Data analysis

Weighted mean, range, and coefficient of variation was calculated and ranked according using the method proposed by Wilding *et al* (1994) for all soil properties across different mapping units.

RESULTS AND DISCUSSION

Physical properties of the studied soils are shown in table 2. The values used in these tables are the weighted averages of the data obtained from the laboratory results. The preponderance of sand (73.85% - 85.93%) fraction in the particle size distribution may be influenced by its lithology and its type of their utilization (Igwe, 2012). The uniformity of silt fraction (5.40%) across the study sites may be due to the weathering environment and the uniformity in parent materials (Akamigbo and Asadu (1983). The clay fraction showed a medium variation to high variation and high variability in clay fraction could be attributed to clay bulge in the subsoil owing illuviation process. Soil's textural class common to the study areas are loamy sand in Doma while sand in Lafia. The SCR had values > 0.15 which according to Yakubu and Ojanuga (2009) reported that SCR below 0.15 was indicative of an old soil while >0.15 was indicative of young soil with weatherable reserves. Major reason Nasarawa soils may have weatherable reserve is the limited amount of rainfall compared to southern state in Nigeria where precipitation exceeds 2500 mm/yr. The bulk density and total porosity had as expected, an inverse relationship with value range that is considered satisfactory for root penetration. However, the lowest bulk density and total porosity were recorded in Lafia forest land use type(LUT4) which suggests that continuous LUT have negative effect on soil aggregate stability especially where SOM accumulate under the forest soil.

Table 2: Physical properties of the studied soils

Properties	Doma			Lafia			
	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	CV (%)
Sand (%)	82.55	73.85	71.78	85.77	84.5	85.93	LV
Silt (%)	5.4	5.4	5.4	5.4	5.4	5.4	LV
Clay (%)	12.05	14.79	22.52	8.8	10.1	9.9	MV
SCR	0.46	0.28	0.24	0.67	0.53	0.55	HV
BD(gcm^{-3})	1.47	1.38	1.32	1.23	1.24	1.28	LV
Tpo (%)	44.27	45.97	50.3	53.31	53.13	53.02	LV
TC	LS	LS	LS	S	S	S	

CV: Coefficient of variation, LV: low variation. MV: medium variation, HV: high variation

Select chemical properties are presented in table 3. The pH (KCl) in Doma was rated very strong acid (4.84 - 4.14) while at Lafia was rated slightly acid (6.34) to neutral (6.63) in forest soils (Chude et al., 2011). The strong acidity in Doma may be due to higher precipitation in that area, land use pattern or use of agrochemicals. TN was rated low (0.14%) in Doma to medium in Lafia with highest value obtain in LUT4 (0.48%). CN ratio <25 is found to be favourable to OM mineralization which therefore implies that forest with the lowest CN ratio had Ca^{2+} and Mg^{2+} release than other LUT though SOM were rated low, forest LUT (table 4) had the highest value (3.71%). This implies that humus formed under this LUT aggregates soil peds better. This finding agrees with Pramod, et al (2023) that improving the capture and storage of atmospheric C through improved land use systems can be a good strategy while also improving the quality of landuse soil system is as one of the most significant factors that control OC and N stocks build up in the soil.

Table 3: Select chemical properties of the studied soils

Properties	Doma			Lafia			
	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	CV(%)
pH (KCl)	4.84	4.39	4.14	6.63	6.52	6.34	LV
pH(H_2O)	5.24	4.29	4.33	6.60	6.68	6.58	LV
EC(µ/cm)	80.62	58.8	102.51	100.44	58.83	55.68	HV
TN (%)	0.19	0.14	0.09	0.48	0.4	0.38	HV
CN ratio	10.6	14.14	17.99	4.69	5.36	5.91	,MV
TEB (cmol/kg)	1.45	1.56	1.34	1.43	0.84	0.23	MV
ECEC(cmol/kg)	1.77	2.54	2.41	1.66	1.27	0.79	MV
%BS	65.6	62.2	55.53	58.75	81.69	29.14	MV
Av.P (mg/kg)	4.39	4.02	3.62	7.68	6.85	6.75	MV

CV: Coefficient of variation, LV: low variation. MV: medium variation, HV: high variation

Soil aggregate indicators are shown in table 4. The clay dispersion or micro aggregate stability indices CDR, CDI, TOC, OM and SCR were generally significantly ($p \leq 0.05$) higher in LUT4, while ASC had negative values in all LUTs except LUT1. Negative ASC values indicate that WDC is higher than total clay determined in calgon. Soils higher in CFI are better aggregated while CDR with higher values is indicative higher ability to disperse. The principle of the smaller value the better applies to CDR and SCR while the bigger value applies to CFI and ASC (Ogban et al., 2022). Negative CFI or low value observed in LUT1, 3, 4 and 5 are due to low SOM/ base saturation (see table 3). Low CFI often correlates with low soil pH or low calcium and magnesium contents in the soil and in such a case where clay particles are highly susceptible to dispersion, not able to for stable aggregates. When ASC is negative, as found in LUT2, 3, 4, 5 and 6 (-0.50%, -1.62%, -3.20% and -1.00%), it indicates that the soils are highly unstable- high degradative tendency owing to the poor structural stability. Soil aggregate and its stability are closely related to soil particle composition, SOM and land use type (Li et al., 2023). The implication is that the soils are frequently subject to different degrees of erosion including accelerated erosion especially under continuous cultivation as seen with the other LUTs and surprisingly in LUT4. Hydraulic conductivity, K_{sat} (cm/hr) values obtained were rated moderate, the LUTs have weighted mean range of 3.44 (cm/hr)- 4.95 (cm/hr). K_{sat} is the rate at which water passes through saturated soil medium. This implies that the soils has limited capacity to transmit water when fully saturated leading to increase runoff caused by associated factors of textural class, compaction (due to tillage), reduced total porosity and low SOM.

Table 4: Aggregate stability index

Properties	Doma			Lafia			
	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	CV(%)
CDR	1.03	0.99	0.94	1.30	1.30	1.10	LV
CDI (%)	1.04	0.99	0.93	1.40	1.60	1.10	LV
ASC (%)	0.83	-0.50	-1.62	-3.20	-3.50	-1.00	LV
CFI (%)	-3.55	4.80	5.93	-0.40	-0.60	-0.10	HV
K_{sat}(cm/hr)	3.46	4.95	3.55	3.79	3.44	4.15	HV
OM (%)	3.26	2.81	2.64	3.71	3.66	3.62	MV
TOC (%)	1.89	1.64	2.11	2.21	2.13	2.11	LV
Ca (cmol/kg)	0.97	1.42	1.21	0.03	0.03	0.05	MV
Ca:Mg	12.1	17.7	15.11	0.17	0.25	3.54	MV

CV: Coefficient of variation, LV: low variation. MV: medium variation, HV: high variation

CONCLUSION

A comparative soil studies in Nasarawa State, Nigeria, reveals generally poor aggregate stability, low agricultural soil quality/ health due to acidic soils, low nutrients (N, P, K, Ca, Mg), with high sand content leading to poor water retention while the nexus between LUT and soil's intrinsic properties degradation. Doma soil mapping units appears to have better aggregate indicators compared to Lafia, obvious higher anthropogenic activities (continuous cultivation) in the later may be a predisposing factor while silt fraction showed uniformity in values obtained even though the SCR indicates presence of weatherable reserves. Doma soils showed stronger soil acidity due to higher precipitation leading to leaching of basic cation (Ca^{2+}, Mg^{2+}, K^{+}) and these influenced the TSOC and SOM. Low CFI often correlates with low soil pH or low calcium and magnesium contents in the soil and in such a case where clay particles are highly susceptible to dispersion. It is recommended that improve the aggregate stability of these soils. Reduce tillage, allow crop residues on the crop field and monitoring clay dispersion changes in a tillage managed system is very important in order to forestall negative impact on soil properties. Monitoring clay dispersion changes in a tillage managed system is very important in order to forestall negative impact on soil properties.

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