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An association between 14 different aggregate stability indices, soil properties, soil depths and eight different soil land use types

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Abstract: Little is known about the impact of the association between aggregate stability indices and land use system in the mineralogy of the soils of which is the objective of our study. To achieve this goal, eight different land use systems and three different soil depths were used for the study. Result findings showed water stable aggregate <0.25mm (WSA5) had high significant ($P < 0.01$) and negative correlation with WSA1 (>2.00mm), WSA2 (2.0-1.0mm), WSA3 (1.00-0.5mm) and WSA4 (0.5-0.25mm), mean weight diameter (MWD), state of aggregation (SA) and degree of aggregation (DA). Sodium (Na) had highly significant ($P < 0.01$) and positive correlation with soil dispersibility at 30minutes (DP30M), while K had no correlation with 14 aggregate stability indices studied. Ca had negative correlation with WSA2, WSA3 and water drop (WD) and Mg had with DP30mins. The CEC correlated negatively and significantly with WSA4 relative to the other 13 aggregate stability indices. OC and OM had highly significant ($P < 0.01$) correlation with all the water stable aggregates (except for WSA3), MWD and WD, while base saturation (BS) and N had no correlation with the 14 aggregate stability indices studied. Available P had significant correlation with WSA1, WSA2 and MWD. The pH in water and KCl correlated positively and significantly withWSA5 and negatively with WSA2; WSA3 and WD. Thus, pH of soil is very vital in the stability of soil aggregates. The indices used proved effective and suitable in the determination of the land use systems.
Keywords: Dispersion, micro-aggregate, water stable aggregate, mean weight diameter, water drop.

I. Introduction

Studies have indicated that land use changes have profound effect on soil properties and crop growth, hence has being found useful in the study of agro-ecosystem transformation and sustainable agricultural production. A good soil structure for crop production depends on the presence of good stable soil aggregation that of course depends again on the rate of wetting and the extent of swelling. Aggregation limits the problem of cultivation and root penetration, ameliorating hard pan behavior of soils resulting from alternate wetting and drying of soils. Aggregates are removed separately during erosion either by water or wind, hence the importance of soil physicochemical properties in the understanding of nutrient dynamics during soil erosion. The stability of aggregates of agricultural soils to water affects the physicochemical and biological processes like OC and exchangeable cations (Mbagwu, 1992; Nweke and Nnabude, 2015a). Clay, OC, CEC and silt fractions are associated with OM in the soil; thus, aggregation is high in fractions where these parameters are high. However, Nweke and Nnabude (2015b) found that the correlation between OC, silt and clay fractions and soil aggregate stability were small and non-significant indicating that the contribution of OM to the stability of the soils studied were very small. Okonofua et al (2023) also affirmed this report in their work when they found OM to be non-significantly and negatively correlated with soil physicochemical variables studied in Benin soils of southern Nigeria.

According to the work of Reid and Gross (1981), macro aggregate > 250mm are stabilized by crop root and hyphae while the stability of micro aggregate is dependent on OM binding agents that is characteristics of soil independent of management. Organic matter is found in every soil fraction and its degradation by soil microbes varied with the land use. Mbagwu and Piccolo (1998) found no significant correlation with the total OM and micro-aggregates in organic waste amended Italian soils. While Golchin et al. (1995) found that aggregate fractions bound with aggregate particulate OM correlated well with aggregate stability than total soil OM. Particulate organic matter (POM) is vulnerable to land use changes, climate and land degradation, hence the most affected in soil erosion problems. Teijero and Bernreite (2022) noted that more removal of POM from soil following erosion problems increase the release of CO_2 to the atmosphere. While Prăvălie et al. (2021) affirmed that loss of organic matter (OM) is one of the major causes of land degradation and soil erosion. Different land uses and crops have different impact on soil aggregates and soil properties. Yousefi et al. (2008), reported that different crop rotations affect OC and aggregate mean weight diameter (MWD). Land use can disrupt soil aggregation and increase the losses of OM and soil nutrients in soil erosion. Thus, the essence of this research is to investigate the association between soil aggregation, soil properties and land use systems using different aggregate stability indices.

II. Materials and methods

Study area

The area is located within latitudes 05^{o} 00'N - 05^{o} 29'N and longitudes 07^{o} 00'E - 07^{o} 33'E of southeast rainforest zone of Nigeria. High annual rainfall that is above 1,800 mm and humidity above 80% during the raining season and temperature of 27^{o}C annually (Nweke et al., 2024). The inhabitant of the area are farmers producing mainly food crops like cassava, yam, maize and vegetable.

Land use system studied and Soil sampling

1. The secondary forest re-growth of 5 years (SFR5): Soil samples were collected from farm site in Abia State University (ABSU) Umudike campus located close to an old oil palm plantation.
2. The secondary forest re-growth of 10 years (SFR10): Soil samples were taken by the bank close to Chinyere stream behind the Institute for Distance Education (IDEA) block, Abia State University (ABSU), Umudike campus.
3. The oil palm plantation >30years (OPP30): Soil samples were collected at the old palm plantation site in Umudike campus of Abia State University.
4. The agro-forest with multi-purpose tress (AFMPTS): Soil samples were collected at the American quarters in National Root Crops Research Institutes (NRCRI) Umudike by the side of the senior staff club close to the lawn tennis court, NRCRI, Umudike.
5. Continuously cropped compound farm (CCCF): Soil samples were taken at the back of female hostel ABSU, Umudike campus.
6. The one (1) year farm with cassava /maize /melons traditional (CMMT): Soil samples were taken from close to old oil palm plantation in ABSU Umudike campus.
7. The one (1) year farm with cassava/maize/melon mechanized (CMMM): Soil samples were collected from the farm in ABSU, Umudike campus.
8. Cocoa based plantation system (CBPS): Soil samples were collected from cocoa farm at Umuaruko village passing through Ahia Eke in Umudike.

   Soil samples for aggregate stability analysis were taken with a spade from the depth 0-10 cm, 10-20 cm and 20-40 cm respectively. The soil samples were carefully lifted and placed in polyethylene bags. Three samples were collected from each depth (three depths mentioned above) in each of the land use system used in the experiment, each of the three samples served as a replicate. The undisturbed soil core samples were taken with the help of the core samplers in each of the three depth 0-10 cm, 10-20 cm and 20-40 cm in all the land use system determined. The soil core samples were used to determine hydraulic conductivity, bulk density and pore size distribution that is micro, macro and total porosity (TP).

Experimental Design

The study was arranged in eight by three (8 x 3) factorial in completely randomized design (CRD) as outline in Steel and Torrie (1980) where factor A is the eight (8) land use systems and factor B is the three (3) soil depths, twenty (24) treatment combinations of the land use systems and soil depths with three (3) replications.

III. Laboratory method

Physical method

Particle Size Analysis: The particle size distribution fraction of the sample from different soil depths and land use systems were determined using the Bouyoucos hydrometer method as described by Gee and Or (2002).

Bulk density: Bulk density was determined using core method as described by Blake and Hartage (1986).

Pore size distribution: Pore size distribution was determined by using the water retention method as described by Obi (2000) while total porosity (TP) was estimated from bulk density (BD) and particle density thus:

$$TP = \left(I - \frac{Pd}{Pd}\right) x\ 100$$

Where BD = Bulk density

PD = particle density

Particle density: Particle density was calculated as described by Obi (2000).

$$Pd = \frac{\text{Oven dry mass of soil}}{\text{Volume of soil}}$$

Field capacity: Field capacity was assumed as water retained at 60 cm tension as described by Obi (1990).

Hydraulic conductivity: Hydraulic conductivity was determined by the modified constant water head methods of Klute (1986) thus;

$$K = \left(\frac{Q\ X\ dz}{At\ X\ dh}\right) x\ hr$$

Where K = saturated hydraulic conductivity cms^{-1}

Q = The steady state volume flow from entire volume $cm^2\ hr^{-1}$

dz = length of core sampler cm

A = Cross sectional area cm

t = change in time interval hr

dh = hydraulic head change cm

Core sampler of length 5 cm and 5.6 cm diameter were used with hydraulic head change of 2.5 cm.

Chemical properties

Soil pH: The pH values of the soil were determined in duplicate both in distilled water (H_2O) and in potassium chloride (0.1N KCl) solution in soil/liquid ratio of 1:2.5. After stirring for 30 minutes, the pH values were obtained using a glass electrode pH meter (Mclean, 1982).

Organic carbon (OC) and organic matter (OM): Organic carbon was determined by the Walkley and Black wet oxidation method as modified by Page et al. (1986), percentage OM was calculated by multiplying the value for OC by the Van Bemmeler factor of 1.724 which is based on assumption that soil OM contains 58% C (Allison, 1982)

Exchangeable bases: Ca and Mg were determined by the complexometric titration method described by Chapman, (1982), Na and K were extracted using N ammonium acetate (NH_4OAC) solution and determined by flame photometer.

Cation exchange capacity (CEC): Cation exchange capacity (CEC) of soil were determined by the ammonium acetate (NH_40AC) method (Dews and Freitas, 1970).

Percentage base saturation: Percentage base saturation was calculated by dividing total exchangeable base (TEB) by cation exchange capacity (CEC) and multiplying by 100

$$\%\ BS = \left(\frac{TEB}{CEC}\right) x\ 100$$

Available phosphorus: Available phosphorus was determine using bray 2 method (Olsen and Sommers, 1982)

Total nitrogen: Total nitrogen was determined using the micro Kjeldahl method as described by Bremner Mulvancy (1982).

Aggregate stability indices: Aggregate stability was determined using 14 different indices which include; wet sieving technique (Yoder, 1936; Kemper and Chepil, 1965). The technique involved the use of sieves with diameters 2,1,0.5 and 0.25 mm each. The quantity of soil sample (< 4.00 mm) from each replication at each depth of the land use system was 40 g and this was placed on the topmost sieve of the nest of sieves and then immersed in water and allowed to soak for 5 minutes and then sieved for 100 oscillations. The soil was kept completely submerged during soaking and wet sieving.

Water stable aggregates (WSA) studied include:

$$WSA1\ (> 2.00mm) = \frac{\text{Wt of aggregate on 2.00mm sieve}}{\text{Initial weight of sample}} x\ 100$$

$$WSA2\ (2.00mm - 1.00mm) = \frac{\text{wt of aggregate on 1.00mm sieve}}{\text{Initial weight of sample}} x\ 100$$

$$WSA3\ (1.00mm - 0.5mm) = \frac{\text{wt of aggregate on 0.5mm sieve}}{\text{Initial weight of sample}} x\ 100$$

$$WSA4\ (0.5mm - 0.25mm) = \frac{\text{wt of aggregate on 0.25mm sieve}}{\text{Initial weight of sample}} x\ 100$$

$$WSA5\ (< 0.25mm) = \frac{\text{wt of aggregate that passed through the 0.25mm sieve}}{\text{Initial weight of sample}} x\ 100$$

Mean weight diameter (MWD)

$$MWD = \sum_{i=1}^{n} x\,i\,wi$$

i.e. the sum of the product of means xi of each size grade and proportion of the total sample weight wi of each size grade.

State of aggregation (SA)

$$SA = \frac{\text{Wt of water stable aggregate} - \text{wt of sand}}{\text{wt of sample}} \times 100$$

Degree of aggregation (DA)

$$DA = \frac{\text{wt of water stable aggregate} - \text{wt of sand}}{\text{wt of sample} - \text{wt of sand}} \times 100$$

Soil dispersibility

1. Dispersibility at 2 minutes shaking (DP2m)
2. Dispersibility at 30 minutes shaking (DP30m)
3. Dispersibility at 2 hours shaking (DP2hrs)
4. Dispersibility at 4 hours shaking (DP4hrs)
5. Dispersibility at 6 hours shaking (DP6hrs)

This was determined by placing 20 g of soil in 350 ml plastic shaker container with 200 ml deionized or distilled water and shaken end-over-end in a mechanical shaker for the time in view. Pipetting 2ml sample from a depth of 2 cm after allowing coarser particle sand to settle for about 1mins, for silt plus clay and after 2 hours for clay alone. The percentage of total clay per total silt plus clay dispersed at each period was calculated thus:

$$SD = \left(\frac{\text{clay}}{\text{clay} + \text{silt}}\right) x\ 100$$

Similar to Middleton, 1930 dispersion ratio and as described by Mbagwu, 1990.

Single water drops method (WD): The single water drop method by McCalla, (1944) and as developed by Smith and Cernuda (1951) and Bruce -Okine and Lal, (1975) also was used.

Data analysis

Data generated from the study was subjected to the ANOVA test based on the factorial experiment. Treatment means were separated using least significant difference (LSD) as describe by Obi (2002). Comparison between the indices and the various soil depths and also relating the aggregate stability indices to the soil physical and chemical properties was done by multiple correlation analysis as outline by Obi (2001) using Statistical Package for Social Science (SPSS) version 15.

IV. Results

Initial soil properties:

Physical properties

The physical properties of the soils prior to the study indicates that the soils are of medium texture (Table 1). Total sand fractions are noted to be higher than the clay and silt fractions across the land use and soil depth. The hydraulic conductivity (HC) was exceptionally higher in 0-10cm soil depth of AFMPTS land use system relative to other soil depths and land uses. Bulk density (BD) and particle density (PD) varied and ranged between 1.253-1.617gcm^{-3} and 2.733 – 4.310gcm^{-3} respectively across land uses and soil depths. In all the land uses, the BD increased as the soil depths increased, while in some land uses (SFR5, SFR10, CMMT, CBPS) PD decreased as the soil depth increased. The porosity of the soil across the land uses ranged from; SFR5 58:26-60.48%; SFR10 59.79-63.88%; OPP30 59.92-68.50%; AFMPTS 51.93 – 58.93%; CCCF 55.65-63.64%, CMMT 54.52-61.67%; CMMM 45.43-49.18% and CBPS 48.31-56.92% respectively across the 3 soil depths studied. The recorded values showed that CMMM gave the least total porosity value (Table 1). The obtained values of Field capacity (FC) and Macro porosity (MACP) for the land uses and soil depths are relatively alike and ranged 25.49 - 43. 93% and 4.30 - 57.06% respectively across the land uses and soil depths. The Micro porosity (MICP) result (Table 1), showed low to medium value in all the land uses and soil depths with an exceptionally lower value (0.33%) in 10-20cm soil depth of CMMM land use.

Table 1: Physical properties of the soils before the study

LUS	Dept cm	Rp	TC	CLAY %	SILT %	FS%	CS%	TS%	HC Cms^{1}	BD gcm^{3}	PD gcm^{-3}	TP%	FC%	MACP %	MICP
SFRS	0-10	1	LS	11.33	7.67	32	49	81	32.9	1.557	3.953	60.25	32.56	50.57	9.68
	10-20	2	LS	12.00	7.67	30.67	49.67	80.33	43.8	1.560	3.953	60.48	29.51	48.12	12.37
	20-40	3	LS	11.33	8.33	27.67	52.67	80.33	28.0	1.570	3.767	58.26	30.53	48.03	10.23
SFR10	0-10	1	SL	11.33	14.33	31.00	43.33	74.33	45.0	1.257	3.487	63.88	42.00	52.01	11.87
	10-20	2	SL	12.00	17.67	29.33	41.00	70.33	49.6	1.433	3.247	59.85	32.19	48.26	11.59
	20-40	3	SL	10.67	9.00	32.33	47.33	79.67	12.2	1.470	3.690	59.79	32.03	47.06	12.77
OPP30	0-10	1	SL	18.67	9.00	21.00	51.33	72.33	83.9	1.253	3.243	59.92	39.14	47.29	12.63
	10-20	2	SL	20.00	10.33	22.67	47.00	69.67	59.6	1.353	3.337	63.08	38.63	48.11	14.95
	20-40	3	SL	13.33	12.33	19.00	55.33	74.33	43.8	1.33	4.310	68.50	39.15	47.50	21.00
AFMPTS	0-10	1	SL	10.00	10.33	27.33	50.00	73.33	133.8	1.293	2.990	56.24	38.95	50.48	5.76
	10-20	2	SL	10.67	13.00	27.00	49.33	76.33	73.0	1.447	3.010	51.93	32.71	47.04	4.89
	20-40	3	SL	11.33	13.00	30.33	45.33	75.67	103.4	1.457	3.593	58.93	33.57	48.76	10.16
CCCF	0-10	1	LS	10.67	9.00	28.33	52.00	80.33	12.20	1.617	3.973	58.29	27.20	43.78	14.51
	10-20	2	LS	12.00	7.67	33.33	47.00	79.00	30.2	1.497	4.300	63.64	36.16	57.06	12.58
	20-40	3	LS	12.67	9.67	31.33	46.33	77.67	14.6	1.590	3.670	55.65	29.69	46.92	8.73
CMMT	0-10	1	SL	13.33	14.33	37.67	34.67	72.33	21.9	1.467	3.837	61.67	29.83	43.69	17.98
	10-20	2	SL	13.67	14.33	28.33	43.33	71.67	30.2	1.430	3.477	54.52	25.49	40.30	14.22
	20-40	3	LS	10.67	7.67	31.67	50.00	81.67	26.8	1.590	3.797	58.01	26.40	40.97	16.72
CMMM	0-10	1	LS	12.67	9.00	31.00	47.33	78.33	41.4	1.453	2.733	48.11	32.08	46.27	1.90
	10-20	2	SL	15.33	11.67	27.67	46.00	73.67	37.7	1.517	2.767	45.43	30.62	45.10	0.33
	20-40	3	SL	17.33	8.33	16.00	58.33	74.33	31.6	1.460	2.737	49.18	32.48	47.79	1.45
CBPS	0-10	1	LS	10.00	8.33	36.67	45.67	82.33	97.3	1.297	3.010	56.92	43.93	55.37	1.55
	10-20	2	LS	10.67	9.00	30.67	44.67	80.33	43.8	1.473	2.930	49.60	32.60	47.96	1.64
	20-40	3	LS	10.67	10.33	32.33	46.67	79.00	58.4	1.547	2.733	48.31	30.73	47.46	0.85

LUS = Land use system; Rp. = Replication; TC = Textural class; FS = Fine sand; CS = Coarse Sand; TS = Total sand HC = Hydraulic conductivity; BD = Bulk density; PD = Particle density; TP = Total porosity; FC = Field capacity; MACP = Macro porosity; MICP = Micro porosity; LS = Loamy sand; SL = Sandy loam

Chemical properties

The soil chemical properties values recorded in Table 2 showed the soils to be acidic, low to medium values in all the parameters assessed across land uses and soil depths. The base saturation (BS) value recorded in 10-20cm depth of OPP30 land use was exceptionally lower (7%) relative to the recorded value of other depths of land uses. In most of the parameters, values recorded were found to be higher in surface soil depth (0-10cm) relative to the subsoils and higher in concentration in OPP30 and SFR10 relative to other land uses.

Table 2: Soil chemical properties of the studied soil

land use system	depth (cm)	Repl	Na^+ Me/100g	K^+ Me/100g	Ca^{2+} Me/100g	Mg^{2+} Me/100g	CEC Me/100g	BS%	OC%	OM%	N%	ppm	pH H_2O	KCl
SFRS	0-10	I	0.1167	0.0300	1.133	0.400	13.20	13	0.867	1.493	0.0887	5.60	5.467	4.567
	10-20	2	0.1167	0.0367	1.067	0.200	7.73	19	0.780	1.343	0.0793	4.04	5.567	4.633
	20-40	3	0.1167	0.0200	1.267	0.333	9.33	20	0.830	1.430	0.1027	4.04	5.600	4.633
SFR10	0-10	1	0.0967	0.0833	0.933	0.600	13.87	12	1.730	2.983	0.1540	7.15	5.333	4.467
	10-20	2	0.1200	0.0800	0.800	0.300	12.00	13	1.223	2.110	0.1167	3.73	5.633	4.500
	20-40	3	0.0833	0.1067	0.733	0.467	14.93	10	1.000	1.736	0.2940	2.80	5.467	4.400
OPP30	0-10	1	0.1200	0.0600	0.800	0.467	11.43	13	1.843	3.177	0.0980	3.73	5.333	4.467
	10-20	2	0.1100	0.0600	0.600	0.333	15.20	7	1.527	2.633	0.1073	3.11	5.600	4.500
	20-40	3	0.1100	0.0733	0.867	0.333	14.70	10	1.160	2.067	0.1027	3.11	5.633	4.300
AFPTS	0-10	1	0.1067	0.0267	1.933	0.333	9.60	25	1.250	2.157	0.0653	6.84	5.467	4.533
	10-20	2	0.0933	0.0267	1.333	0.733	12.27	18	0.903	1.557	0.0467	4.04	5.433	4.533
	20-40	3	0.1200	0.0333	1.133	0.533	12.13	15	0.863	1.493	0.0467	4.97	5.4674	4.433
CCCF	0-10	1	0.1200	0.0367	1.667	0.400	9.60	24	0.880	1.513	0.0887	8.08	5.800	4.767
	10-20	2	0.1400	0.0400	1.533	0.267	13.33	16	0.743	1.277	0.0793	6.84	5.733	4.633
	20-40	3	0.1300	0.0367	1.533	0.333	13.73	13	0.743	1.277	0.0840	4.04	5.500	4.567
CMMT	0-10	1	0.0700	0.0267	0.933	0.467	8.67	18	0.870	1.497	0.0840	7.15	5.667	4.500
	10-20	2	0.0833	0.0400	0.733	0.600	8.80	17	0.673	1.160	0.0840	2.49	5.800	4.767
	20-40	3	0.1067	0.0400	1.000	0.467	8.67	17.37	0.743	1.290	0.0980	1.87	5.200	4.433
CMMM	0-10	1	0.1100	0.367	0.733	0.667	9.87	16	1.087	2.107	0.1167	2.49	5.000	4.267
	10-20	2	0.1100	0.0267	0.733	0.467	10.93	12	0.960	1.880	0.1073	1.87	5.100	4.233
	20-40	3	0.1100	0.0300	0.733	0.467	11.20	12	0.823	1.417	0.1120	1.87	5.167	4.267
CBPS	0-10	1	0.0600	0.0533	2.533	1.600	8.00	51	1.533	2.643	0.1587	14.30	6.400	5.600
	10-20	2	0.0600	0.0400	1.533	1.067	8.40	36	1.247	2.363	0.1213	7.15	6.433	5.533
	20-40	3	0.0600	0.1067	1.000	1.067	8.93	24	0.840	1.450	0.1027	7.46	6.533	5.233

Na = sodium, CEC = cation exchange capacity, K = potassium, BS =base saturation, Ca = calcium, OC = organic carbon, Mg = magnesium, OM = organic matter, P = phosphorus, pH in H_2O = pH in water, pH in KCl = pH in potassium chloride

Correlation relationship between the aggregate stability indices used

The result presented in Table 3 showed the correlation analysis of the aggregate stability indices used. The result indicated that water stable aggregate > 2.00mm (WSA1) were highly significantly ($P < 0.01$) correlated positively with WSA2, mean weight diameter (MWD), state of aggregation (SA), degree of aggregation (DA) and water drop (WD). While it (WSA1) is negatively and highly significantly ($P < 0.01$) correlated with WSA3, WSA4 and WSA5. Water stable aggregate (WSA1) showed non-significant correlation though positive with DP2M, DP30M and DP2Hr with r values of 0.010; 0.167 and 0.209 respectively, while it shows negative but non-significant correlation with DP4hr ($r = -0.040$) and DP6hr ($r = -0.186$). WSA2 correlated positively and highly significant ($P < 0.01$) with WSA3, MWD and WD but significantly ($P < 0.05$) correlated with DA. The WSA4 and WSA5 were negatively but highly significantly ($P < 0.01$) correlated with WSA2. The r values for SA, DP30, DP2hr and DP4hr were 0.152, 0.108, 0.081 and 0.149 respectively though positive but non-significantly correlated with WSA2. WSA2 negatively and non-significantly correlated with DP2m ($r = -0.123$) and DP6hr ($r = -0.133$) respectively. WSA3 showed negative and significantly correlated with WSA5 at (P < 0.01) and DP30m at (P < 0.05). But showed positive and non-significant correlation with WSA4, DA, DP2hr DP4hr and WD and non-significant negative correlated with MWD, SA, DP2M and DP6hr respectively. WSA4 showed positive and highly significantly correlated with WSA5 but negatively and highly significantly (P < 0.01) correlated with MWD and WD. While it showed non-significant correlation with SA (r = -0.169); DA (r = - 168); DP30M (r = -0.074); DP2hr (r = -0.013); DP4hr (r = -0.073); DP6hr (r = -0.139) and DP2M (r = 0.033) respectively. WSA5 at (P < 0.01) was negatively correlated with MWD, SA, DA and WD and at (P < 0.05) negatively correlated with DP2hr and statistically non-significant correlated with DP2M (r = -0.056); DP30M (r = -0.004); DP4hr (r = -0.088) and DP6hr (r = 0.171) respectively. The mean weight diameter (MWD) correlated significantly and positively at (P < 0.01) with SA, DA and WD with r values of 0.473; 0.457 and 0.507 respectively. Other parameters such as DP2M (-0.004); DP30M (0.103); DP2hr (0.126); DP4hr (0.033) and DP6hr (-0.179) were non-significantly correlated with MWD. At P < 0.01 and P < 0.05 sate of aggregation (SA) is positively and significantly correlated with DA and WD respectively, and non-significantly correlated with DP2M (-0.015), and DP6hr (-0.098). At (P < 0.05), DA showed positive and significantly correlated with DP2hr and WD with r values of 0.265 and 0.248 respectively. But non-significantly correlated with DP2M (-0.079); DP30M (-0.036); DP4hr (0.054) and DP6hr (-0.081). The correlation values recorded in the study for DP2M, DP30M; DP2hr, DP4hr; DP6hr and WD showed that they are not statistically significantly correlated.

Table 3: Correlation analysis of the aggregate stability indices used

WSA1	WSA2	WSA3	WSA4	WSA5	MWD	SA	DA	DP2M	DP30M	DP2HR	DP4HR	DP6HR	WD	
WSA1														
WSA2	0.374*													
WSA3	-0.383**	0.305**												
WSA4	-0.667**	-0.741**	0.07											
WSA5	-0.458**	-0.531**	-0.369**	0.312**										
MWD	0.89**	0.567**	-0.224	-0.819**	-0.595									
SA	0.480	0.152	-0.092	-.0169	-0.518**	0.473**								
DA	0.416	0.258*	0.131	0.168	-0.637**	0.457**	0.937**							
DP2M	0.010	-0.123	-0.129	0.033	-0.056	-.0.004	-.0015	-0.079						
DP30M	0.16	0.108	-0.245*	-0.074	0.004	0.103	0.098	-0.036	0.091					
DP2hr	0.209	0.081	0.073	-0.013	-0.237*	0.126	0.230	0.265*	0.037	0.013				
DP4hr	-0.040	0.149	0.114	-0.073	-0.088	0.033	-0.038	0.054	-0.110	-0.211	0.014			
DP6hr	-0.186	-0.133	-0.063	0.139	0.171	-.179	-0.078	-0.081	-0.059	-0.104	0.061	0.078		
WD	0.358**	0.447**	0.156	-0.514**	-0.431**	0.507**	0.248*	0.248*	-0.052	0.109	0.093	-0.137	-0.117	

** = P < 0.01; * = P < 0.05

WSA = Water stable aggregates; MWD = Mean weight diameter; SA = State of aggregation; DA = Degree aggregation; DP = Dispersibility; WD = Water drop

Correlation between aggregate stability indices and soil physical properties

The correlation analysis result between aggregate stability indices and soil physical properties is presented in Table 4. The result showed that WSA1 is not significantly (P < 0.05) correlated with clay, silt, FS, CS, TS, HC, PD and MICP, but highly and positively significantly (P < 0.01) correlated with TP, FC and at P < 0.05 with MACP, while being negatively and highly significantly (P < 0.01) correlated with BD with an r value of -0.344. WSA2 correlated significantly (P < 0.05) with clay (r = 0.279) and TS (r = -0.254), but non- significantly correlated with silt; FS, CS, HC, BD, PD, TP, FC, MACP and MICP respectively. At P < 0.01 and P < 0.05 WSA3 showed negative and positive significant correlation with FS and CS with r values of -0.322 and 0.283 respectively. While being non-significantly correlated with clay, silt, TS, HC; BD, PD; TP; FC; MACP and MICP. WSA4 correlated highly significantly (P < 0.01) with BD (r = 0.377) and FC (r = -0.339) and at P < 0.05 correlated significantly with clay (r = -0.236); TS (r =

0.258) and TP (r = -0.258) respectively. And not statistically significantly (P < 0.05) correlated with silt, FS, CS, HC; PD; MACP and MICP with r values of -0.157; 0.120; 0.092; 0.015; -0.007; -0.158 and -0.162 respectively.
WSA5 correlated highly significantly (P < 0.01) and positively with BD and negatively with FC with r values of 0.378 and -0.398 respectively. At P < 0.05, WSA5 correlated negatively and significantly with clay, TP and MACP with r values of -0.236; -0.235 and -0.243 respectively, but not significantly correlated with silt, FS, CS; TS; HC; PD and MICP. MWD correlated positively and highly significant (P < 0.01) with TP and FC, but negatively correlated highly significantly (P < 0.01) with BD. Its correlation with clay, silt, FS, CS, TS; HC; PD, MACP and MICP is not significant at P < 0.05. SA at P < 0.01 correlated highly significantly and positively with TP and MICP with r values of 0.363 and 0.370 respectively and at P < 0.05 positively significantly correlated with TS (r = 0.233); PD (r = 0.252) and negatively correlated with silt (r = -0.242). But not statistically correlated with clay; FS; CS; HC; BD; FC and MACP. Degree of aggregation (DA) correlated significantly (P < 0.05) and positively with CS; TP and MICP and negatively correlated, but highly significant (P < 0.01) with silt (r = -0.295), but showed non-statistically significant with clay; FS, TS, HC; BD; PD; FC and MACP. Dispersibility at 2 minutes (DP2M), DP30m; DP2hr, DP4hr and DP6hr did not statistically correlated with the soil physical parameters tested except for DP30m that correlated negatively and significantly (P < 0.05) with PD. DP4hr positively correlated significantly (P < 0.05) with clay and DP6hr correlated significantly (P < 0.05) with FS (r = 0.255) and CS (r = -0.264) respectively. Water drop method (WD) correlated positively and highly significant (P < 0.01) with TP and MICP and at P < 0.05 with FS, but negatively and significantly (P < 0.05) correlated with BD, while it recorded non-statistically significant correlation with clay; silt; CS; TS; HC; PD; FC and MACP (Table 4).

Table 4: Correlation between aggregate stability indices and soil physical properties

	CLAY	SILT	FS	CS	TS	HC	BD	PD	TP	FC	MACP	MICP
WSA1	0.077	-0.033	0.007	-0.024	-0.012	0.152	-0.344**	0.106	0.308**	0.308**	0.251*	0.152
WSA2	0.279*	0.113	-0.184	0.019	-0.254*	-0.023	-0.222	-0.014	0.117	0.201	0.144	0.029
WSA3	0.128	-0.092	0.322**	0.283*	-0.090	0.041	0.073	-0.084	-0.118	0.059	-0.028	-0.100
WSA4	-0.236*	-0.157	0.120	0.092	0.258*	0.015	0.377**	-0.007	-0.258*	-0339**	-0.158	-0.162
WSA5	-0.236*	0.160	0.224	-0.212	0.035	-0.189	0.378**	-0.007	-0.235*	-0.398**	-0.243*	-0.086
MWD	0.170	0.024	-0.089	-0.010	-0.119	0.138	-0.443**	0.053	0.307**	0.391**	0.209	0.179
SA	-0.034	-.0.242*	-0.010	0.197	0.233*	0.074	-0.169	0.253*	0.363**	0.159	-0.005	0.370**
DA	0.052	-0.295**	-0.101	0.284*	0.216	0.160	-0.184	0.123	0.233*	0.152	-0.034	0.256*
DP2M	0.127	0.054	-0.042	-0.049	-0.112	-0.113	-0.114	0.092	0.033	0.144	0.099	-0.028
DP30M	0.089	0.074	-0.020	-0.072	-0.112	-0.204	0.214	0.139	0.072	-0.267*	-0.103	0.141
DP2hr	-0.037	-0.092	0.088	0.012	0.146	-0.015	-0.038	-0.049	-0.089	0.046	0.000	-0.091
DP4hr	0.241*	-0.029	-0.068	-0.045	-0.141	-0.117	-0.099	-0.218	-0.183	0.008	-0.072	-0.138
DP6hr	0.012	-0.030	0.255*	-0.264*	-0.008	0.019	0.092	-0.060	-0.172	-0.089	-0.130	-0.094
WD	0.223	0.101	0.277*	0.129	-0.210	-0.037	-0.296*	0.174	0.352**	0.213	0.010	0.353**

** = P < 0.01; * = P < 0.05; FS = Fine sand; TP = Total porosity; TS = Total sand; MACP = Macro porosity; HC = Hydraulic conductivity; CS = Coarse sand; FC = Field capacity; BD = Bulk density MACP = Macro porosity; PD = Particle density

Correlation analysis between aggregate stability indices and soil chemical properties

Exchangeable K, base saturation (BS) and N had no statistically significant correlation with any of the aggregate stability indices tested in the study (Table 5). Ca correlated negatively significant (P < 0.05) with WSA2; WSA3 and WD with r values of -0.273; -0.252 and -0.323 respectively, but not significantly correlated with WSA1; WSA4; WSA5; MWD, SA, DA; DP2m, DP30m, DP2hr; DP4hr and DP6hr. Exchangeable Mg and CEC had no statistical significant correlation with aggregate stability indices studied except that exchangeable Mg correlated significantly (P < 0.05) and negatively with DP30m with r value of -0.247 and CEC positively and highly significant (P < 0.01) correlated with WD and negatively significant (P < 0.05) correlated with WSA4 with r values of 0.374 and -0.236 respectively. OC correlated highly significant (P < 0.01) and positive with WSA1; WSA2; MWD and WD with r values of 0.595; 0.409; 0.712 and 0.498 respectively, but correlated negatively and highly significant (P < 0.01) with WSA4 and WSA5. OC had no statistical significant correlation with WSA3; SA; DA; DP2m, DP30m; DP2hr; DP4hr and DP6hr. OM had highly significant positive correlation with WSA1; WSA2; WSA4; MWD and WD, but showed negative but highly significant correlation with WSA5 and not statistically correlated with WSA3; SA; DA; DP2m; DP30m; DP2hr; DP4hr and DP6hr. Available P correlated positively and highly significant with WSA1 and MWD and correlated negatively and highly significant with WSA3. Its correlation with every other aggregate stability index studied recorded non-statistically correlation. Soil pH in water correlated negatively and significant ($P < 0.05$) with WSA2; WSA3, DA and highly significant and negatively correlated with WD. It correlated positively and significant ($P < 0.05$) with WSA5 but showed not statistically significant correlation with every other aggregate stability index studied. Soil pH in KCl showed positive and significant correlation with WSA3 ($P < 0.01$) and WSA5 ($P < 0.05$) and negative significant correlation with WSA2 and WD while its correlation with every other aggregate stability index were not statistically significant at $P < 0.05$ (Table 5).

Table 5: Correlation between aggregate stability indices and soil chemical properties

	Na	K	Ca	Mg	CEC	BS	OC	OM	N	P	pH in Water	pH KCL
WSA1	0.037	0.130	0.094	0.070	0.058	-0.079	0.595**	0.555**	0.030	0.356*	-0.093	0.080
WSA2	0.104	0.038	-0.273*	-0.005	0.080	-0.142	0.409**	0.445**	0.154	-0.041	-0.268*	-0.252*
WSA3	-0.019	-0.181	-0.252*	-0.155	0.084	-0.017	-0.104	-0.063	0.131	-0.393**	-0.302*	-
WSA4	-0.139	-0.180	0.075	-0.049	-0.236*	0.120	-0.688**	0.688**	-0.176	-0.139	0.197	0.141
WSA 5	0.053	0.176	0.181	0.037	-0.054	0.098	-0.328**	-0.331**	-0.112	-0.051	0.291*	0.260*
MWD	-0.025	0.086	-0.019	0.084	0.135	-0.103	0.712**	0.683**	0.120	0.320**	-0.162	-0.061
SA	-0.088	-0.146	0.007	0.028	-0.100	0.177	0.190	0.126	0.076	0.165	-0.140	-0.084
DA	-0.177	-0.184	-0.081	0.011	-0.129	0.152	0.197	0.151	0.093	0.063	-0.251*	-0.167
DP2M	0.083	-0.057	-0.007	-0.079	0.094	-0.071	-0.079	-0.075	-0.076	-0.022	-0.124	-0.107
DP30M	0.304**	0.047	-0.084	-0.247*	0.129	-0.068	-0.104	-0.107	-0.183	0.036	0.013	-0.006
DP2hr	-0.102	-0.115	0.078	0.067	-0.108	-0.120	0.076	0.098	-0.043	0.021	-0.057	0.094
DP4hr	-0.092	-0.036	-0.068	0.122	0.008	0.021	0.016	0.102	0.000	0.027	0.039	-0.024
DP6hr	-0.112	-0.134	0.155	0.095	-0.105	0.102	-0.088	-0.061	-0.067	0.109	0.168	0.206
WD	0.178	0.073	-0.323*	-0.164	0.374**	-0.134	0.498**	0.463**	0.172	-0.145	-0.317	-0.283

** = $P < 0.01$; * = $P < 0.05$

V. Discussion

Initial soil properties before the study

The distribution of physical and chemical properties of the soils varied with depth and land use systems studied. The textual observation could be attributed to the continuous soil disturbance as a result of farming activities in the area of which enhanced or accelerated soil weathering. The different land use types do not have effect on the soil texture. Soil texture is an inherent soil property that takes longer time before it can be influenced by cultural or management practices. The dominant of the sand fraction relative to silt and clay simple reflect the parent material from which the soils were formed (Ejikeme et al., 2021; Nweke et al., 2021). It equally showed that the finer fractions of silt and clay and some other finer colloidal materials are carried away easily by erosion leaving the coarser fraction sand. Further, it suggests soils that are vulnerable to leaching losses, low in nutrient content as observed in Table 1 and 2, high permeability and porosity. High sand fraction equally shows soil low in moisture retention (water holding) of which could lead to plant water deficit. The studies of Awdenegest et al. (2016) and Gebeyaw, (2015) showed that soil separates (sand, silt, clay) significantly varied with the land use type and soil depth. The high BD of the soils recorded in both land uses and soil depth could be due to low OM content of the soils, high compaction from the impact of raindrops. The recorded values of TP, FC, MACP, MICP and HC of the soils simply indicated soils with high pore values, water availability and retention, reduction in runoff erosion and soils in which nutrient recycling and water transmission will not be a problem. Generally, the chemical parameters of the soils indicated the soils to be acidic and low in nutrient content of which most are below their critical level for crop production in the study area. Thus, indicating that the studied soils are leached and deficient in plant nutrients.

This could be attributed to high rainfall and temperature witness in the area, that cause leaching losses and erosion. Thus, for maximum production of the soils adequate and proper treatment/amendment are required.

Relationship between aggregate stability indices used, physical and chemical parameters assessed and soil depth

The stability of soil aggregates has been shown to be influenced by land use types, texture, soil depth and mineralogy. The non-significant correlation observed between some of the aggregate stability indices used may be due to differences in the aggregate sizes, clay content of the texture, dispersibility periods, mineralogical composition or probably biological activities. The gluing of soil particles is influenced by physicochemical reactions in surfaces of clay minerals or by polysaccharide and other products from microbial decomposition of soil OM. Again, macro aggregates are less stable than micro-aggregates and more susceptible to cultivation equipment and rain drop impacts leading to its dispersion or breakup. Also, water infiltration rate, runoff erosion, crusting and sealing of soils have been known to affect soil dispersibility, clay dispersion and aggregate stability. All these scenarios probably might have influenced the correlation result obtained from the study. The positive correlation indicated that as one of the aggregates correlated increased the other as well increased, while negative correlation indicates that as one of the aggregate indices correlated increased the other decreased. This clearly showed that relationship existed between soil properties determined, aggregate stability indices studied and soil depth. The highly significant ($P < 0.01$) and negative correlation observed between water stable aggregate 5 (WSA5 < 0.25) and all the macro (WSA1-4) test of stability, MWD, SA and DA agrees with the work of Nweke et al. (2023) who reported that WSA < 0.25 correlated significantly and negatively with all the macro test of stability. The result findings could be attributed to OC content and clay mineralogy. Kebebew et al. (2022) in their studies reported highly significant negative and positive correlation of clay with sand, silt and BD with TP and WHC (water holding capacity) respectively. Clay has large surface area that provide sites for the retention and exchange of cations. Structural stability of aggregates decreased with OC content and soil management practices. Guo and Gifford (2002) noted that land use changes certainly affect C dynamics by differences in C input and direct effect of accompanying soil disturbances. While SOM, very complex and heterogeneous in composition according to Del Galdo et al. (2003) is generally mixed or associated with the mineral constituents to form soil aggregates. Thus, holds soil particles together improving soil structural stability.

Soils of southeast, Nigeria are composed of crystallized clays that are mainly kaolinites (1:1 clay mineral) of which are low activity clay. In low activity clay soils, the chemical nature and quantity of oxides is an important factor in soil aggregation and stability of aggregates. Low activity clay soils with high amount of oxides (Fe and Al-oxides) are more stable in water, but the stability gradually decreased as the soil texture becomes increasingly sandy (observed in soils studied) which is poor in exchangeable bases and cannot hold and exchange cations. Thus, poor influence in soil structural stability. Huygens et al. (2005) in their works observed that the extractable Al content in the soil is positively related to the stability of soil aggregates. This simple suggest that the less the extractable Al in soil, the less stable the soil aggregates, the more the SOM remain in the macro OM pool. All these scenarios might have contributed to the nature of the result obtained from the study.

The result of the relationship between aggregate stability indices and the physical parameters of the soils showed positive and negative significant correlation in very few parameters. However, the positive correlation relationship indicates that as the physical properties increased, the stability of the aggregates equally increased. The negative correlation indicates that when the physical properties increased the stability of the aggregates decreased. While if the values of the physical properties decrease the aggregate stability is enhanced. The r values are varied and small value indicate that the stability of the soil aggregates is enhanced. The clay-polycation – OM reactions in soils is very important in soil aggregation and aggregate stability of soils. Clay and silt fractions are associated with OM and soil stability depends on the physicochemical properties of clay, OM mineralization binding micro-aggregates to macro aggregates. Mbagwu and Piccolo (1998) noted that OM effectively stabilized silt + clay fraction within dry micro-aggregates with organic waste amended Italian soils. Though not all OM compounds in soils are responsible for soil aggregation and increase in clay content does not necessarily result in an increased stability. Under tillage systems in tropical soils, lack of silt partially cause compaction, while OM due to its ability to restrict age hardening process retard the stability of soil aggregates. Higher clay dispersibility of water stable aggregates occur most in cultivated soils due to low OM content. Mbagwu and Piccolo (1998) recorded significant correlation between silt + clay and humic acid content. While Okoyefi et al. (2017) found positive correlation between SOM and clay as well as SOM and silt. Clay content in soils are influenced by illuviation, eluviation and erosion caused by land opening. Hysteresis of the colloidal stability of clay occur when system changes from flocculation to dispersion. Decreasing aggregate size particles increased the content of silt + clay in larger aggregates separated by wet and dry sieving (Nweke and Nnabude, 2015a). Pores in micro aggregate vary with the texture of soils and land use and rain drop impacts cause aggregate breakdown and translocation of finer materials leading to loss of pore space at the soil surface. Cultivation as noted by Nweke and Ilo, (2019) reduce macrospores due to reduced SOC associated with land use and continuous cropping increase macro-pores. At reduced porosity associated with high bulk density, there exist high buildup of run-off water and consequent deterioration of macro-aggregates and intra-aggregate pores. Decreased BD is associated with increased OM, the range in studied soil poses no serious problem to crop production as it is quite high, its decrease in value observed in some soil depth of land use may be due to OM reduction and less aggregation.

Although Na had no significant correlation with most of the aggregate stability indices, its highly significant ($P < 0.01$) and positive correlation with DP30 (dispersibility at 30 minutes) is evidence that Na cause dispersion of soil aggregation. While K showed very limited or no influence in soil aggregation by virtue of its non-significant correlation with 14 aggregate stability indices studied. The negative correlation coefficient Ca had with WSA2, WSA3 and WD and Mg with DP30M showed that the two elements can cause dispersion of soil aggregates. The importance of Ca and Mg in clay aggregate stability and dispersion have been reported by Mengel and Kirkby (1987). They concluded their study by saying that leaching of calcium and magnesium lead to dispersion and weak aggregation in soils. Correlation result of CEC with the 14 aggregate stability indices, showed negative and significant ($P < 0.05$) correlation with WSA4 relative to the other 13 aggregate stability indices. This may be associated with CEC, OM and OC concentrations of the soils (Table 2). The higher the CEC, the less stable are the aggregates. Albrecht (1996) opinioned that when the contributions of Na and Mg to CEC exceed 30%, water stable macro aggregates are rare and this type of soil is susceptible to dispersion and disaggregation. Organic carbon (OC) and OM had highly significant correlation with all the water stable aggregates WSA (except for WSA3), MWD and WD. This is an indication that OC and OM influenced soil aggregation. One of the measures of good structure is the stability of soil aggregates in water. This however, is influenced mostly by the amount of OM in the soil (Piccolo 1996; Nweke 2015). Nonetheless, the positive relationship between total OM in soil and soil aggregation is not always clearly revealed as wide range of organic and functional groups of partially decomposed organic compounds influence soil aggregation. Further, the size, location and biochemical composition of the organic compounds influences the formation and stabilization of soil aggregates. The molecular structure and location of SOM especially particulate OM were found by Golchin et al. (1994) to strongly influence aggregate stability. Brenda et al. (2024), Azuka and Igue (2020) found SOC/OM to have significant positive correlation with Ca, BS, CEC and TN, P, BD and TP respectively. While Wasonga et al. (2024) noted OC, P and N to have positive correlation and with C: N, C:P and N:P. Organic Matter (OM) disposition rather than the type and amount is very important in soil aggregation. Higher OC content reduces the gain in stability with time and OC decreases with decreasing aggregate size (Nweke and Nnabude, 2014). Soil aggregate improvement have implications for a number of parameters like oxygen circulation in soils, OM mineralization, water infiltration rate, BD, FC etc. While the stability of aggregates encourages the physical protection of SOM losses by erosion or mineralization. Land use changes disrupt SOM, soil erodibility, microbial activity and bioavailability of organic materials. Base saturation (BS) and nitrogen (N) had no correlation with the 14 aggregate stability indices studied. This could be associated with OC content and the texture of the soils. Carbon and N are intimately related to finer soil particles and differences in OC could arise from the variability in the distribution of clay, silt and sand fractions. Soil organic carbon (SOC) content of low activity clays especially of tropical soils (like southeast soils of Nigeria) in general depends on the intensity of land use, cultural and tillage related practices (Feller, 1993). The importance of which tends to increase with increases in clay + silt content. The significant correlation coefficient available P had with WSA1, WSA3 and MWD is evidence that higher content of P is associated with macro-aggregate than in micro-aggregates. Both pH in water and KCl correlated significantly positive with the micro-aggregation index WSA5 which implies that as the pH increases or decreases the micro-aggregate index increases or decreases, while both pH correlated with macro-aggregate indices WSA2, WSA3 and micro-aggregate index WD negatively showing that as one increases the other decreases. Thus, the pH of soil is very vital in the stability of soil aggregates.

VI. Conclusion

The result findings showed that all the aggregate stability indices used in the study correlated significantly ($P < 0.01$ and $P < 0.05$) either positively or negatively with each other and with physical as well as chemical parameters. Though some were not statistically significant. This showed clearly that relationship existed between the indices used as well as physical and chemical soil parameters studied. The positive correlation indicates that as one of the aggregates correlated increased, the other also increased, while negative correlation indicates that as one of the aggregate indices correlated increases the other decreases. Na, Ca and Mg were found to influence soil aggregate dispersibility while OC and OM positively influenced soil aggregation. Soils of low aggregate stability are more prone to erosion, loss of plant available nutrients and mineralizable OM. Continuous and intensive cropping lower aggregate stability of soils as observed in CCCF, therefore the most common approach to improve aggregation and stability of soil aggregates is to incorporate organic residues into the plough layer to increase the OM status of the soil. This will turn around the physicochemical status of the soil as it will improve the water holding capacity and infiltration, decrease soil compaction and increase the availability of exchangeable cations. Finally, the indices used for the determination showed that most of them were very effective and suitable in the determination of the land use system which includes the various wet-sieving methods, macro and some of the micro indices studied.

VII. Compliance with Ethical Standards

There is no conflict of interest of any kind with regard to the publication of this work. The authors were fully in charge of the research work, sponsored the work themselves and agreed to send the work to this journal.

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