

EFFECT OF AGRICULTURE LAND USE PRACTICES ON SELECTED SOIL PROPERTIES AND MACRO-AGGREGATE STABILITY: A CASE STUDY OF COASTAL PLAIN SAND IN AKWA IBOM STATE, NIGERIA.

Abstract

The study was carried out in Coastal plain Sands, Akwa Ibom State, Nigeria to evaluate Macro-aggregate stability under three land-use types; Rubber Plantation (RP), Oil Palm Plantation (OPP) and Forest plot (FP). Random soil and core samples were collected in five Points in each of the three land-use types, given a total of 15 samples, bulked for physical and chemical analyses. Aggregate Separation was done using a nest of four sieve sizes. Macro-aggregate stability indices means weight diameter of dry and wet (MWD_d and MWD_w), water stability aggregate (WSA), aggregate Clay (AC), exchangeable sodium percentage (ESP) and aggregate silt plus Clay (ASC) were calculated. The data were subjected into descriptive statistics and correlation Matrix. The result indicates that sand was the dominant particle size fraction. Macro-aggregate stability indices result revealed that MWD_w recorded highest value at RP (1.128) and lowest at FP (0.963). WSA and AC had highest mean value at RP (26.82) and OPP (11.562) and RP (4.85), mean value at OPP (1.54) and OPP (13.35) and lowest value of RP (1.22) and FP (7.35), respectively. Aggregate silt plus clay increases flocculation of soil aggregate, while exchangeable sodium percentage causes disintegration of soil aggregate.

Keywords: Soil structure, Macro-aggregate stability, Land-use types, Acid Soils, Aggregate-stability indices.

Introduction

Stability of soil aggregate is very reliant on type of land use practices and mineral that are present in the soil. Kay (1998) and Essien *et al.* (2022) pointed out that instability of soil structure is caused by land-use and soil/crop management practices. According's to Gupta and Sharma (1990), the presence of excessive amounts of exchangeable sodium reverse the process of aggregate and causes soil aggregates disintegration into their constituent individual particles sand. Silt and clay and cause macro-aggregate to break down and from smaller aggregate (Micro-aggregate).

Improper land-use practices cause soil degradation, that leads to unhealthy soil, which brought about decline in soil to function properly and low productive potential and diminishes the resource base (Ogban *et al.*, 2022). Soil aggregate stability measures the ability of the soil structural units to resist change and management of this soil against degradative forces (Igwe and Obalum, 2013). The author added that the Collapse of macro-aggregate yields micro-aggregate, which form their building blocks, and external forces acting on a soil can also foster formation of aggregate from disperse materials. Soil influence many physical and biogeochemical processes in agriculture (Obalum *et al.*, 2012). It is a composite body or granule of loosely bound minerals particles within a soil and is characteristically mediated by relative amount of organic matter in soil.

Research recognized two major size-based categories, macro and macro-aggregate formed by both aggregation and fragmentation processes (Opara, 2009). The groups are further divided by size. Each group differs from the other in properties such as binding agents, carbon and nitrogen distribution. Soil aggregate stability is the basic unit of soil structures and contribute to soil carbon sequestration function and carbon stabilization (Makonnen *et al.*, 2015).

The possible mechanisms of aggregate formation are very complex. The formation maintenance of a high degree of aggregation is one of the most difficult tasks of soil management. It is also one of the most importance, since it is a potent means of influencing ecosystem function. Brady and Weil (1974) stated that the smaller aggregates are more stable than the larger ones. So, maintaining the much-priced larger aggregates requires much care. Kay (1998) reported that many factors influencing aggregate stability such as environment factors, soil management factor, plant influences and soil properties, pedogenic processes, microbial activities, exchangeable ions, nutrient reserves and moisture availability are important in the stabilization of soil aggregates. Brady and Weil (1999) observed that earthworms move soil particles around. Often ingesting them and forming pellets or cast, and the movement of plant roots forces the particles to come into close contact and encourage aggregation. Soil materials integrate into soil, changes soil characteristics that reflect long-term land use and are important indicators of soil quality. Essien *et al.* (2019), explained main mechanisms acting in the formation of aggregate and that Al-hydroxide, OH-AL polymers may play a significant role in cementing clay particles, while Edem (2007) ; Essien *et al.* (2024), added that organic matter is the major agent stimulating the formation and stabilization of granular crumb type of aggregates and enhances the capacity of the soils to hold and exchange ions. Sollin *et al.* (1996) showed that clay is related with soil organic carbon stabilization, which contribute to good soil aggregation. The biological processes of aggregation which involves activities of micro-organisms, earthworms burrowing the soil producing organic glues and enmeshment by roots and

Fungal hyphae, also influence, aggregation of the soil. Soil macro-aggregate stability is measured directly with indices derived from soil properties (Isikwue *et al.*, 2012; Igwu and Obalum, 2013; Ogban *et al.*, 2022). Usually disintegration of macro-aggregates begins with breakdown and weakening of aggregate bonds, which were, as a function of soil properties Indices of aggregate according to Juriga and Simansky (2018) and Ogban *et al.* (2022),

explained that stability of micro-aggregate is essential for improved macro aggregation. Since tropical soils are highly weathered erodible and instable, much has not been done in macro-aggregate stability under different land use practices in Akwa Ibom State. Therefore, there is need to increase stability of macro-aggregate that is more suitable in acid soils, Akwa Ibom State, Nigeria.

Materials and Methods

Study Location

The study was conducted on soil formed on Coastal plain sands parent material in Southeastern, Nigeria. The sampling area is situated between latitude $4^{\circ}40'$ and $5^{\circ}15' N$ and Longitude $7^{\circ}30' E$ and $8^{\circ}15' E$, (Essien and Ogban, 2018). The climate of the study area is hot humid tropic (Inyang, 1976), and is divided into two seasons, the wet or rain season which lasts from April to October, and the dry season which last from November to March. The annual rainfall averaging between 1,875 to over 2,500mm (Inyang, 1976.) The rains are described as less effective, due to its intensity, of about 150 to 200mm h^{-1} for a relatively short duration of 5 to 10 minutes, which a relative high proportion is lost as runoff. Generally, the areas are in ecology where rainfall exceeds. The evapotranspiration for at least 8 months in a year with the different contributing to high runoff and potentially high soil erosion. Mean annual temperature varies between $21^{\circ}C$ - $29^{\circ}C$ and relative humidity is between 60%-85%. A variety of geological formation occur in study area, the dominant parent materials are the Quaternary Benin formation or unconsolidated Coastal plain sands, the Tertiary Bende Ameki (sandstone) formation and River Alluvium (Ojanga *et al.*, 1981; Peters *et al.*, 1989). The soils are rich in free iron, but have low weathering potential and minerals reserve and therefore are characterized with low physical and chemical fertility status, due to prolonged deep weathering and cycles of erosion (Ofomata, 1975). The soil has loamy texture in the surface, and sandy clay and clay in the subsurface.

The vegetation patterns favors the luxuriant tropical rainforest which has however been almost completely replaced by secondary forest and are grouped into Raphia/oil palm forest, Cocoa plantations, swamp forest, swamp grassland (Fallow rice fields) and dry season crops in the area includes Telfairia (Fluted Pumpkin), Okro, Peppers, Maize, Melon, Cassava garden eggs and Cocoyam's.

Field Methods

Soil samples were collected in three (3) land-use types that was not less than ten (10) years of establishment (Rubber plantation, oil palm plantation and Forest). Core samples were collected at each sampling location with iron cylinders measuring 7.2cm a long and 6.8cm width. The soils in the cylinders were secured with a piece of calico and rubber band for determination of saturated hydraulic conductivity, bulk density and total porosity calculated.

Laboratory Analysis

The bulk samples were air dried and passed through a 2mm sieve for the following analysis. Particle size analysis was done using Bouyoucos Hydrometer method as described by Udo *et al.* (2009), after dispersing the soil particles with sodium hexameta-phosphate solution. The textural class of the soil was determined using the textural triangle. Saturated Hydraulic conductivity (K_{sat}) was determine using the constant head permeameter method (Dane and Top, 2022). The saturated hydraulic Conductivity was calculated using the equation.

Comment [R1]: Kindly check the coordinates

Comment [R2]: Suggestion:

Soil samples were collected from three distinct land-use types—rubber plantation, oil palm plantation, and forest—each with an establishment history of no less than ten (10) years.

Comment [R3]: Kindly check the spelling

is it calico? a type of woven cotton fabric often used in fieldwork to secure soil samples due to its durability and permeability

Comment [R4]: The soil within the cylinders was secured with calico and rubber bands to facilitate the determination of saturated hydraulic conductivity, bulk density, and total porosity.

Comment [R5]: Not italized

Comment [R6]: determined

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$$K_{sat} = \frac{QL}{\Delta hAt} \dots\dots\dots \text{Equation 1}$$

$$\Delta h$$

Where

K_{sat} = Saturated hydraulic conductivity (cm hr^{-1})

Q = Discharge rate ($\text{cm}^3 \text{ min}^{-1}$)

L = Length of soil column (cm)

Δh = Change in hydraulic head (cm)

A = Cross sectional area through which the flow takes place (cm^2)

T = Time (minutes)

Bulk density was determined using core samples as described by (Grossman and Renish, 2002). Soil samples were oven dried at 105°C to a constant mass and bulk density calculated.

Using the equation.

$$b = \frac{M_s}{V_t} \dots\dots\dots \text{equation 2}$$

$$V_t$$

Where

b = bulk density (Mg m^{-3}),

M_s = Mass of oven dry soil (Mg)

V_t = Total volume of soil ($\text{M}^3 \text{ M}^{-3}$)

The total volume of soil was calculated from the internal dimension of the cylinder. Total porosity calculated from the internal dimension of the cylinder. Total porosity was calculated from particle size and bulk density relationship as follows;

$$f = \left(\frac{100}{tb} - 1 \right) \frac{cs}{100} \dots\dots\dots \text{Equation 3}$$

where

f = Total porosity ($\text{m}^3 \text{ m}^{-3}$),

tb = Bulk density (Mg m^{-3}) and

cs = Particle density (Mg m^{-3})

Organic matter was determined by Walkley and Black wet digestion method (Nelson and Sommers, 1982), organic matter was obtained by multiplying the result from organic carbon with the van Bemmelen factor of 1.724.

Comment [R8]: Properly write the equation using an equation tool so that it will not be confusing to the readers.

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Available phosphorus was determined by the Bray P1 method. The phosphorus in the extraction was measured by the method of Murphy and Riley (1962). Exchangeable Bases (Ca, Mg, Na and K) were determined by extraction using ammonium acetate (in NH₄ OAc) solution (Thomas, 1982). The available K and Na were determined using Atomic Absorption Spectrophotometer. Total Nitrogen was determined using macro-Kjeldahl digestion method (Bremner, 1996). Exchangeable Acidity was determined using KCL extraction method (McLean, 1982). Effective Cation Exchange Capacity (ECEC) was obtained by summation of the exchangeable bases and exchangeable acidity, also electrical conductivity was determined in 1:2.5 soil/water ratio using conductivity bridge (Udo et al., 2009).

Comment [R11]: Ca

Base saturation was calculated as follows;

$$\% B_{sat} = \frac{TEB}{ECEC} \times 100 \dots \dots \dots \text{equation 4}$$

Comment [R12]: Not italicized

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Where

B_{sat} = Base saturation,

Comment [R14]: Be consistent with the equation kindly check with subscript

TEB = Total exchangeable bases

ECEC = Effective cation exchange capacity.

Indices of Macro-aggregate stability

Mean weight diameter of dry aggregate (MWD_d) and wet aggregate (MWD_w), are indicator of aggregate stability. 50g of air 4mm sieved soil sample was shaken for 10 minutes on top of sieves of diameters, 4.0-2.0, 2.0-0.25, 0.25, 0.25-0.05 and < 0.05mm the mass of aggregate on each sieve that resisted breakdown was determined. All aggregate fractions were collected, weighted, remixed and used for the wet sieving analysis. In the wet sieving procedure, the soil was per-soaked for 10 minutes on the topmost sieve in net above, and was vertically raised and lowered through a distance of about 4cm for 10 minutes and computed from the equations;

Comment [R15]: Mean Weight Diameter of Dry aggregate

Comment [R16]: W

Comment [R17]: This part is quite confusing can you rephrase this ??? Make it clear...

$$MWD = \sum_{i=1}^{n_x} \omega_i \dots \dots \dots \text{equation 5}$$

Where

MWD = Mean weight diameter

\bar{x} = Mean diameter of each size fraction (mm),

W_i = The proportion of the total sample weight occurring in size of fraction,

N = Number of sieves used

Water stability Aggregates (WSA)

Aggregate clay (AC) was calculated from the equation

$$AC = TC - WDC \dots \dots \dots \text{equation 6}$$

Where

AC = Aggregate clay (g kg⁻¹)
 TC = Total clay (g kg⁻¹)
 WDC = Water-dispersible clay (g kg⁻¹)

TC = Total clay

WDC = Water dispersible clay.

Exchangeable Sodium percentage (ESP) was calculated from the equation

$$ESP = \frac{\text{Exchangeable Na}}{CEC} \times 100 \dots\dots\dots \text{equation 7}$$

Where;

ESP = Exchangeable sodium percentage

CEC = Cation exchange capacity.

Aggregate silt plus clay (ASC) was used to estimate the stability of the various aggregate – size fractions

$$ASC = (TC + T_{si}) - (WDC + WD_{si}) \dots\dots\dots \text{equation 8}$$

Where

ASC = Aggregated silt plus clay,

TC = Total clay

T_{si} = Total silt

WDC = Water- dispersible clay

WD_{si} = Water dispersible silt

Statistical Analysis

The data generated were fitted into 3x5 experiment in a complete Randomized Design. Descriptive statistical Analysis of means, standard deviation and co-efficient of variation were used to measure central tendency, while correlation analysis was used to establish the relationship between soil properties and macro-aggregate stability indices.

RESULT

Effect of Land-use Types on soil physical Properties

Physical properties of soil under different land-use types are presented in Table 3. Coarse sand content had a mean value of 692 ± 9.4g kg⁻¹ (CV = 90.99%) at rubber plantation, 723 ± 8.70g kg⁻¹ (CV = 75.67%) at oil palm plantation and 648 ± 5.19g kg⁻¹ (CV = 26.89). in forest plot. Fine sand content had a mean value of 022 ± 8.81 g kg⁻¹ (CV = 77.61 %) at rubber plantation: 127 ± 5.66 kg⁻¹ (CV = 31.99) at oil palm plantation and 177 ± 5.07 g kg⁻¹ (CV =

Comment [R18]: Effect of Land-use Types on Soil Physical Properties

Comment [R19]: I would suggest that you will not repeatedly write or enumerate what is presented in your table. You may write same as what you did in chemical properties their were sort of comparison of your results and etc. in this way youre presentation is insightful.

Comment [R20]: Table 1?? Check pls

Comment [R21]: Kindly check data consistency

Comment [R22]: Kindly check value consistency

25.69 %) at forest plot. Total sand content had a mean value of $860 \pm 3.00 \text{ g kg}^{-1}$ (CV = 9.01 %) at rubber plantation, $849 \pm 4.72 \text{ g kg}^{-1}$ (CV = 22.26%) at oil palm plantation and $825 \pm 4.82 \text{ g kg}^{-1}$ (CV = 23.24 %) at forest plot. The highest sand fraction means value (723 g kg^{-1}) was observed at rubber plantation and lowest value (648 g kg^{-1}) was observed at forest plot. Silt content had a mean value of $25 \pm 2.05 \text{ g kg}^{-1}$ (CV = 4.19%) at rubber plantation, $49 \pm 4.17 \text{ g kg}^{-1}$ (CV = 17.39%) at oil palm plantation and $7.23 \pm 2.23 \text{ g kg}^{-1}$ (CV = 4.95%). The silt content was high in oil palm plantation and low in forest plot. Clay content had a mean value of $115 \pm 1.9 \text{ g kg}^{-1}$ (CV = 3.67 %) at rubber plantation and lowest mean value of $100 \pm 3.52 \text{ g kg}^{-1}$ (CV = 12.37%) at oil palm plantation.

Comment [R23]: mean

Bulk density had a mean value of $1.31 \pm 0.21 \text{ Mg m}^{-3}$ (CV = 0.04%) at rubber plantation, $1.69 \pm 0.25 \text{ Mg m}^{-3}$ (CV = 0.06%) oil palm plantation and $1.47 \pm 0.16 \text{ Mg m}^{-3}$ (CV = 0.02%) at forest plot. Bulk density revealed that the highest value ($1.69 \pm 0.25 \text{ Mg m}^{-3}$ (CV = 0.06%)) was recorded at oil palm plantation, while the lowest mean value ($1.31 \pm 0.21 \text{ Mg m}^{-3}$ (CV = 0.04%)) was recorded at rubber plantation. Total porosity had a mean value of $0.51 \pm 7.76 \text{ m}^3 \text{ m}^{-3}$ (CV = 60.25%) at rubber plantation, $0.36 \pm 9.38 \text{ m}^3 \text{ m}^{-3}$ (CV = 88.07%) at oil palm plantation and $0.44 \pm 5.89 \text{ m}^3 \text{ m}^{-3}$ (CV = 34.79%) at forest plot.

Saturated hydraulic conductivity (K_{sat}) had a mean value of $0.32 \pm 0.27 \text{ m}^3 \text{ m}^{-3}$ (CV = 0.07%) at rubber plantation, $0.08 \pm 0.04 \text{ m}^3 \text{ m}^{-3}$ (CV = 0.00%) at oil palm plantation and $0.11 \pm 0.06 \text{ m}^3 \text{ m}^{-3}$ (CV = 0.00%) at forest plot.

Effects of Land use type on soil Chemical Properties

Chemical properties of soil under different land use type are presented on [table 3](#).

Comment [R24]: Table 2? Check pls

Soil pH had a mean value of 5.3 ± 5.3 (CV = 0.04%) at oil palm plantation and 5.2 ± 0.44 (CV = 0.19%) at forest plot.

EC had a mean of $0.033 \pm 0.04 \text{ dsm}^{-1}$ (CV = 0.00%) at rubber plantation, $0.032 \pm 0.02 \text{ dsm}^{-1}$ (CV = 0.00%) at oil palm plantation and $0.031 \pm 0.05 \text{ dsm}^{-1}$ (CV = 0.00%) at forest plot.

Land type	Cs gkg	Fs gkg	Ts gkg	Si gkg	Cl gkg	Bd Mgm ⁻³	Tp m ³ m ⁻³	K _{sat} m ³ m ⁻³
Table 1 Soil Physical Properties under different land use types								
Rubber plantation								
\bar{x}	692	220	860	25	115	1.31	0.51	0.32
Std (±)	9.54	8.81	3.00	2.05	1.91	0.21	7.76	0.27
CV (%)	90.99	77.61	9.01	4.19	3.67	0.04	60.25	0.07
Oil palm plantation								
\bar{x}	723	127	849	49	100	1.69	0.36	0.08
Std (±)	8.70	5.66	4.27	4.17	3.52	0.25	9.38	0.04
CV (%)	75.67	31.99	22.26	17.39	12.37	0.06	88.07	0.00
Forest plot								
\bar{x}	648	177	825	73	102	1.47	0.44	0.11
Std (±)	5.19	5.07	4.82	2.23	2.64	0.16	5.86	0.06
CV (%)	26.89	25.67	23.24	4.95	6.99	0.02	34.79	0.00

CS = Coarse sand , FS = Fine sand , Ts = Total sand , Si = Silt , Cl = Clay , Bd = Bulk density , Tp = Total porosity , K_{sat} = Saturated hydraulic conductivity.

Comment [R25]: subscript

UNDER PEER REVIEW

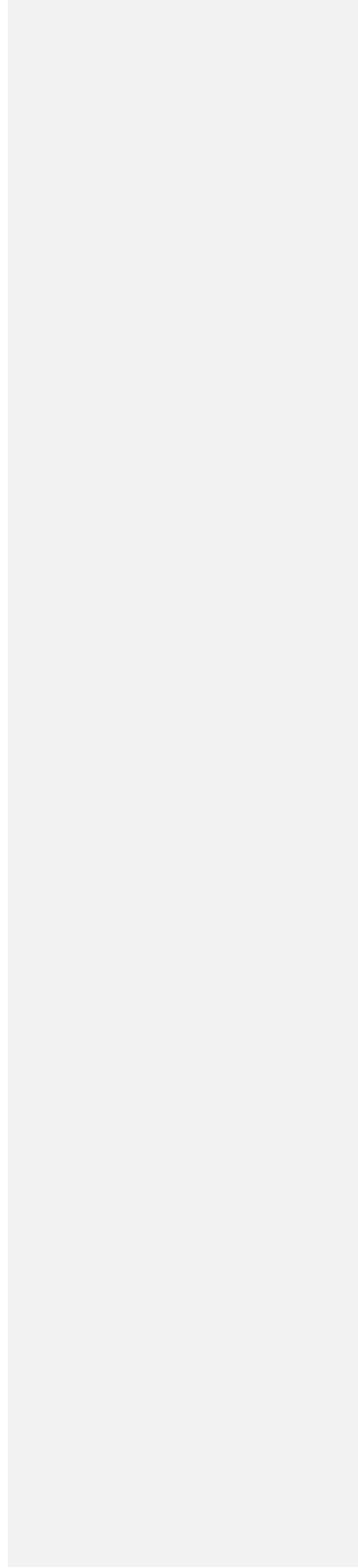


Table 2 Soil Chemical Properties Under different land use type

Land use type	pH	EC	OC	AV.P	K	Ca	Mg	Na	EA	ECEC	B _{sat}	AL	
	(H ₂ O)	dsm	%	mgkg ⁻¹	←————— cmolk ⁻¹ —————→				%	→	→		
mgkg⁻¹													
Rubber plantation													
\bar{x}	5.3	0.033	3.46	2.62	0.12	3.3	0.62	0.06	1.92	6.03	68.3	0.15	0.17
Std (±)	0.34	0.04	1.68	2.24	0.01	0.60	0.44	0.00	0.47	1.08	4.30	0.03	0.69
CV (%)	0.14	0.00	2.81	5.02	0.00	0.38	0.19	0.00	0.23	1.16	18.5	0.00	0.47
Oil palm plantation													
\bar{x}	5.3	0.032	3.45	3.05	0.12	4.0	1.15	0.06	1.73	7.05	75.18	0.19	0.22
Std (±)	0.19	0.02	0.59	5.73	0.00	0.97	0.87	0.01	0.22	0.97	3.86	0.01	0.05
CV (%)	0.04	0.00	0.35	32.86	0.00	0.94	0.79	0.00	0.05	0.93	14.88	0.00	0.00
Forest plot													
\bar{x}	5.2	0.031	4.10	2.79	0.12	2.8	1.68	0.06	1.98	6.6	70.26	0.17	0.19
Std (±)	0.44	0.05	0.73	4.40	0.01	0.94	0.56	0.00	0.43	1.04	5.01	0.03	0.03
CV (%)	0.19	0.00	0.53	19.39	0.00	0.88	0.32	0.00	0.19	1.08	25.11	0.00	0.00

EC = Electrical Conductivity; OC = Organic Carbon; Av. P = Available Phosphorus; K = Potassium Ca = Calcium;

= Magnesium; Na = Sodium; EA = Exchangeable acidity; ECEC = Effective Cation Exchange Capacity; B_{sat} = Base saturation; AL = Aluminum; Fe = Iron.

Comment [R26]: Av.P

There was a general low EC values, indicating the low presences of sorts in the basin. Critical EC values, for crop production and soil health is 0.15 dms^{-1} . For the studies sorts, EC values were low and were far less than 0.15 dms^{-1} . The level of electrical conductivity in all the land use type do not exceed the critical limit. Organic Carbon had a mean value of $3.46 \pm 1.68\%$ (CV = 2.81 %) at rubber plantation, $3.45 \pm 0.59\%$ (CV = 0.35%) at oil palm plantation and $4.10 \pm 0.73\%$ (CV = 0.53%) at forest plot. Organic carbon content was low.

Available phosphorus had a mean value of $2.62 \pm 2.24 \text{ mgkg}^{-1}$ (CV = 502%) at rubber plantation, $3.05 \pm 5.73 \text{ mg/kg}$ (CV = 32.86 %) at oil palm plantation and $2.76 \pm 4.40 \text{ mg/kg}$ (CV = 19.39 %) at forest plot. Exchangeable Potassium (K) had a mean value of $0.12 \pm 0.01 \text{ cmol/kg}$ at oil palm plantation, $0.12 \pm 0.01 \text{ cmol/kg}$ (CV = 0.00%) at rubber plantation and $0.12 \pm 0.01 \text{ cmol/kg}$ (CV = 0.00%) at forest plot. Exchangeable calcium (Ca) had a mean value of $3.3 \pm 0.60 \text{ cmol/kg}$ (CV = 0.38%) at rubber plantation, $4.0 \pm 0.97 \text{ cmol/kg}$ (CV = 0.94%) at oil palm plantation and $2.8 \pm 0.94 \text{ cmol/kg}$ (CV = 0.88 %) at oil palm plantation. Exchangeable Magnesium (Mg) had a mean value of $0.62 \pm 0.44 \text{ cmol/kg}$ (CV = 0.19%) at rubber plantation, $1.15 \pm 0.87 \text{ cmol/kg}$ (CV = 0.76%) at oil palm plantation and $1.68 \pm 0.56 \text{ cmol/kg}$ (CV = 0.32%) at forest plot. Exchangeable Sodium (Na) had a mean value of $0.006 \pm 0.00 \text{ cmol/kg}$ (CV = 0.00%) at rubber plantation, $0.06 \pm 0.01 \text{ cmol/kg}$ (CV = 0.00%) at oil palm plantation and $0.06 \pm 0.00 \text{ cmol/kg}$ (CV = 0.00%) at forest plot. The same mean value was observed in the three land use types.

Exchangeable acidity (EA) had a mean value of $1.92 \pm 0.47 \text{ cmol/kg}$ (CV = 0.23%) at rubber plantation, $1.73 \pm 0.22 \text{ cmol/kg}$ (CV = 0.05%) at oil palm plantation and $1.98 \pm 0.43 \text{ cmol/kg}$ (CV = 0.19%) at forest plot. Effective cation exchange capacity (ECEC) had a mean value of $6.03 \pm 1.98 \text{ cmol/kg}$ (CV = 1.16%) at rubber plantation, $7.05 \pm 0.97 \text{ cmol/kg}$ (CV = 0.93%) at oil palm plantation and $6.67 \pm 1.04 \text{ cmol/kg}$ (CV = 1.08%) at forest plot. ECEC did not follow a specific trend, because of differences in soil properties. **D use types had low values of ECEC.** This could be attributed to the continuous cropping and environmental deterioration in coastal plain sand soils in the area (Udo *et al.*, 2009). Base saturation had a mean value of $68.3 \pm 4.30\%$ (CV = 18.5%) at rubber plantation, $75.18 \pm 3.86\%$ (CV = 14.88%) at oil palm plantation and $70.26 \pm 5.01\%$ (CV = 25.10%) at forest plot. Rubber plantation recorded the low mean value while the highest mean value was recorded in oil palm plantation. Aluminum (Al) had a mean value of $15 \pm 0.03 \text{ cmol/kg}$ (CV = 0.00%) at rubber plantation, $0.19 \pm 0.04 \text{ cmol/kg}$ (CV = 0.00%) at oil palm plantation and $0.17 \pm 0.03 \text{ cmol/kg}$ (CV = 0.00%) a forest plot. Iron (Fe) recorded a mean value of $0.17 \pm 0.69 \text{ cmol/kg}$ (CV = 0.43%) at rubber plantation, $0.22 \pm 0.05 \text{ cmol/kg}$ (CV = 0.00%) at oil palm plantation and $0.19 \pm 0.03 \text{ cmol/kg}$ (CV = 0,00%) at forest plot.

Effect of Land Use Type on Macro – aggregate Stability Indices

Macro-aggregate stability indices under different land use type are shown in Table 3. The result revealed that Mean Weight Diameter Dry (MWDd) had a mean value of $1.256 \pm 0.176 \text{ mm}$ (CV = 14.0%) at rubber plantation,

Comment [R27]: Can you do like this for your table 1 results??? This is more better that enumerating again what is in the table.

Comment [R28]: Kindly check sentence

1.054 ± 0.08 mm (CV = 7.2%) at oil palm plantation and 1.352 ± 0.149 mm (CV = 11.0%) at forest plot. Mean Weight Diameter Wet (MWDw) had a mean value of 1.128 ± 0.111 mm (CV = 0.84%) at rubber plantation, 1.088 ± 0.24 mm (CV = 22.3%) at oil palm plantation and 0.936 ± 0.107 mm (CV = 11.4%) at forest plot . The result revealed that in forest plot soil aggregate is enhanced because the higher the value the more instability and more water absorbed by aggregate causes volumetric expansion which break down aggregate into smaller sizes.

Water Stability Aggregate (WSA) had a mean value of 26.82 ± 4.802 % (CV = 17.9%) at rubber plantation, 11.562 ± 6.012 % (CV = 51.9 %) at oil palm plantation and 15.789 ± 5.722 % (CV = 36.2%) at forest plot. Water stability aggregate was observed to be high at rubber plantation and low at oil palm plantation Aggregate Clay (AC) had a mean value of 4.85 ± 4015 % (CV = 85.4 %) at rubber plantation 6.24 ± 1.77 % (CV = 28.2 %) at oil palm plantation and 5.028 ± 3.162 % (CV = 62.8 %) at forest plot. Oil palm plantation recorded highest mean value, followed by forest plot and then rubber plantation.

Exchangeable Sodium percentage (ESP) had a mean value of 1.22 ± 0.20 % (CV = 15.9 %) at rubber plantation, 1.54 ± 0.14 % (CV = 8.8%) at oil palm plantation and 1.304 ± 0.212 % (CV = 16.2 %) at forest plot. The highest mean value was recorded in oil palm plantation while the lowest was observed in rubber plantation.

Aggregate silt plus Clay (ASC) had a mean value Of 9.14 ± 5.94 % (CV = 64.9 %) at rubber plantation, 13.35 ± 2.88 % (CV = 21.5 %) at oil palm plantation and 7.35 ± 1.115 % (CV = 15.1%) at forest plot. Oil palm plantation was observed to have the highest mean value, while forest plot had the least value. Means of ASC did not follow a definite pattern for the different land use type perhaps as a result of localized differences in soil properties.

Relationship between Soil physical Properties and Macro-aggregate Stability Indices

Table 4 shows correlation between soil physical properties and macro-aggregate stability indices.

Clay negatively significantly correlated with Exchangeable sodium percentage ($r = 0.606^*$, $p < 0.001$) and positively significantly correlated with aggregated silt plus clay ($r = 0.589^*$, $p < 0.01$). This relationship shows that clay content with exchangeable sodium percentage decrease stability of aggregate, while clay with aggregated silt plus clay positive relationship enhances stability of aggregate (Essien *et al.*, 2023). Bulk density (BD) positively significantly correlated with total porosity ($r = 1.000$, $p < 0.001$), negatively correlated with saturated hydraulic conductivity ($r = 0.759^*$, $p < 0.001$). Total porosity (TP) positively significantly correlated with saturated hydraulic conductivity ($r = 0.759^*$, $p < 0.001$) the relationship shows that saturated hydraulic conductivity increase with total porosity and can also decrease depending on the severity of erosion that may cause sealing of pore space which hinder penetration of water in the soil (Idiong *et al.*, 2024). Aggregate clay positively significantly correlated with exchangeable sodium percentage ($r = 0.597$, $p < 0.01$), showing that aggregated clay increases flocculation of particles, whereby reducing disintegration of soil particles.

Exchangeable sodium, percentage negatively significantly correlated with aggregated silt plus clay ($r = 0.555$, $p < 0.001$). This relationship shows that ESP decrease with ASC increase. Since ESP brings instability of aggregate, with more aggregated silt plus clay the effect of ESP reduces.

Comment [R29]: delete

Comment [R30]: I

Table.3 Indicators of Macro-aggregate Stability Under different land use types

Land use types	MWDd mm	MWDw mm	WSA %	AC %	ESP %	ASC %
bber plantation						
\bar{x}	1.256	1.128	26.82	4.85	1.22	9.14
Std(±)	0.176	0.11	4.802	4.15	0.20	5.94
CV (%)	14.0	9.84	17.9	85.4	15.9	64.9
Oil palm plantation						
\bar{x}	1.054	1.088	11.562	6.24	1.54	13.35
Std (±)	0.08	0.24	6.012	1.77	0.14	2.88
CV (%)	7.2	22.3	51.9	28.2	8.8	21.5
Forest plot						
\bar{x}	1.352	0.963	15.789	5.028	1.304	7.35
Std (±)	0.49	0.107	5.722	3.162	0.212	1.115
CV (%)	11.0	11.4	36.2	62.8	16.2	15.1

MWDd = Mean weight diameter dry, MWDw = Mean weight diameter wet, WSA = Water stability aggregate, AC = Aggregated clay, ESP = Exchangeable sodium percentage, ASC = Aggregated silt plus clay

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Table 4 Correlation matrix of soil physical properties and macro-aggregate stability indices

CI	1.000									
	CI	Bd	Tp	K _{sat}	MWDd	MWDw	WSA	AC	ESP	ASC
Bd	0.190	1.000								
Tp	-0.190	1.000*	1.000							
K _{sat}	-0.057	-0.759*	0.759*	1.000						
MWDd	0.161	0.456	-0.456	-0.213	1.000					
MWDw	0.046	0.038	-0.038	0.177	0.188	1.000				
WSA	-0.332	0.354	-0.354	0.377	0.239	0.393	1.000			
AC	0.975	0.211	-0.211	-0.079	0.207	0.000	-0.393	1.000		
ESP	-0.606*	-0.309	0.309	-0.003	-0.282	-0.029	-0.487	0.597*	1.000	

CI = Clay; Bd= Bulk density; Tp = Total porosity; K_{sat} = Saturated hydraulic conductivity; MWDd = Mean Weight meter dry; MWDw = Mean Weight Diameter wet; WSA = Water stability aggregate; AC = Aggregated clay; ESP = hangeable sodium percentage ASC = Aggregated silt plus Clay.

0.555* 1.000

	ASC
0.589*	0.023
-0.023	-0.080
-0.382	0.068
-0.068	0.493 -

DISCUSSION

The result shows that particle size was dominated by sand fraction for all the land use types, followed by clay and silt, soil particles were irregularly distributed. This is what Ogban and Essien (2016); Mark et al. (2024); Essien et al. (2023) associated the findings to, in Coastal Plain Sand Parent Materials in Akwa Ibom State. Bulk density revealed that the highest value was recorded in oil palm plantation. This may be caused by soil being undisturbed for over 10 years has consolidated, since the study was carried out on plots planted at least ten years ago (Essien et al., 2022). The high hydraulic conductivity in rubber plantation could be attributed to high porosity, which is characterized by large pore spaces (Nsikak et al., 2024).

Organic matter result shows that there was a disparity and low content of organic matter, could be caused by localized variation and low supply of organic materials across the land use types (Akata et al., 2024; Akpan et al., 2021). Available Phosphorus indicates that oil palm plantation recorded the highest mean value, followed by forest plot and rubber plantation. Umoh et al. (2021), explained that the concentration of P fixed increased with increasing rates of P added in the soil, also based on the inherent fertility of the soils. Umoh et al. (2021), reported that oil palm plantations are mostly suitable for the soils of the area, due to phosphorus being one of the elements boosting oil palm growth in the area.

Conclusion

The evaluation of macro-aggregate stability reduces disintegration of soil particles which in turn reduces soil instability. The relationship between physical properties and macro-aggregate stability indices shows that clay contents with exchangeable sodium content decreases stability of soil. To obtain a significant macro-aggregate stability, proper scrutiny should be employed towards land use management practices thereby preventing methods that will lead to macro-aggregate instability.

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Comment [R31]: Suggestion:

The result shows that the sand fraction dominated the particle size distribution across all land-use types, followed by clay and silt, with soil particles irregularly distributed. This observation aligns with findings by Ogban and Essien (2016), Mark et al. (2024), and Essien et al. (2023) on soils derived from Coastal Plain Sand parent materials in Akwa Ibom State.

Comment [R32]: Bulk density measurements revealed the highest value in the oil palm plantation, likely due to soil compaction over more than a decade of undisturbed conditions, as the study focused on plots established at least ten years ago (Essien et al., 2022).

Comment [R33]: which is characterized

Comment [R34]: c

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Comment [R35]: Kindly check consistency Igwu or Igwe

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UNDER PEER REVIEW

