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# Effect of Agriculture Land Use Practices on Selected Soil Properties and Macro-Aggregate Stability: A Case Study of Coastal Plain Sand, Akwa Ibom State, Nigeria

**SAM, I. J.** [a*]**, Edet, I. G.** [b]**, ESSIEN, O. A** [b] **and Thomas, U. F** [b]

[a] *Department of Soil Science and Land Resources Management, University of Uyo, Uyo, Akwa Ibom State, Nigeria.*
[b] *Department of Soil Science, Akwa Ibom State University, Obio Akpa Campus, Akwa Ibom State, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

The study was carried out in Coastal plain Sands. Southeastern 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 (MWDd and MWDw), water stability aggregate (WSA),

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*Corresponding author: Email: iniobongsam21@gmail.com;

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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 MWDw 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.*

## 1. 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 Guptal 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 (Macro-aggregate) (Essien et al., 2024).

Improper land-use practices causes 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 & 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 (Essien, et al., 2019).

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 (Grossman and Reinsch., 2002). 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. HSU (1977), 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), 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 & 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-aggregates are 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 University Teaching and Research Farm, Obio Akpa Campus.

There is need to increase macro-aggregate that is more suitable in acid soils, southeastern Nigeria.

## 2. METHODOLOGY

### 2.1 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 $4^0$40 and $5^0 15^1$ N and Longitude $7^0$ 301 E and $8^0$ 151 E, (Essien & 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℃-29℃ 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 (Flutted Pumpkin), Okro, Peppers, Maize, Melon, Cassava garden eggs and Cocoyam's.

### 2.2 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 caligo and rubber band for determination of saturated hydraulic conductivity, bulk density and total porosity calculated.

### 2.3 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 & Topp, 2022). The saturated hydraulic Conductivity was calculated using the equation.

$$Ksat = \frac{Q}{\Delta hAt} \qquad \text{Equation 1}$$

Where

$K_{sat}$ = Saturated hydraulic conductivity ($cmhr^{-1}$)
Q = Discharge rate ($cm^3 \ min^{-1}$)

L = Length of soil column (cm)

$\Delta h$ = Change in hydraulic head (cm)

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

T = Time (minutes)

Bulk density was determine using core samples as described by (Crass man and Renish, 2002). Soil samples were oven dried at 105℃ to a constant mass and bulk density calculated.
Using the equation.

$$Ib = \frac{MS}{Vt} \qquad \text{Equation 2}$$

Where

Ib = bulk density ($Mgm^{-3}$),

Ms = Mass of oven dry soil (Mg)

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

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;

$$f = \{tb\{\times \quad \}00 \quad \} \qquad \text{Equation 3}$$

Where

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

tb = Bulk density ($Mg\ m^3$) and

cs = Particle density (M3 m-3)

Organic matter was determined by Walkley and Black wet digestion method (Nelson & Sommers, 1982), organic matter was obtained by multiplying the result from organic carbon with the van Bemmele factor of 1.724. Available phosphorus was determined by the Bray P1 method. The phosphorus in the extraction was measured by the method of Morphy and Riley (1962). Exchangeable Bases (ca, Mg, Na and K) were determine by extraction using ammonium acetate (in NH, OAC) solution (Thomas, 1982). The available K and Na were determine using Atomic Absorption Spectrophotometer. Total Nitrogen was determined using macro-Kjedahl 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).

Base saturation was calculated as follows;

$$\%\,Bsat = \frac{TEB}{ECEC} \times 100 \qquad \text{Equation 4}$$

Where

Bsat = Base saturation,

TEB = Total exchangeable bases

ECEC = Effective cation exchange capacity.

## 2.4 Indices of Macro-Aggregate stability

Mean weight diameter of dry aggregate (MWDd) and wet aggregate (MWDw), 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 producers, 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;

$$MWD = \sum_{1=1}^{n_{\underline{x}_i}} \quad \omega_i \qquad \text{Equation 5}$$

Where

MWD = Mean weight diameter

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

Wi = 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

$$AC = TC - WDC \qquad \text{Equation 6}$$

Where

AC = Aggregate clay (gkg$^{-1}$gregate clay (gkg$^{-1}$gregate clay (gkg$^{-1}$)

TC = Total clay

WDC = Water dispersible clay.

Exchangeable Sodium percentage (ESP) was calculated from the equation

$$ESP = \frac{Exchangeable\ Na}{CEC} \times 100 \quad \text{Equation 7}$$

Where;

ESP = Exchangeable sodium percentage

CEC = Cation exchange capacity.

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

$$ASC = (TC + Tsi) - (WDC + WDsi) \quad \text{Equation 8}$$

Where

ASC = Aggregated silt plus clay,

TC = Total clay

$T_{si}$ = Total silt

WDC = Water- dispersible clay

$WD_{si}$ = Water dispersible silt

### 2.5 Statistical Analysis

The data generated were fitted into 3×5 factorial experiments in a compete 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.

## 3. RESULTS

### 3.1 Effect of Land-Use Types on Soil Physical Properties

Physical properties of soil under different land-use types are presented in Table 1. 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 = 25.69 %) at forest plot. Total sand content had a mean value of 860 ± 3.00 g kg$^{-1}$ (CV = 9.01 %) at rubber plantation, 849 ± 4.72 g kg$^{-1}$ (CV = 22.26%) at oil palm plantation and 825 ± 4.82 g kg$^{-1}$ (CV = 23. 24 %) at forest plot. The highest sand fraction means value (723gkg$^{-1}$) was observed at rubber plantation and lowest value (648 gkg$^{-1}$) was observed at forest plot. Silt content had a mean value of 25 ± 2.0 5g kg$^{-1}$ (CV = 4.19%) at rubber plantation, 49 ± 4.17g kg$^{-1}$ (CV = 17.39%) at oil palm planation and 7.23 ± 2.23g kg$^{-1}$ (CV = 4.95%). The silt content was high in oil palm plantation and low in forest plot. Clay context had a mean value of 115 ± 1.9g kg $^{-1}$ (CV = 3.67 %) at rubber plantation and lowest mean value of 100 ± 3.52g kg$^{-1}$ (CV = 12.37%) at oil palm plantation.

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

Saturated hydraulic conductivity ($K_{sat}$) had a mean value of 0.32 ± 0.27 cmmin-$^{1}$(CV = 0.07%) at rubber plantation, 0.08 ± 0.04 cmmin-$^{1}$ (CV = 0.00%) at oil palm plantation and 0.11 ± 0.06 cmmin-$^{1}$ (CV = 0.00%) at forest plot.

### 3.2 Effects of Land Use Type on Soil Chemical Properties

Chemical properties of soil under different land use type are presented on Table 2.

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 ± 0.04 dSm$^{-1}$ (CV = 0.00%) at rubber plantation, 0.032 ± 0.02 dsm$^{-1}$ (CV = 0.00%) at oil palm plantation and 0.031 ± 0.05 dsm$^{-1}$ (CV = 0.00%) at forest plot.

**Table 1. Soil Physical Properties under different land use types**

| **Land** | **Cs** | **Fs** | **Ts** | **Si** | **Cl** | **Bd** | **Tp** | $K_{sat}$ |
|---|---|---|---|---|---|---|---|---|
| **use type** | **gkg** | **gkg** | **gkg** | **gkg** | **gkg** | **Mgm$^{-3}$** | **m$^{3}$ m$^{-3}$** | **m$^{3}$m$^{-3}$** |
| **Rubber plantation** | | | | | | | | |
| $\underline{x}$ | 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** | | | | | | | | |
| $\underline{x}$ | 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** | | | | | | | | |
| $\underline{x}$ | 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, Ksat = Saturated hydraulic conductivity*

**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** | **Fe** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **($H_2$o)** | **dsm** | **%** | **mgkg$^{-1}$** | | ← | **cmolkg$^{-1}$** | | | **%** | → | **mgkg$^{-1}$** | → |
| **Rubber Plantation** | | | | | | | | | | | | | |
| $\underline{x}$ | 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** | | | | | | | | | | | | | |
| $\underline{x}$ | 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** | | | | | | | | | | | | | |
| $\underline{x}$ | 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; Mg= Magnesium; Na = Sodium; EA = Exchangeable acidity; ECEC = Effective Cation Exchange Capacity; $B_{sat}$ = Base Saturation; AL = Aluminum; Fe = Iron*

Organic Carbon had a mean value of 3.46 ± 1.68% (CV = 2.81 %) at rubber plantation, 3.45 ± 0.59% (CV = 0.35%) at oil palm plantation and 4.10 ± 0.73% (CV = 0.53%) at forest plot.

Available phosphorus had a mean value of 2.62 ± 2.24 mgkg$^{-1}$(CV = 5.02%) at rubber plantation, 3.05 ± 5.73 mg/kg (CV = 32.86 %) at oil palm plantation and 2.76 ± 4.40 mg/kg (CV = 19.39 %) at forest plot. Exchangeable Potassium (K) had a mean value of 0.12 ± 0.01 cmol/kg at oil palm plantation, 0.12 ± 0.01 cmol/kg (CV = 0.00%) at rubber plantation and 0.12 ± 0.01 cmol/kg (CV = 0.00%) at forest plot. Exchangeable calcium (Ca) had a mean value of 3.3 ± 0.60 cmol/kg (CV = 0.38%) at rubber plantation, 4.0 ± 0.97 cmol/kg (CV = 0.94%) at oil palm plantation and 2.8 ± 0.94 cmol/kg (CV = 0.88 %) at oil palm plantation. Exchangeable Magnesium (Mg) had a mean value of 0.62 ± 0.44 cmol/kg (CV = 0.19%) at rubber plantation, 1.15 ± 0.87 cmol/kg (CV = 0.76%) at oil palm plantation and 1.68 ± 0.56 cmol/kg (CV = 0.32%) at forest plot. Exchangeable Sodium (Na) had a mean value of 0.006 ± 0.00 cmol/kg (CV = 0.00%) at rubber plantation, 0.06 ± 0.01 cmol/kg (CV = 0.00%) at oil palm plantation and 0.06 ± 0.00 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 ± 0.47 cmol/kg (CV = 0.23%) at rubber plantation, 1.73 ± 0.22 cmol/kg (CV = 0.05%) at oil palm plantation and 1.98 ± 0.43 cmol/kg (CV =0.19%) at forest plot. Effective cation exchange capacity (ECEC) had a mean value of 6.03 ± 1.98 cmol/kg (CV = 1.16%) at rubber plantation, 7.05 ± 0.97 cmol/kg (CV = 0.93%) at oil palm plantation and 6.67 ± 1.04 cmol/kg (CV = 1.08%) at forest plot. ECEC did not follow a specific trend, because of differences in soil properties. Land 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 ± 4.30% (CV = 18.5%) at rubber plantation, 75.18 ± 3.86% (CV = 14.88%) at oil palm plantation and 70.26 ± 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 ± 0.03 cmol/kg (CV = 0.00%) at rubber plantation, 0.19 ± 0.04 cmol/kg (CV = 0.00%) at oil palm plantation and 0.17 ± 0.03 cmol/kg (CV = 0.00%) a forest plot. Iron (Fe) recorded a mean value of 0.17 ± 0.69 cmol/kg (CV = 0.43%) at rubber plantation, 0.22 ± 0.05 cmol/kg (CV = 0.00%) at oil palm plantation and 0.19 ± 0.03 cmol/kg (CV = 0.00%) at forest plot.

### 3.3 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 ± 0.176 mm (CV = 14.0%) at rubber plantation, 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 instable 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 0f 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.

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

| **Land use types** | **MWDd** | **MWDw** | **WSA** | **AC** | **ESP** | **ASC** |
|---|---|---|---|---|---|---|
| | **mm** | **mm** | **%** | **%** | **%** | **%** |
| **Rubber plantation** | | | | | | |
| $\underline{x}$ | 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** | | | | | | |
| $\underline{x}$ | 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** | | | | | | |
| $\underline{x}$ | 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*

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

| | **Cl** | **Bd** | **Tp** | **$K_{sat}$** | **MWDd** | **MWDw** | **WSA** | **AC** | **ESP** | **ASC** |
|---|---|---|---|---|---|---|---|---|---|---|
| Cl | 1.000 | | | | | | | | | |
| 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 | |
| ASC | 0.589* | 0.023 | -0.023 | -0.080 | -0.382 | 0.068 | -0.068 | 0.493 | -0.555* | 1.000 |

*Cl = Clay; Bd= Bulk density; Tp = Total porosity;* $K_{sat}$ *= Saturated hydraulic conductivity; 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.*

### 3.4 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 increases 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 (Mbabah, 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.

## 4. DISCUSSION

The result shows that particle size distribution was dominated by sand fraction for all the land use types, followed by clay and silt, soil particles were irregularly distributed. This is in line with the findings of Ogban and Essien (2016), Mark et al., (2024), Essien, et al., (2023) on Coastal Plain Sand soils in Akwa Ibom State. Bulk density revealed that the highest value was recorded in oil palm plantation. This may be cause by soil being undisturbed for over 10 year 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 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 due to localized variation and low supply of organic materials across the land use types (Akata, et al., 2024, Akpan, et al., 2021). 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 dsm$^{-1}$. The level of electrical conductivity in all the land use type do not exceed the critical limit. Available Phosphorus indicates that oil palm plantation recorded the highest mean value, followed by forest plot and rubber plantation. Umoh et al., (2021) observed that the low phosphorus could be attributed to the inherent fertility of the soil and formation of less soluble phosphorus product with time. Umoh et al., (2021), reported that oil palm plantation are mostly suitable for the soils of the area. Aggregate silt plus clay increases flocculation of soil aggregate, while exchangeable sodium percentage causes disintegration of soil aggregate.

The negative correlation with total porosity may be that low porosity increases bulk density, this hampered water penetration while positive correlation with total porosity and saturated hydraulic conductivity indicates that high porosity increases the rate of hydraulic conductivity. The negative correlation between ESP and AC indicates that ESP causes dispersion of aggregated clay particles that leads to soil instability. Positive relationship between ASC with clay shows that with aggregated silt + clay, soil stability is enhanced.

## 5. CONCLUSION

The physical properties of the soil vary in concentration in agricultural land use practices. Generally the soils were sandy with low bulk density at rubber plantation. pH was moderate acidic with low organic matter content and low ECEC in all the three land use types. 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 leads to macro-aggregate instability.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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