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Research Article
Properties and Aggregate Stability of Soils of Dissimilar Lithology under Land Use Systems in Imo State, Nigeria

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Abstract
Background and Objective: The productivity of soil is influenced by the tenacity soils of different parent materials withstands the impact of raindrop as well as the land use system. This study therefore investigated the effects of land use types on soils of contrasting parent materials on aggregate stability and soil physicochemical properties. **Materials and Methods:** Soils from false bedded sand stone and coastal plain sand were evaluated under palm plantation, cassava farm land and plantain plantation. Dispersion Ratio (DR), Clay Dispersion Index (CDI), Clay Ratio (CR) and Clay Flocculation Index (CFI) were used to measure the stability of soil aggregates. Data were analyzed using one way analysis of variance and correlation analysis. **Results:** Highest value of moisture content (386.37 g kg^{-1}) was recorded in plantain plantation under false bedded sand stone while the highest value of soil pH (6.24) was recorded in palm plantation under false bedded sand stone. Soil pH was lowest (4.71) in cassava farm land under coastal plain sand. The lowest values of DR (0.40) and CDI (26.1) which showed more stability of soil aggregates were recorded in plantain plantation site under false bedded sand stone. Significant negative correlations existed between CDI with base saturation, moisture content, organic matter, total exchangeable bases and total nitrogen. Dispersion Ratio (DR) significantly correlated negatively with moisture content. **Conclusion:** Soil aggregates in false bedded sandstone under plantain plantation were more stable than soils in coastal plain sand under palm plantation or cassava cultivated land. Therefore; agronomic practices that will enhance soil organic matter for better stability in coastal plain should be adopted.

Key words: Aggregate stability, dispersion ratio, land-use, parent material, soil degradation, soil erodibility

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The productivity of soil and its ability to withstand water and wind erosion depends on the aggregate stability of the soil[1,2]. The stability of soil is a complex property that influences soil properties such as carbon stabilization, the porosity of soil, water penetration, soil bulk density and soil air[3]. The retention of water in the soil, hydraulic conductivity as well as the erodibility of soil to erosion depends on the stability of soil aggregates[4]. Therefore the maintenance of soil aggregate stability is vital for sustaining soil productivity, soil erosion control and control of soil degradation and environmental pollution[2]. Igwe and Obalum[5] explained soil aggregate stability as a major soil physical attributes which can serve as an indicator of soil structural quality. The stability of aggregate therefore is a key factor of soil resistivity to mechanical stress[6]. Liu *et al.*[4] described land use system as human use of land for agricultural, economic, recreational, conservational and governmental purposes. Studies have shown that changes in land use system such as deforestation, tillage, overgrazing and mineral fertilization can bring variations in soil properties[7]. Understanding the effects of land use system on soil attributes is vital for enhancing food security and environmental quality[5]. Most often, different land use types could occur on soils of similar lithology or on soils of dissimilar lithology[6]. Parent material is a major soil forming factor that affects soil physical, chemical and biological properties[8] as well as soil degradation and ecosystem resilience in a given location. Agronomically, plant root development, drainage and water availability to plants may be affected by the parent material domiciled in a given area[9]. Understanding the relationship between parent materials and land use system on soil aggregate stability will help in policy development that will enhance soil fertility, environmental safety and food security. However, the number of studies on the effect of land use system on soils of contrasting parent material on the stability of soil aggregates is limited. Hence, this research work examined the effect of land use system on the aggregate stability of soils of contrasting parent material.

MATERIALS AND METHODS

Study location: The study was carried out at two locations of varying parent materials in 2018. The locations and their parent materials were Obowo (False bedded sand stone) and Owerri (Coastal plain sand). Obowo is located at latitude 5°81'N and longitude 7°34'E, while Owerri is located at latitude 5°47'N and longitude 7°02'E. These locations were within the same agro-ecological zone of southeast Nigeria. The average annual rainfall and temperature in the locations are 1800-2200 mm and 27-31°C, respectively.

Field study: This study was conducted within a period of three months from June 1 to September 30, 2018.

Parent materials and land use systems were used to locate the sampling points. Two parent materials (false bedded sand stone and coastal plain sand) were studied under three land use systems (plantain plantation, cassava cultivated land and palm plantation). In each parent material, 9 samples were collected, 3 from each land use given a total of 18 soil samples. This was done on the 18th and 19th June, 2018. Sampling depth was 0-30 cm. Core samplers were used to collect soil sample for bulk density determination. From 2nd-9th June, 2018, the samples were air dried, sieved and subjected to laboratory analysis (Fig. 1).

Laboratory analysis: Samples were analyzed in the laboratory from 10th-29th July, 2018 using the following methods. Soil particle sizes were determined in water and in calgon by hydrometer method[10]. Bulk density was measured using core method according to Grossman and Reinsch[11]. Gravimetric moisture content was determined gravimetrically by oven drying the samples[12] at 15°C and computed as follows:

$$\text{Gravimetric moisture content} = \frac{\text{Mass of water}}{\text{Mass of oven dried soil}} \times 100 \quad (1)$$

Soil total porosity was determined with the equation:

$$\text{Total porosity} = 1 - \frac{\text{Bulk density}}{\text{Particle density}} \times 100 \quad (2)$$

Estimation of soil aggregates stability: Soil aggregate stability was estimated using four indices namely: Clay Flocculation Indices (CFI), Dispersion Ratio (DR), Clay Dispersion (CD) and Clay Ratio (CR) according to Igwe *et al.*[13] and Igwe and Obalum[5]:

$$\text{DR} = \frac{\text{Silt}(\%) + \text{Clay}(\%)\ (\text{water})}{\text{Sitl}(\%) + \text{Clay}(\%)(\text{calgon})} \quad (3)$$

$$\text{CFI} = \frac{\text{Clay}(\%)(\text{calgon})}{1} \times 100 \quad (4)$$

$$\text{SDI} = \frac{\text{Clay}(\%)(\text{water})}{\text{Clay}(\%)\ (\text{calgon})} \times 100 \quad (5)$$

$$\text{CR} = \frac{\text{Sand}\ (\%)}{\text{Clay}(\%) + \text{Silt}(\%)} \quad (6)$$

Low values of CR, DR and CDI indicate less erodibility and hence higher stability of soil aggregation while the higher the value of CFR the higher stability of soil aggregate[5].

Soil pH was determined using 1:2:5 soil to liquid ratio both in water and in KCl[14]. Organic carbon was determined using chronic wet oxidation method[15]. Total nitrogen was determined according to Brady and Weil[16]. Available P was determined using bray II solution method[15]. Exchangeable Ca and Mg was determined using EDTA complexion metric titration while Na and K was determined using flame photometry[17]. Total exchangeable bases were calculated by addition of the exchangeable bases (Ca, Mg, K, Na). Exchangeable Acidity (Al and H) was analyzed using IN KCl with 0.5 NaOH using phenolphthalein indicators[18]. Effective cation exchangeable capacity was derived from the summation of total exchangeable acid and total exchangeable bases while percentage base saturation was determined by dividing exchangeable bases with ECEC and multiplied by 100.

Data analysis: Data were subjected to analysis of variance (ANOVA) using one-way ANOVA from 5th-8th August, 2018. Significant means were separated using Least Significant Difference (LSD) at 0.05 probability level. Relationship between aggregate stability ratio and soil properties was determined using correlation.

RESULTS

Physical properties of soils in the studied locations: The physical properties of soils of the studied locations are presented in Table 1. The textural classes of coastal plain sand and false bedded sand stones were sandy loam and silt clay loam, respectively. Soil bulk density, total porosity and gravimetric moisture content in the three land use types and in the two parent materials significantly ($p = 0.05$) differ from each other. The lowest bulk density of 0.64 g cm^{-3} was recorded in plantain plantation while the highest moisture content (386.37 g kg^{-1}) was recorded in plantain plantation under false bedded sand stone.

Chemical properties of soils in the studied locations: The chemical properties of the studied soils are shown in Table 2. Soil pH, organic matter, total nitrogen, available phosphorus and exchangeable bases significantly ($p = 0.05$) differ in the three land use systems under the two parent materials. Under land use types, there was higher soil pH in palm plantation and low soil pH in cassava farm land. Under parent materials, soil pH was highest in false bedded sand stone with lowest value in coastal plain sand. The highest soil total nitrogen was recorded in false bedded sand stone under plantain plantation farm and the lowest recorded in coastal plain sand under cassava farm land. The highest available phosphorus was recorded in false bedded sand stone under plantain plantation while the lowest was recorded in coastal plain sand under cassava cultivated land (Table 2). Exchangeable bases, effective cation exchange capacity, base saturation and aluminum saturation was significantly ($p = 0.05$) influenced by land use system.

Effect of land use on erodibility indices of the studied soil: Results on the erodibility ratio of the studied soils showed that

Table 1: Physical properties of the studied soil

Land use type	Location	Parent material	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	TC	BD (g cm^{-3})	TP (%)	MC (g kg^{-1})
Palm plantation	Uratta	Coastal plain sand	834.67	54.67	110.67	SL	0.67	74.50	316.77
Palm plantation	Agunze	False bedded sand stone	748.00	101.33	150.67	SCL	0.73	72.50	353.30
Cassava farm land	Amanze	False bedded sand stone	752.00	108.00	137.33	SCL	0.83	68.37	219.50
Cassava farm plant	Naze	Coastal plain sand	888.00	61.33	50.67	SL	0.68	74.43	279.57
Plantain plantation	Naze	Coastal plain sand	861.33	48.00	90.67	SL	0.64	75.73	322.90
Plantain plantation	Amanze	False bedded sand stone	681.33	134.67	184.00	SCL	0.76	71.30	386.37
LSD (0.05)			107.20	63.37	54.38		0.18	6.92	113.20

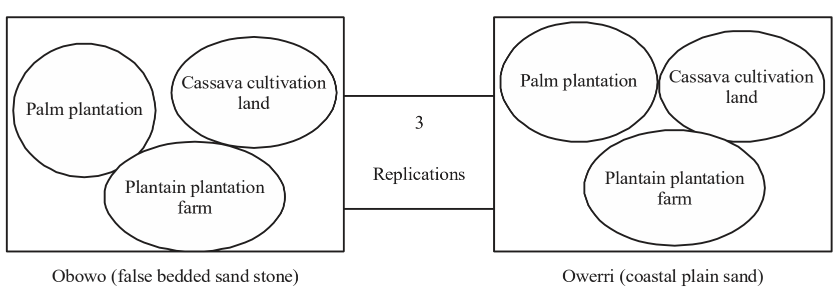

Fig 1: The layout of the study

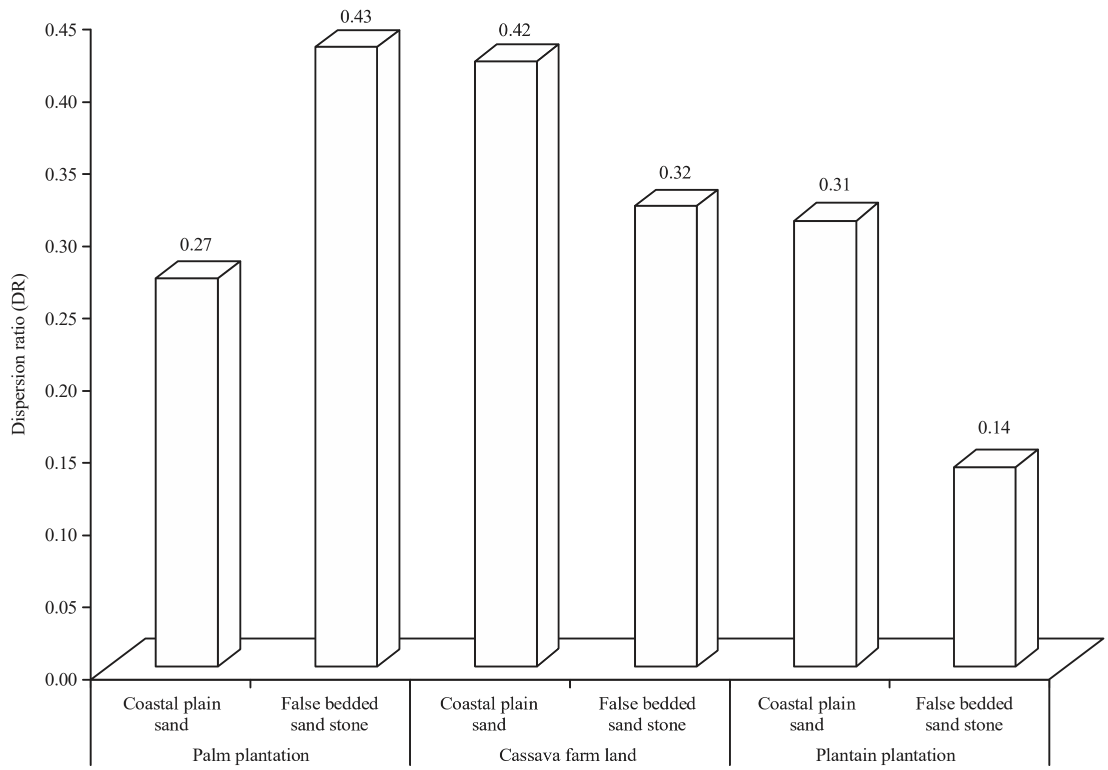

Fig. 2: Effect of land use types and parent materials on Dispersion Ratio (DR)

Table 2: Chemical properties of the studied soil

Land use	Location	Parent material	pH (H_2O)	Org. carbon	Org. matter	Total N	Avail. P	Ca	Mg	K	Na	TEB	TEA	ECEC	BS
Palm plantation	Uratta	CLS	5.01	9.37	16.23	1.20	6.94	2.20	1.27	0.13	0.24	3.84	0.67	4.51	84.97
Palm plantation	Agunze	FSS	6.24	14.43	25.20	1.08	6.12	1.87	0.87	0.22	0.24	3.20	0.67	3.86	82.73
Cassava farm land	Amanze	FSS	4.71	15.97	27.57	1.05	7.02	1.60	0.80	0.19	0.10	2.69	1.03	3.72	72.20
Cassava farm land	Naze	CLS	4.77	12.43	22.07	0.81	3.38	2.67	1.20	0.19	0.15	4.21	1.00	5.21	80.83
Plantain plantation	Naze	CLS	5.83	13.90	26.67	1.25	5.69	2.67	1.52	0.16	0.08	4.37	0.87	5.21	83.30
Plantain plantation	Amanze	FSS	5.54	12.10	20.93	1.38	7.41	1.87	1.33	0.25	0.11	3.55	0.83	4.39	80.87
LSD(0.05)			0.89	3.59	8.72	0.31	3.9	0.48	0.54	3.9(ns)	0.11	0.85	0.17	0.83	3.14

CSL: Coastal plain sand, FSS: False bedded sandstone

the values of DR, CDI, CR and CFI significantly ($p = 0.05$) differ in the three land use systems. The lower the value of dispersion ratio (DR) the higher the stability of soil aggregates to resist the impact of rainfall. In Fig. 2, the lowest DR was observed in plantain plantation farm under false bedded sand stone.

Clay Dispersion Index (CDI) had the lowest value in plantain plantation under false bedded sand stone. This result was similar to the results in DR (Fig. 3). The lower the value of DR, the stronger the stability of soil aggregates. The highest value of CDI was observed in cassava farm land under coastal plain sand. Similarly, the lower the value of Clay Ratio (CR), the stronger the stability of soil aggregates (Fig. 4). The lowest value of CR was recorded in palm plantation under false bedded sand stone. Different trends were observed in clay flocculation index (CFI) (Fig. 5) in which the highest CFI was observed in palm plantation under false bedded sand stone.

Relationship between erodibility index and soil properties: Relationship between CDI, CR, DR and CFI with soil properties are presented in Table 3. Significant negative correlations existed between CDI with Base Saturation (BS), Moisture Content (MC), Organic Matter (OM), total exchangeable bases and total nitrogen (TN). Dispersion Ratio (DR) correlated significantly with moisture content. There was significant positive correlation between CFI and BS as well as gravimetric moisture content.

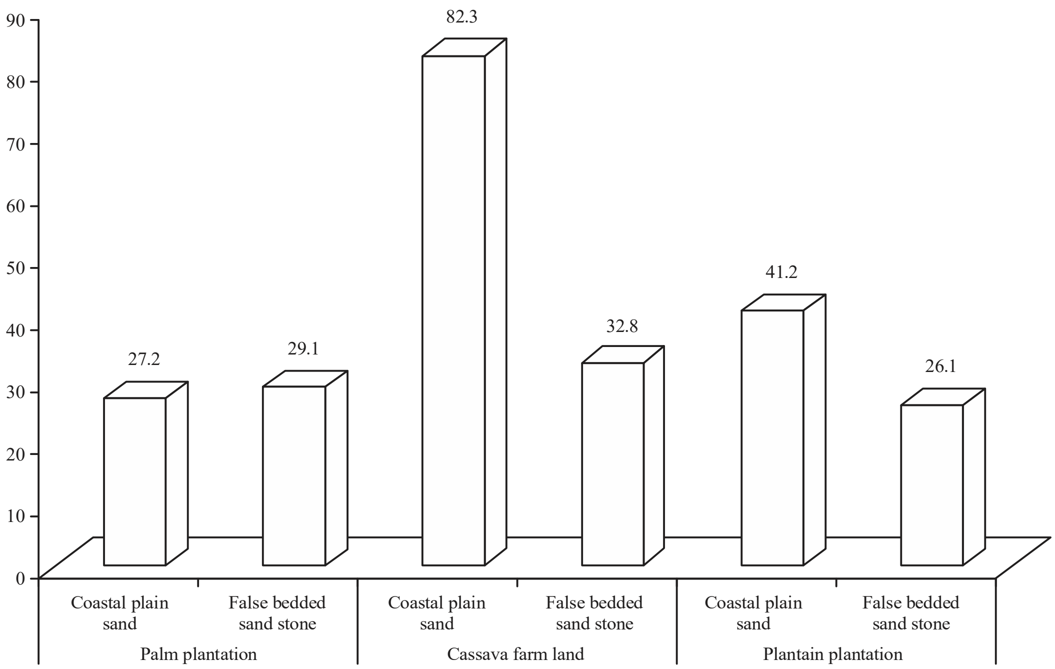

Fig. 3: Effect of land use types and parent materials on Clay Dispersion Index (CDI)

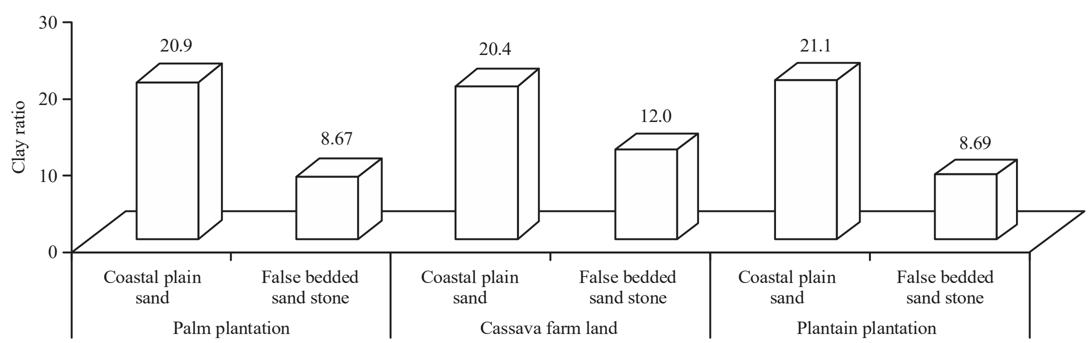

Fig. 4: Effect of land use types and parent materials on Clay Ratio (CR)

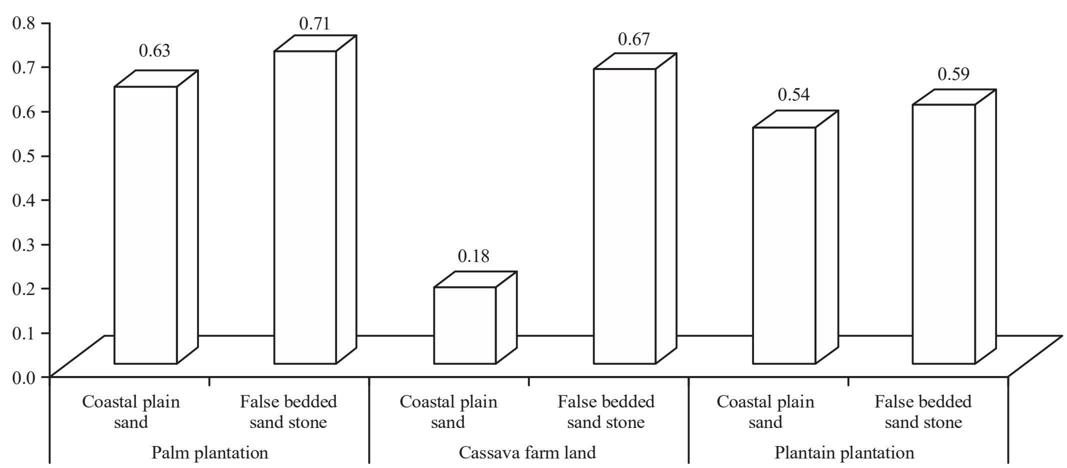

Fig. 5: Effect of land use types and parent materials on Clay Flocculation Index (CFI)

Table 3: Correction between erodibility index and soil properties

Property	CDI	CFI	CR	DR
Al. Sat	0.6121*	-0.5916*	-0.1059	0.0623
Bulk density	-0.4582*	-0.6948*	-0.1497	0.2283
Base saturation	-0.9004**	0.8793**	-0.1400	-0.3714
ECEC	-0.4209	0.4264	0.1427	-0.3994
Moisture content	-0.8304**	0.7168**	-0.5798*	-0.5920*
Organic Matter	-0.6486*	0.6961*	0.0923	-0.2472
TEA	0.6652*	-0.6252*	0.1725	0.1191
TEB	-0.5864*	0.5819*	0.1103	-0.4306
Total Nitrogen	-0.6441*	0.6507*	0.1830	-0.3013
pH (H_2O)	-0.5844*	0.5176*	0.1321	-0.1652

*'**Significant at 0.05 and 0.01 probability level, respectively

DISCUSSION

Parent material is one of the major soil forming factors. There were variations in the textural classes of the soil with respect to parent materials under the three land use types of the studied soils. This observation was in line with the previous works of Adaikwu *et al.*[19] who stated that soil texture is a function of parent materials which has been influence by climatic conditions over a long period of time. Similarly, Onwudike *et al.*[20] and Shepaherd *et al.*[21] have shown that land use system influences the particle size distribution of soil. False bedded sand stone retained more moisture than coastal plain sand due to high sand fraction in the coastal plain sand that encourages runoff and leaching; hence increasing erodibility of soil to the impact of rainfall. Onwudike *et al.*[20] made the same observation on the effect of land use types on soil properties of similar lithology.

Low pH in coastal plain sand under cassava cultivated land could be attributed to the particle size distribution of the soil with sand fraction dominating the soil fractions (Table 1). This encourages leaching of soil organic matter and basic cations thereby enabling acid forming cations to dominated the colloidal surface. This observation is in line with Onweremadu *et al.*[6], who recorded low pH in fluvisols of Owerri, southeastern Nigeria. False bedded sand stone recorded lower DR than coastal plain sand due to higher organic matter in false bedded sand stone which helps to bind soil aggregates together. According to Onwudike and Mbonu[22], the higher the value of CFI, the lower the stability of soil against rain drop. Therefore, false bedded sand stone was observed to have lower values of DR, CDI, CR and lower value of CFI. Cassava farm land recorded highest values of DR, CDI and CR with lowest value of CFI. This could be attributed to agronomic practices like tillage and exposure of soil to climatic factors. Coastal plain sand influenced these parameters due to the particle sizes of the soil with poor organic matter content which made the soil porous hence resulting to poor aggregate formation.

The negative relationship between CDI with, BS, MC, OM, TEB, TN and soil pH indicated that an increase in the values of base saturation, moisture content, total exchangeable bases, total nitrogen and soil pH could reduce the value of clay dispersion ratio thereby increasing the stability of soil aggregates. Similarly, increase in soil gravimetric moisture content reduces the value of Clay Ratio (CR) and Dispersion Ratio (DR) showing improvement in soil aggregate formation. In the case of Clay Flocculation Ratio (CFI) decrease in the value of bulk density increases CFI while increase in the values of BS and moisture content increases the value of CFI showing better soil aggregate stability. These interactions were possible due to higher accumulation of soil organic matter, increased soil pH and exchangeable bases as was observed in false bedded sand stone under plantain plantation and palm plantation. Onwudike and Mbonu[23] recorded similar results on the contribution of agricultural wastes on soil aggregate stability and attributed the effect to high organic matter content in the added agricultural wastes.

CONCLUSION

There were variations in the physicochemical properties of soil in the three land use types studied under different parent materials. Establishment of plantain plantation and palm plantation on these parent materials have shown to help bind soil fractions together thereby increasing the stability of the soil. Aggregate stability of soils in cassava cultivated lands were low and therefore agronomic practices such as minimum tillage organic manure application and mulching should be practiced to increase soil organic matter content that helps to hold soil particles together.

SIGNIFICANCE STATEMENT

This study discovered the importance of land use system in improving the aggregate stability of soil of contrasting parent materials that can be beneficial for improving productivity and environmental sustainability. This study will help the researchers to uncover the critical areas of improving soil aggregate stability under different land use system that many researchers were not able to explore. Thus a new theory on improving soil aggregation under different land use systems may be arrived at.

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