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Land use effect on soil aggregate stability and soil carbon sequestration in selected locations of Southeastern Nigeria

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Abstract

Information on soil aggregate stability and carbon sequestration is crucial for the recommendation of efficient soil management practices. Variation in aggregate stability and soil organic carbon in whole soil and also in water-stable aggregates were evaluated in four different locations of Southeastern Nigeria. The land uses considered were cultivated (CL), excavated (EX), fallow (FA), forest (FR), and grazing (GZ). Soil samples were collected at a depth of 0 – 15 cm using the transect method and analyzed for particle size distribution (PSD), aggregated silt + clay(ASC), clay flocculation index (CFI), dispersion ratio (DR), percent aggregate stability(%AS), mean weight diameter (MWD), soil organic carbon (SOC) in whole soil and water-stable aggregates (4 – 2, 2- 0.25, 0.25 – 0.053 mm). It was a factorial experiment replicated three times in a randomized complete block design (RCBD). The result showed that texture in the four locations varied between loamy sand (NS and UM) and sandy loam (NU and UMD). It seemed PSD controlled micro aggregate stability hence significantly higher ASC (NU), CFI(NU and UMD), and lower DR (UMD) were registered over NS and/or UM. On the other hand, significantly higher SOC in bulk soil and carbon sequestered in 4 – 2, 2- 0.25, 0.25 – 0.053 mm WSA compared to other locations were indicated in UM and UMD consequently % AS and MWD were significantly higher compared to NS and NU. Land use effect indicated significantly highest clay (133 g/kg) ASC (18.9 %) MWD (1.5 mm) CFI (0.6) % AS (70.6), lowest sand (734g/kg), and DR (0.30) in the GZ land use compared to other land uses except that CFI and %AS in the GZ were statistically at par with the value in FR land use. The SOC in bulk soil followed this order FR=GR>FA=CL=EX. The highest potential for SOC sequestration compared to other land uses in >2 and 2 – 0.25 mm WSA was in FR (58.3 g/kg) and GR (35.4g/kg) respectively while for 0.25 -0.053 mm WSA the order was FR=GR=CL=FA=EX. The result of this study showed that FR and GZ land use improved aggregate stability, SOC in whole, and WSA over other land uses and the magnitude of the effect depended on the characteristics of the location. The use of organic manure, reforestation, and well-managed fallow in CL, EX, and FA land use respectively is recommended.

Keywords: Land use; Aggregate stability; Water-stable aggregates; Soil organic carbon; Sequestration

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1.0. Introduction

Aggregate stability is a soil physical property that measures the resistance of soil structure against destructive forces which may be mechanical or physicochemical (Singh, *et al* 2019). Indices used in measuring aggregate stability of soils include: mean weight diameter (MWD) (Larney, 2008); geometric mean diameter (GMD); water-stable aggregates (WSA); aggregate stability index (ASI test) (Trinidad et al 2012). Micro-aggregate (aggregate < 0.25mm) stability indices such as CDI, ASC, and CFI are crucial in infiltration, sealing, and crust formation, runoff, and soil erosion (Levy and Miller, 1997) may be important indicators of soil degradation (Boix-fayos, 2001).

Carbon sequestration is the process involved in carbon capture and the long–term storage of atmospheric carbon dioxide (Roger and Brent 2012) or other forms of carbon to mitigate global warming. Soil structure, soil nutrient cycling, and soil microbial community are all influenced by soil organic carbon (Liu, *et al.* 2019).

Land-use changes influence soil organic matter and its quality hence affecting fertility (Nanganoa *et al.,* 2019). Nega (2013) reported lower soil organic matter in arable lands compared to forest and plantation soils. Also, micro-aggregate stability was reported to be highly correlated with land use in some Nigerian tropical soils (Opara, 2009). Lehtinen *et al.*. (2014) reported that cultivated soils were more affected by decreasing aggregate stability when compared with the uncultivated soils, which was in agreement with the result of Oguike and Mbagwu(2009) who showed that in continuously tilled soils dispersion ratio was higher with lower clay flocculation index which implies poor stability in cultivated soils. Ahukaemere, *et al.*, (2012) recorded lower organic carbon in continuously tilled soil compared to fallow and oil palm plantation soils which will indirectly affect aggregation.

Improper land use, rainstorm linked to current global climate change, may contribute to the breakdown of unstable aggregates into transportable smaller particles. The industrial revolution accompanied by the conversion of the natural ecosystems for other uses has depleted soil organic carbon (Lal,2015). Considering climate variability, fluctuations in temperature and precipitation may affect soil organic carbon storage (Herold *et al.,* 2014). Grazing reduces carbon input affecting microbial organic matter decomposition (Dlamini *et al.,* 2016). Aggregate stability is very important and affects infiltration, root development, and resistance to water and wind erosion. (Nunes, 2020). Changes in aggregate stability may serve as an early indicator of recovery or degradation of soil (Delelegn *et al.,* 2017). Aggregate stability is an indicator of organic matter content, biological activity, nutrient cycling, porosity, and infiltration (Nanganoa *et al*. 2019). Aggregation affects soil water characteristics and carbon stabilization (Six et al, 2004, Berhe and Kleber, 2013; Kodesova *et al*., 2008). Soil organic carbon enhances the release of plant nutrients, improves soil structure, biological and physical health of soil (Thangavel *et al.,*2019).

These properties may vary depending on location. Therefore, this study will help in monitoring changes in soil quality due to land use in different locations of Southeastern Nigeria.

The main objective of this study is to evaluate the effect of land use on soil aggregate stability and soil carbon sequestration in four locations of Southeastern Nigeria.

2.0. Methodology

This study was conducted in Nsukka (NS), Neke Uno (NU) in Enugu State; Umuahia (UM), and Umudike (UMD) in Abia State Southeastern Nigeria. The location in NS and (NU) are located in the derived savannah of southeastern Nigeria and lies between N06^{0}.37.901' and N06^{0}.51.138' and between longitude E007^{0}.32.024' and E0070.25.520' while UM and UMD lies within latitude N05^{0}.28.764' and N05^{0}.32.906' and between longitude E0070.28.163' and E007^{0}.28.402' in rainforest agro-ecological zone of Southeastern Nigeria. A detailed description of experimental locations and land use is shown in appendix1.

Table 1: Description of study locations and land-use history

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Loc.	LU	Longitude	Latitude	Elevation	Remark/major crop
NS	FR	N06^{0}.51.393'	E007^{0}.26.337'	476.4	Native forest
NS	FA	N06^{0}.51.609'	E007^{0}.26.107'	472.8	12 years
NS	GR	N06^{0}.51.163’	E007^{0}.25.520’	476.7	Cattle grazing land (UNN)
NS	EX	N06^{0}.51.138'	E007^{0}.25.698'	472.4	
NS	CL	N06^{0}.51.417'	E007^{0}.26.280'	477.6	Cassava >15 years
NU	FR	N06^{0}.39.908'	E007^{0}.31.850'	208.4	Native forest:
NU	FA	N06^{0}.38.374'	E007^{0}.32.078'	204.2	Natural fallow >15years
NU	GR	N06^{0}.38.360'	E007^{0}.32.078'	206	Cattle Free Ranching
NU	EX	N06^{0}.37.901'	E007^{0}.32.024'	193.2	
NU	CL	N06^{0}.38.404'	E007^{0}.31.802'	204.2	Cassava,>15 years
UM	FR	N05^{0}.31.928'	E007^{0}.28.272'	148.1	Abia State Forest reserve UM.
UM	FA	N05^{0}.32.906'	E007^{0}.28.360'	125.9	Natural fallow >15years
UM	GR	N05^{0}.32.528'	E007^{0}.28.163'	125.9	grazing land (Sheep and Goats)
UM	EX	N05^{0}.32.879'	E007^{0}.28.402'	112	
UM	CL	N05^{0}.28.906'	E007^{0}.32.355'	125.3	Cassava >15 years
UMD	FR	N05^{0}.28.764'	E007^{0}.32.266'	119	M OUA Forest reserve
UMD	FA	N05^{0}.28.885'	E007^{0}.32.074'	108.2	Natural fallow >15Years
UMD	GR	N05^{0}.28.810'	E007^{0}.32.303'	108.8	MOUA Cattle grazing land
UMD	EX	N05^{0}.30.556'	E007^{0}.31.567'	142.8	
UMD	CL	N05^{0}.28.906'	E007^{0}.32.355'	118.9	Cassava, >15years

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UNN – University of Nigeria Nsukka
Loc: Location; NS- Nsukka; NU- Neke Uno; UM - Umuahia; UMD – Umudike
LU – Land use: FR – Forest; FA – Fallow; GR – Grazing; EX – Excavated; CL - Cultivated

The soils of Enugu State are of sedimentary origin (Balogun, 2000), while the soils of Abia State are derived from Coastal Plain Sand. The study area has a tropical wet and dry season lasting from April to October and the dry season from November to March. The average annual precipitation in the derived savannah is 1600-1800 mm and an average temperature of 28^{0} C, while the average annual temperature in the rainforest locations is 26^{0} C with an annual rainfall of 2163 mm . The soils of both agro zones belong to the order Ultisol (Soils Survey Staff, 2010).

2.1 Experimental design

The experiment was arranged as a 4 x 5 factorial experiment replicated three times in a Randomized complete block design (RCBD). The numbers represent four locations and five land-use types: grazing, forest, excavated, fallow and cultivated land use.

2.2 Sampling and sample preparation

The five land-use types were identified in all the locations and soil samples were collected using the transect method at a sampling depth of 0-15cm and were replicated three times. The composite samples were air-dried and subsamples were passed through a 4mm and 2mm sieve to obtain samples for laboratory analysis. The sample > 2 mm was used for the determination of water-stable aggregates, macro aggregate stability indices, and carbon associated with water-stable aggregates while the sample < 2 mm was used to determine particle size distribution, micro aggregate stability indices defined by clay flocculation index (CFI), aggregated silt + clay(ASC) and dispersion ratio (DR) and soil organic carbon (SOC).

2.3 Laboratory Analysis

Physical analysis

The particle size distribution of less than 2 mm fine earth fraction, was measured by the hydrometer method using sodium hexametaphosphate as the dispersion agent according to Gee and Bauder (1986).

Micro aggregate stability indices were measured by the determination of the amounts of silt and clay in Calgondispersed and water-dispersed samples using Bouyoucos hydrometer method of particle size analysis described by Gee and Bauder (1986). The data obtained were used in calculating the following micro aggregate stability indices;

ASC = [% clay + % silt (calgon)] – [% clay + % silt (water)]

DR= [% silt + clay (water)] / [%silt + clay (calgon)].

CFI is %clay in water/ % clay in calgon

Where ASC is Aggregated silt + clay, DR is dispersion ratio and CFI is clay flocculation index

The distribution of water-stable aggregates was estimated by the wet sieving technique described in detail by Kemper and Rosenau (1986). To separate the water-stable aggregate, 25 gm samples of the > 2 mm air-dried aggregates were put on top of a nest of two sieves measuring 0.25 mm, 0.053 mm and was pre-soaked for 10mins in water. The sieves and their content were oscillated vertically, once per second, in water 20 times using 4cm amplitude. Care was taken to ensure that the soil particles on the topmost sieve were always below the water.

The resistant aggregates on each sieve were oven-dried at 60 ºC for 24 hr and weighed. The mass of < 53-micron WSA was obtained by the difference between the initial sample weight and the sum of sample weight collected on the >2 mm, 0.25 mm, and 53-micron sieve nests.

Aggregate stability was calculated using the formula

= [(Wt of WSA > 0.25mm– Wt. of sand) /(Original wt. of the sample – Wt. of sand)]* 100

Where WSA is Water stable aggregates and Wt = weight

The mean weight diameter (MWD), another measure of stability was calculated using the formula:

$$MWD = \sum^{n}_{i=1} Wi\ Xi$$

Where Wi is the weight of aggregate in the ith aggregate size range as a fraction of dry weight of sample and Xi is mean diameter of any particular size range of aggregates separated by sieving.

Organic carbon

The soil organic carbon in whole soil and WSA was determined by Walkey and Black wet oxidation method as modified by Nelson and Sommer (1996).

Statistical analysis

Data collected were analyzed using Genstat Discovery edition 4.1. Where the F-values were significant at P=0.05, the means were separated using FLSD.

3.0. Results and Discussion

The main effect of land use was evaluated and the result was presented in Table 2. It was obvious that land use did not affect texture hence sandy loam (SL) was registered in all land-use types. The texture is an intrinsic property of the soil which may not be easily changed by management Obi (2000). However, particle size distribution (PSD) showed that grazing registered significantly lower sand (734 g/kg), higher clay (133 g/kg) compared to other land-use types. Also, higher silt in grazing land use was not significantly different from other land uses. Variation in particle size distribution may arise from tillage, exposure of topsoil, the addition of manure from animal droppings and beddings, and erosion. Bezabih *et al.,* (2015) attributed the higher sand and lower silt and clay fraction in cultivated compared to the forest, grazing, and fallow to tillage, predisposing the soil to loss of fine particles by erosion. On the contrary, the build-up of organic matter from leaf litter, root biomass, and animal manure which increases aggregation may account for the reduction in soil loss.

Table 2: Main effect of land use on soil texture and particle size distribution

Parameter Land use	Sand	Clay (g/kg)	Silt	Texture
Cultivated	766	114.4	119.6	SL
Excavated	770	117.5	112.6	SL
Fallow	759	113.5	127.4	SL
Forest	771	117	112.	SL
Grazing	734	133	133.	SL
LSD(0.05)	16.5	13.16	ns	

SL- Sandy loam

The main effect of location on texture and particle size distribution was evaluated and the result is presented in Table 3. The textures varied from sandy loam NU and UMD) to loamy sand (NS and UM). It was observed that soils within the same agro zone had different textures which may be attributed to different parent material (NS and NU). The soil of NS is formed from the Nsukka formation while soil from NU is formed from sandstone and shale (Jungerius 1964). The variation in UM and UMD, though from coastal plain sands may be due to differences in intensity of use and management. Some authors have reported changes in texture and suggested variations in pedogenic processes and erosion as reasons for the change (Tellen *et al.,* 2018; Yerima and Van Ranst 2005).

The soil particle size distribution showed that sand content followed this order UM=NS>UMD>NU while the highest clay in UMD was statistically similar to NU. The location in NU was 75.5, 76.7, 69.73 % higher in silt compared to NS, UM, and UMD respectively. These results inferred that the PSD was dependent on the peculiarity of the location.

The interaction of land use and location on PSD was significant and the result is shown in Table 4. The texture still varied between sandy loam to loamy sand except for the change to sandy soil in cultivated land use of UM. Among the four locations, the significantly highest sand content (894 g/kg) was indicated in the cultivated land use of UM though not different from FR and EX of NS and UMD respectively. The lowest sand content (542 g/kg) in FA and CL and highest silt (306, 326 g/kg) in FA and CL respectively were indicated in NU compared to other land uses in all the locations. Soils in NU are formed from either sandstone or shales (Jungerius 1964), therefore variation may come not only from land-use but from differences in parent material at sampling points.

Table 3: Main effect of Location on texture and particle size distribution

Parameter Location	Sand (g/kg)	Clay	Silt	Texture
NS	825.4	108.3	66.3	LS
NU	603.8	124.9	271.3	SL
UM	828.0	108.9	63.1	LS
UMD	783.7	134.2	82.1	SL
LSD (0.05)	14.75	11.77	18.83	

NS- Nsukka; NU- Neke Uno; UM - Umuahia ; UMD – Umudike

Table 4: Interaction of location and land use on soil Texture and PSD

Parameter Location	Land use	Sand (g/kg)	Clay	Silt	Texture
NS	Cultivated	813.3	112.3	74.4	LS
	Excavated	775.7	138.9	85.4	SL
	Fallow	875.7	72.3	52.0	LS
	Forest	883.3	72.3	44.4	LS
	Grazing	769.1	145.2	65.3	SL
NU	Cultivated	542.4	152.3	305.3	SL
	Excavated	670.1	97.1	232.8	SL
	Fallow	542.0	132.0	326.0	SL
	Forest	661.6	85.6	252.8	SL
	Grazing	603.5	157.1	239.5	SL
UM	Cultivated	894.9	72.3	32.8	S
	Excavated	763.5	163.7	72.8	SL
	Fallow	842.4	98.9	58.7	LS
	Forest	782.4	132.3	85.3	LS
	Grazing	856.8	77.1	66.1	LS
UMD	Cultivated	813.3	120.8	65.9	SL
	Excavated	870.1	70.4	59.5	LS
	Fallow	776.8	150.4	72.8	SL
	Forest	750.1	177.1	72.8	SL
	Grazing	708.3	152.3	139.5	SL
LSD (0.05)		33.0	26.3	42.1	

The highest clay (177 g/kg) compared to all land use in all the locations was observed in FR land use of UMD though not different from EX (163.7 g/kg), CL(152g/kg), and GR (157 g/kg), of UM and NU respectively. The high clay in EX land use of UM may be ascribed to clay migration to lower depths (Tufaa *et al.,* 2019). Also, variations may not only be due to land used but to differences in parent materials between locations and within a location. The study suggests that PSD did not follow the order of natural vegetation having higher fine particles as reported by some researchers (Osakwe and Igwe 2013; Ozalp *et al.,* 2015) but indicated that the effect of land use was dependent on the characteristics of each location. In this study, 50% of the locations (NS and UMD indicated that grazing land use was more superior in enhancing PSD evidenced by higher clay and silt and lower sand fractions. Higher clay and silt with lower sand enhances water holding capacity and nutrient absorption while higher sand and lower fine particles may encourage leaching and loss of water through percolation and water erosion.

Aggregate stability indices

The main effect of land use on aggregate properties (Table 5) showed significantly ($p \leq 0.05$) higher amount of ASC (18.9%) lowest DR (0.30) and highest CFI in the grazing land use compared to other land uses except significantly similar CFI values among GR, FR, and FA. Improvement in micro aggregate stability in grazing land use over other land-use types may be attributed to its higher amount of fine particles (Table 2) or higher SOC (Table 8). Organic matter input through animal manure and fodder may increase aggregation reducing loss of soil particles. Tillage and removal of the top layer of the soil can lead to erosion and loss of fine particles. Opara (2009) reported a decline in micro aggregate stability indices in plantations, fallow, and cultivated lands compared to the forest with a greater decline in arable land.

Highest AS was recorded in grazing land use (70.6 %) but was not significantly ($p \leq 0.05$) different from the forest (66.6 %) but higher than fallow land use (63.48%), cultivated (38.6%), and excavated land use (47.9%). Lower values in excavated and cultivated land use may be due to the removal of topsoil and tillage. Furthermore, MWD increased in Grazing land use (1,5 mm) above all land use types probably due to quantity and type of organic carbon input through a straw in animal feed and manure from their droppings. Cultivated and excavated land use indicated lower MWD which may be ascribed to loss of organic matter in the enriched topsoil consequently affecting the aggregate stability. This is in agreement with the result of Gupta *et al.,* (2010) who reported that MWD has smaller values in the cultivated than fallow soils indicating maximum disturbances through tillage and as well as protection of SOC in macro-aggregates. Lawal *et al.,*(2009) in a land-use study in Northern Nigeria also reported that AS and MWD were higher in forest and fallow compared to cropland. At lower depths, a decline in SOC may affect aggregate stability (Alexia, *et al*., 2017) which may be the reason for the lower macro aggregate stability observed in the excavated land.

Table 5: Main effect of Land use on aggregate stability indices

Parameter	ASC	DR	CFI	AS	MWD
Land use				(%)	(mm)
Cultivated	15.9	0.37	0.47	38.55	0.98
Excavated	15.4	0.34	0.50	47.90	0.90
Fallow	16.5	0.34	0.59	63.48	1.04
Forest	15.4	0.35	0.58	66.6	1.25
Grazing	18.9	0.30	0.6	70.6	1.50
LSD (0.05)	1.74	0.03	0.06	5.54	0.13

The main effect of location on ASC was significant($p \leq 0.05$) and the result is presented in Table 6. The location in NU registered 57.27, 57, 42.25 % higher ASC compared with NS, UM, and UMD. This may be attributed to the highest silt and lowest sand indicated in location NU compared to other locations (Table 3) suggesting that ASC is partly dependent on the content of clay and silt in a soil sample. Ashford *et al.,*(1972) reported in an experiment that the higher the sand content, the higher the amount of clay recovered during mechanical shaking. Also, significantly ($p \leq 0.05$) lowest DR (0.31) in UMD compared to NS and UM, and highest CFI (0.58) in UMD though not different from the location NU (0.58) and NS (0.55) may be due to highest clay and SOC in that location (Table 3 and 9). Gochin *et al.,* (1995) indicated that dispersion of clay is a function of clay mineralogy, $CaCO_3$, and soil organic matter.

Table 6: Main effect of location aggregate stability indices

Parameter	ASC	DR	CFI	AS	MWD
Location		(%)		(mm)	
NS	11.57	0.38	0.54	51.91	0.92
NU	26.98	0.33	0.58	43.6	1.00
UM	11.59	0.36	0.45	60.94	1.16
UMD	15.58	0.31	0.58	58.24	1.13
LSD (0.05)	1.56	0.04	0.05	4.95	0.12

The result for AS (%) and MWD ranged from 43.6 (NU) - 60. 84% (UM) and 0.92 (NS)-1.16 mm (UM) respectively. The highest MWD and AS in UM were not significantly different from UMD. The result seems to suggest that factors such as clay and SOC may not be the only aggregating agent at the macro aggregate scale because the location in UMD had about 40 and 20 % higher SOC and clay respectively compared to location UM yet no significant difference in MWD and AS was observed. Some researchers have reported an increase in aggregation as a result of the presence of iron and aluminum oxide and other cations (Barthès *et al.,* 2008; Igwe *et al* ., 2009). Also, variation in management such as manure, fertilizer application, and intensity of tillage may contribute to variations observed. The interaction of land use and location on a micro aggregate and macro aggregate stability indices was significant ($p \leq 0.05$**).** and the result is presented in Table 7. The value for ASC ranged between 33.7 (NU- CL) and 4.47 % (UM- CL) The highest ASC compared to other land uses in other locations in NU was not significantly different from FA in the same location while significantly lowest ASC compared to other land uses was recorded in CL land use of UM. This result buttressed the point that ASC was partly dependent on particle size distribution as shown in NU that the land use (CL) with the highest silt and clay content in the experiment (Table 4) recorded the highest ASC. This result supports the report of Leifeld (2003) that micro aggregate stability is dependent on PSD. On the other hand lowest ASC in CL land use of UM agrees with other research findings that tillage exposes the soil to erosion with loss of fine materials indirectly affecting PSD and micro aggregation (Osakwe 2014). This result suggests that ASC is influenced by location and land use or either of the two factors.

The interaction effect on DR was significant($p \leq 0.05$). The lowest dispersion ratio (0.18) was recorded in GR of l UMD but was not significantly different from FR, EX, CL in UMD, UM, and UN respectively. This result clearly showed that values were not as a result of land use but the peculiarity of each location. However, the highest DR value in CL (0.57) of UM, is a demonstration of a decline in micro aggregate stability as a result of tillage especially in soils derived from coastal plain sands with a very fragile nature. Similarly highest CFI (0.79) in FR land use in UMD was not significantly different from values in GR, EX, and CL of the locations in UMD, UM, and NU respectively. Again effect was purely dependent on location. The lowest value recorded in CL land use (0.2) of UM implied loss of aggregation as a result of tillage. These results on the decline of micro aggregation with cultivation are in agreement with the report of other workers Osakwe et al. 2014) found lower DR and higher CFI in forest land use compared to arable land use in some locations of southeastern Nigeria. Golchin *et al.,* 1985 indicated a decline in soil quality in fallow and cultivated soils attributing it to a decline in SOC consequently increasing dispersed clay through a decline in SOC with a consequent increase in dispersed clay. Higher ASC, CFI, and lower DR is crucial for reducing soil erosion, surface sealing and crusting, enhancing water infiltration and soil carbon sequestration,

Interaction of location and land use on AS and MWD was significant($p \leq 0.05$). The highest AS (79.62%) and MWD (1.62 mm) in GR of the location in UMD were not significantly different from FR, FR, GR, and GR in UMD, UM, UN, NS. The result seems to suggest that macro aggregate stability is affected by levels of soil organic carbon in bulk soil and associated with aggregates > 0.25 mm (Table10) and also clay content (Table 4) hence these two factors influenced the % AS and MWD in the experiment. The lowest % AS (18 %) and MWD (0.3) was recorded in CL land use of the location in NS though not different from the EX land-use location of UMD.

Table 7: interaction of land use and location on aggregate stability indices

parameter Location	Land use	ASC	DR	CFI	AS (%)	MWD (mm)
NS	Cultivated	12.63	0.32	0.49	18.13	0.30
	Excavated	16.15	0.28	0.70	52.59	0.90
	Fallow	7.39	0.43	0.50	53.63	0.65
	Forest	7.32	0.42	0.44	57.2	0.68
	Grazing	16.33	0.30	0.75	78.0	1.37
NU	Cultivated	33.77	0.26	0.67	66.56	1.13
	Excavated	20.33	0.38	0.44	22.91	0.22
	Fallow	32.95	0.28	0.62	66.04	1.10
	Forest	221. 3	0.37	0.52	53.57	1.08
	Grazing	26.61	0.33	0.63	74.59	1.49
UM	Cultivated	4.47	0.57	0.2	47.53	0.61
	Excavated	18.33	0.22	0.67	40.46	1.21
	Fallow	10.44	0.35	0.48	66.49	1.27
	Forest	15.72	0.28	0.56	79.3	1.51
	Grazing	9.00	0.38	0.33	63.5	1.20
UMD	Cultivated	12.63	0.33	0.51	47.40	0.88
	Excavated	6.95	0.47	0.18	25.56	0.33
	Fallow	15.23	0.32	0.75	67.64	1.24
	Forest	19.23	0.23	0.79	70.99	1.55
	Grazing	23.85	0.18	0.67	79.62	1.62
LSD (0.05)		3.48	0.075	0.12	11.07	0.26

This result demonstrated that enhanced macro aggregation was indicated in forests and GR where there were inputs of organic carbon through litterfall and animal manure. Kalhoro *et al.*,(2017) worked on the land use effect on soil aggregates showed a positive correlation between soil organic matter and MWD. On the other hand cultivation and removal of topsoil are associated with a decline in soil organic carbon, loss of clay, and silt particle by the process of soil erosion. Junior *et al*., (2014) reported a decline in MWD following deforestation and more intensified soil management. Decline in soil macro aggregate stability adversely affect soil water movement characteristics, bulk density, root penetration and growth, seed germination, and seedling emergence.

Total soil organic carbon and aggregate associated carbon

The study evaluated the main effect of land use on total soil carbon and aggregate associated carbon (Table 8). The results of this study showed that mean values for soil organic carbon were 10,27, 9.56, 11.59,18.67 and18.34 g/kg in cultivated, excavated, fallow, forest, and grazing land use respectively (Table 6). The result indicated higher values in forest and grazing land use compared to other land uses. Murty *et al*., (2002) postulated that the conversion of forest to pasture did not result in a significant loss of soil carbon. The same trend of higher SOC in forests and grazing land was maintained across all aggregate sizes except for significantly low value recorded in the excavated land compared to cultivated and fallow land uses. The increase in SOC of forest land might be as a result of the litter falls and plant residues on the surface of the soil (Gebrelibanos and Mohammed 2013) while the increase in grazing land might be as a result of controlled grazing management that is associated with animal manure, fodder or bedding(Hermine 2010; Mohammed *et al*., 2018). Girmay and Singh (2012) reported higher mean SOCS in Northern Ethiopia due to animal excrement Lower values in cultivated land may be due to tillage (Lobe *et al.,* 2001), removal of plant residue (Mohammed *et al.,* 2018), and increased mineralization and minimum protection of SOC (Itanna *et al*., 2011).

Table 8:Main effect of land use on aggregate and soil organic carbon in bulk soil

Parameter		ASOC (g/kg)			SOC(g/kg)
Aggregate size(mm)		>2	2-0.25	0.25-0.053	Bulk
land use	Cultivated	11.3	13.6	17.3	10.27
	Excavated	2.9	15.6	11.9	9.56
	Fallow	15.5	13.1	15.3	11.59
	Forest	24.9	31.1	23.7	18.67
	Grazing	25.28	35.4	21.1	18.14

ASOC- Aggregate soil organic carbon SOC – Soil organic carbon in whole soil

The main effect of location on soil organic carbon in bulk soil and water-stable aggregates is presented in Table 9. The values of soil organic carbon in bulk soil ranged from 10.52 (NS) – 20.67 g/kg (UMD). It was observed that NS and NU in the derived savannah of southeastern Nigeria had statistically similar values and were significantly lower than in UM and UMD in the rainforest zone of southeastern Nigeria. However, SOC in UMD was 39.82% higher compared to the value in UM. Similarly, soil organic carbon sequestered both in the macroaggregates ((>2 mm,2-0.25 mm) and micro aggregates (> 0.053 mm) were significantly higher in UM and UMD compared to NU and NS except for a non-significant difference between UM and NS in the amount of SOC sequestered in 2-0.25 mm WSA. Textural characteristics such as clay content (Table 3) may have influenced the SOC content. Plante *et al*., (2006) and Hoyle *et al.,* (2011) reported that clay content increases the amount of SOC through physical protection from microbial breakdown. The lower temperature in the rainforest agro-ecological zone may favor more accumulation of SOC than in the derived savannah with high temperature which increases mineralization consequently reducing SOC. Again, variations may occur due to different tree densities and types of organic matter input (Nanganoa, *et al.* 2019). Salehi *et al.,*(2013) reported that the effects of trees on soil properties occur mostly due to the increase of organic matter and the release of nutrients from it.

Table 9:Main effect of location on aggregate and soil organic carbon in bulk soil

Parameter	ASOC (g/kg)			TSOC(g/kg)
Aggregate size (mm)	>2	2-0.25	0.25-0.053	Bulk
Location				
NS	11.43	17.5	13.8	10.52
NU	10.04	14.1	13.1	10.96
UM	19.98	18.84	23.4	12.44
UMD	25.27	37.1	23.4	20.67
LSD (0.05)	2.03	5.91	4.6	0.43

The interaction effect of land use and location on soil organic carbon in bulk soil and water-stable aggregate fractions was significant ($p \leq 0.05$). The result presented in Table10 indicated that the highest amount of soil organic carbon in bulk soil was significantly registered in forest soil of UMD (29.06 g/kg) compared to other land use in the study areas except for the GR land use of UMD that showed no significant effect. From the result in the four locations, 50% of the locations (NU and UM) had significantly highest soil organic carbon in the forest land use. This may be expected due to the accumulation of SOC through litterfall on forest floors. The lowest value compared to other land use types across all locations was indicated in excavated land use (6.68g/kg) in UM. Furthermore, it was noteworthy that 75% of the locations (NU, UM, and UMD) indicated the lowest soil organic carbon in cultivated and excavated land use. This may be due to the destruction of macroaggregates by tillage with loss of SOC and the removal of organic-rich surface soil by excavation.

The interaction effect of land use and location on aggregate associated SOC in 4-2 mm WSA was significant. The significantly($p \leq 0.05$) highest SOC compared to all land uses in the four locations was registered in FR land use (39.3 g/kg) of UM D though not significantly different from GR in the same location while the lowest ASOC (0 g/kg) was recorded in CL of NS and EX land use of NU, UM, and UMD. The result suggests that direct input of organic matter through litterfall and animal dung enhanced SOC sequestration at this aggregate size crucial for macro aggregate stability. The result of lower SOC in cultivation and excavation suggests that continuous cultivation without external input of organic matter and removal of topsoil causes a decline in SOC. Other studies have reported a decline in SOC when natural vegetation is converted to cropland (Liu *et al.,* 2014).

The interaction of location and land use on SOC sequestration in 2 – 0.25 mm WSA was evaluated and the result was presented in Table 10. Generally, comparing the four locations across the land use types, the highest aggregate associated carbon was in GR land use (54.1 g/kg) in UMD.

Table 10: Interaction of location and land use on aggregate and SOC in bulk soil

Parameter		ASOC (g/kg)		SOC (g/kg)	
Aggregate size (mm)		>2	2-0.25	0.25-0.053	Bulk
Location	Land use				
A	Cultivated	0.00	11.2	**16.6**	9.71
	Excavated	11.5	3.9	3.8	9.91
	Fallow	7.8	7.5	6.67	6.38
	Forest	14.83	32.4	22.5	9.51
	Grazing	23	31.4	**19.5**	17.09
B	Cultivated	7.8	7.7	9.4	8.11
	Excavated	0.0	12.9	14.3	7.18
	Fallow	10.2	6.9	10.7	11.04
	Forest	18.3	32.4	19.1	17.29
	Grazing	13.8	11.1	12.1	11.17
C	Cultivated	12.6	8.3	9.4	9.18
	Excavated	0.00	8.4	5.5	6.78
	Fallow	20.1	19.2	27.2	12.04
	Forest	27.1	25	29.4	18.82
	Grazing	26	32.3	24	15.36
	Cultivated	24.7	26.7	22	14.1
D	Excavated	0.00	30	21	14.36
	Fallow	24	17.9	22.7	16.89
	Forest	39.4	34.4	23.9	29.06
	Grazing	38.3	54.5	29.3	28.93
LSD (0.05)		4.33	13.21	9.75	0.95

The reason for this high organic carbon storage may be linked to the inherent high organic carbon content in that location, cattle dung as well as fodder provided as animal feed and accumulation over the years. This location indicated the highest SOC in whole soil (Table 10), ASC, CFI, AS, and least DR (Table 7) which may have enhanced the highest soil organic carbon storage in aggregates. Furthermore, the lowest SOC was registered in EX land use (3.8 g/kg) in NS, with a non-significant difference with CL and FA land use in the same location; CL, EX FA, and GR land use in N; CL and EX in UM. Cultivation and excavation are land use practice that encourages the loss of SOC through erosion, increased mineralization, removal of crop residue and removal of organic matter rich topsoil hence the potential for carbon sequestration is thereby jeopardized. Tillage disintegrates aggregates and increases access to soil microbes to soil organic carbon with consequent loss of soil organic carbon (Dungait *et al.,* 2012).

The interaction of land use and location on SOC associated with micro aggregates > 0.053 mm was significant and the result is presented in Table 10. The values ranged from 29.1 - 3.8 g/kg in GR of UMD and EX in NS respectively. The highest amount of aggregate associated carbon in GR was not significantly different from all land uses in that location, GR, FR, and FA in UM and FR in NS. The lowest value was not significantly different from the value in FA in NS; CL and FA in NU; CL and EX in location UM. Although some authors reported that management may not affect micro aggregate SOC storage at this aggregate size, the result of this research suggests that effect is location-specific as shown that though in UMD no change in SOC was indicated among the land uses, in other locations significant variations were observed. On the other hand, the effect of organic matter input through forest litter or animal manure was pronounced in higher carbon over other land use. Micro aggregate sequestration is important in long carbon storage.

4.0 Conclusion

The result of this study showed that land use significantly affected aggregate stability, soil organic carbon in whole soil, and soil organic carbon in water-stable aggregates across the four locations. Grazing and forest land use showed higher aggregate stability, SOC in bulk soil and water-stable aggregates over fallow, cultivated, and excavated lands buttressing the effect of forest litter and animal manure in improving soil quality. The micro aggregate stability indices were affected by textural characteristics while aggregate stability and MWD were affected by a combination of texture and soil organic carbon hence different values in the locations were a result of variations in PSD or/and soil organic carbon. Cultivation of arable lands must be followed up with conservative strategies such as residue retention and application of manure while excavated lands should undergo reforestation for the restoration of the topsoil. The fallow lands should be well managed by deliberately choosing plants that can restore and enhance soil instead of natural fallow.

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