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Influence of granulometric composition and organic matter management on soil stability against water erosion in Southeastern Nigeria

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ABSTRACT

The study investigated the influence of granulometric composition and organic matter on soil stability and eroded sediment under simulated rainfall for some soils from southeastern Nigeria. The experiment was conducted at the Glasshouse of the Department of Soil Science, University of Nigeria Nsukka (UNN). The experimental design was a 3 x 3 factorial in CRD replicated three times and involved three different soils (Nando, Abakaliki and UNN) and three poultry manure rates: 0, 20 and 40 t ha^{-1}. Soils were measured into transparent plastic bowls, and organic treatments applied, and the entire set up left to restructure for five months. The soils were subjected to simulated rainfall at rainfall intensity of 75 mm^{-1}. From this, the runoff was collected and measured and the mass of eroded sediment determined as a measure of soil erosion. Results showed that the water-stable aggregate fractions generally increased as the fraction size decreased. Water-stable aggregates of the organic treatments followed the order: 0.50 mm >0.1 mm >2 mm; 1 mm > 0.50 mm> 2 mm, and 0.50 mm > 2 mm > 1 mm at Nando, Abakiliki and UNN, respectively. Aggregate stability decreased in the order of: 25.1 (Abakiliki) < (Nando) < 35.3 (UNN). Increased application of organic treatments did not affect the run-off volume and sediment yield. State of aggregation (SOA), CDR and WDSi and aggregated silt + clay (ASC) significantly ($p<0.05$) correlated with coarse sand, while WDC, SOA, MWD and WDSi significantly ($p > 0.05$) correlated with Fe, Al, Mn and % organic manure.

1.0. Introduction

Soil is a crucial component of the biosphere that determines the biogeochemical, hydrological and erosional cycles and delivers various essential ecosystems goods and services (Brevik *et al.*, 2015; Keesstra *et al.*, 2016). However, soils are often threatened by several degradation factors among which is soil erosion, a clear indication of soil degradation in the tropics (Mbagwu and Obi, 2003). Therefore, preventing and reducing soil erosion is a major environmental and economic challenge in this region where climate change is already perceptible (Ezeaku, 2014). In Nigeria, the problem of soil erosion is more pronounced in the southern part of the country where high-energy storms are frequent on bare soils during the rainy season (Jebari, 2009). Mbagwu (1988) noted that 25% of Nsukka area in southeastern Nigeria had an estimated annual soil loss rate that exceeds 30 t ha^{-1}. Susceptibility of soil to water erosion is mostly due to the structure of the soil (Doran and Parkin, 1994). A good structure exerts influence on the functioning of the soil, thus crucial in sustaining long-term crop production in agricultural soils (Mbagwu and Auerswald, 1999).

Soil aggregate stability is a composite granule of loosely bound material particles within a soil. The relative amount of organic matter characteristically mediates it in the soil and influences many physical and biogeochemical processes in agricultural lands (Obalum *et al.*, 2012). According to Opara (2009), soil aggregates are soil structural unit of two major size-based categories: macro- and micro-aggregates formed by both aggregation and fragmentation processes. Micro-aggregate is the collapse of macro-aggregate and is regarded as soil aggregates less than 250 μm in size.

Soil aggregate stability is the ability of the aggregate to remain undisrupted under stress or slaking. It is an indicator of soil susceptibility to runoff and erosion (Barthes and Roose, 2002). Aggregate stability is particularly important to consider when issues are examined that relate to soil fertility and natural resources conservation (Cammeraat and Imeson, 1998; Amezketa, 1999; Bronick and Lal, 2005). Soil aggregate stability and aggregate size information are used to evaluate the sensitivity of soil to crusting and erosion (Cerdà, 2000); the conditions for seed germination and rooting of crops, and the soil capacity to sequester organic carbon (Lynch and Bragg, 1985); predict the effects of various agricultural practices, such as tillage and organic matter additions, including soil erosion (Yin *et al*., 2009). Aggregate stability is a valuable soil property that affects the movement and storage of water, aeration, erosion, biological activity and the growth of crops (Lal and Stewart, 2012).

Research on soil aggregate stability is an essential requirement considering the importance of water erosion damages onsite and offsite (Keesstra *et al*., 2016). Soil aggregate stability is a definitive variable to understand soil erosion processes in agricultural and forest soils (Haregeweyn *et al*., 2013), since it reflects the actual vulnerability of topsoils to physical degradation (Obalum and Obi, 2012; Stanchi *et al*., 2015). Soil aggregate stability studies serve as early warning signs of vulnerability and resilience of soils. They can be useful for evaluating the influence of land use and for erosion control management (Cammeraat and Imeson, 1998).

Soil aggregate stability is studied by examining the process of aggregate disintegration or the factors that stabilize aggregates. Soil stabilizing factors are primarily related to soil characteristics such as clay mineralogy, iron and aluminium oxides (sesquioxides) and organic materials, which may be affected by agricultural practices. The type and amount of clay present in the soil influences the stability of aggregates (Igwe, 2012). Boix-fayos *et al*. (2001) reported that the water stability of micro-aggregates showed a positive correlation with clay content. According to Seta and Karanthanasis (1996), dispersibility of clay and silt-sized particle fractions when immersed in water affects many soil physical properties, such as shrink-swell and hydraulic conductivity of the soil. Also, Igwe *et al*. (2006) reported that soils with water-dispersible clay (WDC) had high potential to disperse. They added that when such soil disperses on saturation with water, it leads to aggregate breakdown, forming seals and crusting and reduces the permeability of water.

Aggregate stability of soils can be measured by wet-sieving or raindrop techniques which rely on the principle of cyclically submerging and sieving the soil in water to emulate the natural stresses involved in the entry of water into soil aggregates (Kemper and Rosenau, 1986). The derivation of many aggregate stability indices involves all aggregate size classes, and the indices provide information on the overall stability of the soil (Udom and Anozie, 2018). Typical examples are mean weight diameter (MWD) of aggregates, geometric mean diameter (GMD) (An *et al*., 2010), clay dispersion index and flocculation that are used to measure micro-aggregation after long-term application of organic manure (Udom *et al*., 2013).

Researches have shown that organic manure application improves soil physical properties. Organic manure management has effects on soil aggregation (Wortmann and Shapiro, 2008; Koelsch, 2017). It increases microbial activity and production of microbial polysaccharides (Haynes and Naidu, 1998), while soil amended with organic wastes show a reduction in dispersibility of aggregates (Mbagwu *et al.*, 1993).

Application of manure fertilizer has a significant influence on soil physical and chemical properties in agroecosystems. However, the effect on the distribution of aggregates in southeastern Nigeria is not fully understood. Again, the contribution of granulometric composition and soil organic matter towards the aggregate stability of soils in southeastern Nigeria is scantly documented. Therefore, the knowledge of how the stability of aggregates of our fragile soils is influenced by granulometric composition and soil organic matter is essential in southeastern Nigeria where high rainfall erosivity, variable biomass production and intensive tillage can accelerate soil's susceptibility to water erosion on agricultural lands. Also, there is a need to determine the dynamic change of the distribution of aggregates as influenced by organic manure management, especially in a glasshouse experiment. The primary objective of the study was to determine the influence of granulometric composition and organic matter on soil stability and eroded sediment for some soils from southeastern Nigeria. Illustration of the relationship between granulometric composition, organic treatments and soil aggregates will improve our understanding of the changes in soil stability indices, which could serve as early indicators of soil degradation or recovery for improved soil productivity.

2.0. Materials and Methods

2.1. Soil Description and Sampling

Composite topsoil used for the study was collected at a soil depth of 0 – 20 cm, from three locations: Nando (Anambra State), Abakaliki (Ebonyi State) and Nsukka (Enugu State). The soil depth (0-20 cm) was chosen because most vegetable crops are surface feeders (Ezeaku, 2001).

Nsukka is located by latitude 06^o 52' N and longitude 07^o 24' E with an elevation of about 419 metres above sea level. The study site is the gently undulating to undulating plains of the University of Nigeria Nsukka Research and Teaching Farm. The soil is very deep, dark-reddish brown at the top layer and reddish in the subsoil. The parent material is colluviums on false-bedded sandstone with clay mineralogy composed mainly of kaolinite (Akamigbo and Igwe, 1990). Abakaliki (latitude 05^{0}40'and 06^{0}45'N; longitude 07^{0}30' and 08^{0}30' E) area is made up of some upland and lowland soils. The lowlands are usually hydromorphic soils, whose morphology is influenced by seasonal water logging caused by underlying impervious shale. The soil texture is clay loam, moderatetly to poorly drained with gravely subsoil in some locations, especially the uplands adjacent to lowland areas. The parent material is weathered shales (shale residuum and schists of the Asu River group). The soils are characterized and classified as hydromorphic lithosols. The soils of this class are usually pale-coloured and mottled in the sub-soil (FDALR, 1990).

Nando is bounded by longitudes 6^{0}55' E and 7^{0}00' E and latitudes 6^{0}15' N and 6^{0}20' N and falls within the Anambra basin (Egbunike, 2007). The lithostratigraphic units within Nando include the Imo Shale (Paleocene) and the

Ameki Formation (Eocene). The Imo Shale is represented by the shale unit overlain by a sandy mudstone unit. At the same time, the Ameki Formation is made up of a clay unit overlain by a sandstone unit. The Imo Shale is made up of two units, namely the shale unit and the sandy mudstone unit. The shale unit is generally dark grey, silty, micaceous, and contains woody tissues. Shallow to the deep marine environment is inferred from these sedimentary features.

2.2. Glasshouse study

The study was done at the Glasshouse of the Department of Soil Science situated at the University of Nigeria Teaching and Research Farm, Nsukka (latitude 06°52ˈN; longitude 07°24ˈE). The site elevation is 447m above sea level. The rainfall pattern is bimodal: the rainy (April – October) and the dry seasons (November – March). The relative humidity is rarely below 60% (Asadu *et al*., 2002).

2.3. Experimental Design and Treatments

The experimental design was a 3 x 3 factorial in completely randomized design (CRD) replicated three times, implying three different soils and three poultry manure rates (t/ha). The rate of the soil was 0, 20 and 40 tha^{-1} for Nando, University of Nigeria, Nsukka (UNN) and Abakaliki.

2.4. Soil collection and preparation

Different weights in the range of 10.5 to 11 kg of the soils were collected from the surface horizon of the soil profile to represent physical and chemical conditions of the soil surface accurately. The soil was collected from the top 20 cm of the surface. Three replicate soil samples were randomly excavated in each location using a soil drill (diameter, 4 cm) and then mixed to produce a composite sample. The soils were air-dried at room temperature. The soil was sieved through a coarse (2.0 mm) screen to remove rocks and debris. The soils were partitioned into two: samples for determining of the aggregates, and a subsample for determination of total SOC content.

The soil box [transparent plastic bowls (dimension – 30 cm x 25 cm x 20 cm) with twenty 10-mm drain holes in the bottom)] was filled by scooping enough dried, sieved, and homogenized soil to about half deep when smoothed out (about 3.5 cm). The bottom of the boxes was lined with cloth to keep soil from washing out of the holes in the box while allowing water to flow through when the soil is saturated.

The soil was evenly spread and packed. Each box was pack to achieve a soil depth of 5 cm and uniform bulk density. Amendment with different rates of poultry droppings (0, 20 and 40 tha^{-1}) was made, and the entire set up left to decompose for two weeks. The sieved soils were allowed to restructure for five months. In which, 500 cl of water was applied per plot daily.

The soils were subjected to metal box simulated rainfall in the glasshouse at rainfall intensity of 75 mm/h. The soil boxes were placed on a bottomless frame to minimize splash that would otherwise occur from a solid platform immediately below the soil boxes and allows free drainage from the holes in the bottom of the boxes.

The rainfall simulation operation was done by putting water into a bucket on top of the constructed block platform where the water flows through the hose into the metal box containing the measured soils. The time of runoff initiation for each box was recorded when water draining from the drain spout turns from a slow drip to a continuous stream.

Runoff samples were collected at prescribed time intervals of 5 minutes during the event by switching. The runoff samples were collected, and volume recorded using a graduated meter rule. The runoff water was removed immediately after measurement and poured into a plastic bowel where it was allowed to decant for 24 hours. After that, the sediments were removed using a wash bottle into smaller containers where the sediments were allowed to dry. The dry sediments were after that measured to determine the sediment yield. The mass of eroded sediment determined served as a measure of soil erosion. However, according to Grismer (2012), standards vary in studies using rainfall simulators to evaluate erosion.

2.5. Determination of aggregate distribution

The particle size distribution of the < 2mm was measured by the hydrometer method as described by Gee and Bauder (1986) using sodium hydroxide as the dispersing agents and with deionized water alone for the determination of water-dispersible clay and silt. The micro stability indices were computed as follows

$$\text{Dispersion ratio (DR)} = \frac{\%\text{ silt + clay (water)}}{\%\text{ silt + clay dispersed}}$$

$$\text{Clay dispersion ratio (CDR)} = \frac{\%\text{clay (water)}}{\%\text{ clay dispersed}}$$

$$\text{Clay flocculation index} = \frac{\%\text{clay (dispersed) - }\%\text{clay (water)}}{\%\text{ clay dispersed}} \times \frac{100}{1}$$

$$\text{Clay dispersion index} = \frac{\%\text{clay (water)}}{\%\text{ clay dispersed}} \times \frac{100}{1}$$

Aggregated silt and clay (ASC) = % clay + silt (dispersed) - % clay + silt (H_20)

2.5.1. Separation of water-stable aggregates

The method of Kemper and Rosenau (1986) was used to separate the water-stable aggregate (WSA). In this method 25 g of the > 4.75 mm air-dried aggregates was put on top of a nest of sieves measuring 2 mm, 1mm, 0.50 mm,0.25 mm and < 0.25 mm was presoaked for five minutes in water. The sieves and their contents oscillated 35 times in water at sixty seconds. After wet sieving, the resistant soil materials on each sieve and unstable (< 0.25) aggregates were quantitatively transferred into a container, dried in the oven until the steady weight is achieved. The percentage ratio of the aggregates in each sieve represents the WSA of size classes; > 2.00, 2.00-1.00, 1.00-0.50, 0.50 and < 0.25 %.

Aggregate stability and state of aggregation were measured as the mean weight diameter (MWD) of stable aggregates and was calculated as follows:

$$MWD = \sum_{i=0}^{n} w_i x_i$$

where x_i is mean diameter of any particular size range of aggregates separated by sieving and

w_i is the weight of aggregates in that size range as a fraction of the total dry weight of the sample analyzed.

Larger mean weight diameter value indicates higher proportions of macro-aggregates and therefore, higher stable to water erosion. The MWD has often been used to indicate the effect of different management practices on soil structure (Six *et al*., 2000).

$$\text{Aggregate stability (As) \%} = \frac{\text{WSA—Mass of sand}}{\text{Mass of sample}} \times \frac{100}{1}$$

$$\text{State of aggregation \%} = \frac{\text{WSA—Mass of sand}}{\text{Mass of sample—Mass of sand}} \times \frac{100}{1}$$

2.5.2. *Determination of chemical properties:* Sub soil samples collected and air-dried were ground and passed through < 2 mm sieve for the determination of total SOC content, which was determined by Walkley and Black dichromate oxidation according to Nelson and Sommers (1982) method. After that, the percentage of organic matter content was calculated by multiplying the organic carbon value by the conventional "Van Bernmalen"- factor of 1.724. Iron (Fe), Aluminium (Al) and Manganese (Mn) elements determinations were done by reading the samples with AAS using Association of Official Analytical Chemistry (AOAC) (2003) method.

*2.6. Data Analyses***:** The data collected were subjected to the two-way analysis of variance (ANOVA) for each soil using GENSAT 2007 discovery edition and means were separated with least significant difference (LSD) at 0.05 probability level. Correlation analysis of aggregate stability against granulometric composition and organic matter as well as a runoff and sediment yield was done.

3.0. Results and Discussion

The results of particle size distribution (percent sand, silt and clay) content of topsoil (0-20 cm) show that Nando and UNN soil was sandy loam and loamy sand, respectively. At the same time, that of Abakaliki was sandy clay loam.

3.1. Aggregate Size Distribution and Stability of the Soils

The aggregate size distribution and stability of the three soils studied are shown in Table 1. The proportion of water-stable aggregate fractions generally increased as the fraction size decreased across the location soils. The water -stable aggregate sizes between 2 mm and 1mm were observed to be higher in UNN with the range 3.99 to 3.11%. Again aggregate sizes between 0.5 and 0.25 mm found to be higher in UNN in contrast to Nando and Abakaliki, respectively.

Adding organic material promotes soil aggregation and stability. It can be observed that incorporating organic materials increased 2 mm and 0.50 mm water-stable aggregate at UNN relative to Abakiliki and Nando (Table 1). The average water-stable aggregate of the organic treatments followed the order: 0.50 mm > 0.1 mm > 2 mm, 1 mm > 0.50 mm > 2 mm, and 0.50 mm > 2 mm > 1 mm at Nando, Abakiliki and UNN, respectively. The soils that have aggregate sizes greater than 0.50 mm could be considered to have better resistance to breakdown by high-intensity tropical rainfall. Legout *et al.* (2005) noted that aggregate sizes are more beneficial because they resist such negative interference as crusting, slaking and sealing which may cause a decrease in the infiltration rate and the resultant over land flow. Furthermore, the aggregate breakdown will lead to these undesirable environmental problems.

Percent aggregate stability increased with an increase in organic treatment. For instance, in Abakiliki soil, the highest aggregate stability value obtained was 46.5 % at 40 t ha^{-1} and the lowest value (10.8%) obtained at 0 t ha^{-1}. On the other hand, the values of % AS decreased with an increase in organic treatment in both soils of Nando. In contrast, in UNN, the percent aggregate stability values obtained were variable. The highest value was obtained in 20t ha^{-1} and the lowest value (22.0 %) in 40 t ha^{-1} (Table 1). The results also showed the following decreasing order of % AS across the locations: 25.1 (Abakiliki) < (Nando) < 35.3 (UNN).

The increase of % AS with an increase in organic treatment at Abakaliki is supported by some research reports (Haynes and Naidu, 1998; Wortmann and Shapiro, 2014; Koelsch, 2017). It was reported that organic manure management affects soil aggregation as it stabilizes aggregates (Haynes and Naidu, 1998). Stable soil aggregates have a beneficial influence on soil moisture status, nutrient dynamics, and soil maintenance and soil porosity. Increases in porosity and aggregate stability also serve to improve other soil physical properties, which include decreased bulk density and compaction, increased water holding capacity, infiltration capacity and hydraulic conductivity, and decreased surface crusting and runoff volumes. A report by Koelsch (2017) showed that manure increases the formation of more extensive (macro) and more stable soil aggregates. He noted that manures reduce runoff and soil erosion; increase water infiltration into the soil, possibly leading to higher drought tolerance. Wortmann and Shapiro (2014) conducted studies and concluded that water-stable large macro-aggregates were increased two to three times for manured soils compared to commercially fertilized soils. All macro-aggregates increased by 10 to 20% for manured soil, and the increase was consistent across all soil types evaluated.

However, the decrease in % AS with increase in poultry manure treatment particularly in Nando (Table 1) is supported by the report of Mbagwu *et al*. (1993) which showed that organic matter does not affect aggregate stability. Goldberg *et al.* (1990) had earlier showed that organic matter could act as an aggregating or disaggregating agent or have no noticeable effect at all on aggregate stability depending on its composition in the soil or the relative contribution of other aggregating or dispersive agents.

The mean-weight diameters (MWD) as a measure of water stability of aggregates were between 0.79 and 1.45 mm with a mean of 1.16 mm at Nando. In contrast, at Abakaliki and UNN, the MWD ranged from 0.98 to 1.63 mm and 1.19 to 2.25 mm, respectively (Table 1). Very unstable soils and those that are weakly aggregated always have low MWD (Baker *et al*., 2004). They concluded that lower MWD favours an increase in porosity. However, this contradicts an earlier report by Todd and Wander (2003) that an increase in MWD for soils of the same bulk density may represent an increased percentage of macropores at the expense of water-storage mesopores and that MWD was a useful index of soil structure.

From Table 1, the percentage state of aggregation (% SOA) values was variable in trend. However, the % SOA in Nando decreased with an increase in organic treatment. In contrast, at Abakaliki, the trend increased with an increase in organic treatment but variable in that of UNN soils. The highest value (38 %) of SOA was obtained at 20 tha^{-1}applications in UNN soil, while the lowest value (15.1 %) was obtained in Abakaliki at the 20 tha^{-1}organic treatment application.

The results of colloidal stability indices (water dispersible clay, water dispersible silt, clay dispersion ratio, clay flocculation index, dispersion ratio and clay dispersion index) are presented in Table 2. The water dispersible clay (WDC) values increased with the rate of organic treatment in Nando soil but consistently decreased in both Abakaliki and UNN soils. The highest mean value of WDC was obtained in Abakaliki soil (8.15) followed by Nando (7.26) and lowest value in UNN soil (5.71) (Table 2). The result of water dispersable silt (WDSi) shows that Abakaliki soil had the highest mean value of 22.2, while the lowest value (6.88) was obtained in UNN and intermediate value (11.3) in Nando. The highest value obtained in Abakaliki suggests that clay and silt may have leached more in the location soils than in others. Based on the treatment applications, WDSi value was highest at 20 tha^{-1} in Abakaliki and UNN but 40 tha^{-1} at Nando.

Result of the clay dispersion ratio (CDR) obtained in the three location soils studied is presented in Table 2. The highest value was obtained in Abakiliki soil (1.33) followed by Nando (0.89) and the lowest value (0.39) obtained in UNN soil. The lower values of CDR obtained at 20 tha^{-1} in Nando and UNN relative to the high value of 40 tha^{-1} Abakaliki, implies the probability of a consequence of high rate of clay dispersion in Abakaliki soils when submerged and could lead to instability of the micro aggregates. This further suggests that the application of 20 tha^{-1} helps in soil aggregation and micro aggregates stability in Nando and UNN than Abakaliki soils.

Table 1: Percent aggregate size distribution and stability of the soils of three locations and contrasting organic matter man-

Treatment (t/ha)	2 mm	1 mm	0.5 mm	0.25 mm	MWD (mm)	AS (%)	SOA %
				Nando			
0	2.43	3.38	4.45	4.86	1.25	38.5	36.7
20	3.17	3.04	3.54	4.25	0.79	29.7	26.9
40	1.12	2.88	4.09	6.07	1.45	27.2	21.5
				Abakaliki			
0	2.52	2.45	3.13	2.64	1.00	10.8	15.7
20	2.11	3.13	2.94	2.30	0.98	17.9	15.1
40	2.15	2.87	1.99	2.49	1.63	46.5	25.5
				UNN			
0	4.93	2.65	4.55	4.20	1.99	39.3	30.6
20	4.99	3.76	4.40	4.06	1.19	44.6	38.0
40	2.06	2.92	3.36	4.15	2 25	22.0	18.3
$LSD_{0.05}$	Ns	Ns	Ns	Ns	Ns	Ns	Ns

As % - percent aggregate stability, MWD – mean weight diameter, Ns – not-significant

Clay flocculation index (CFI) which indicates micro-aggregate stability has the highest mean value of 0.56 g g^{-1} in UNN soils followed by Nando soils (0.48 g g^{-1}) and the lowest value (0.45 g g^{-1}) in Abakaliki soils. Across the locations and treatment rates, highest CFI value was obtained with 20 tha^{-1} in UNN. This explained that application of organic (poultry) manure at 20 tha^{-1} improved micro-aggregate stability through enhancement of CFI. The low CFI values of 0.48 g g^{-1} and 0.45 g g^{-1} obtained in Nando and Abakaliki soils, respectively, further explained their insignificant roles in improving the micro-aggregate stability of the soils. This is consistent with the study of Udom and Anozie (2018). Igwe *et al.* (2006) noted that a higher value of CFI in soil indicates higher or better stability of the soils.

Clay dispersion index (CDI) and dispersion ratio (DR), as estimates of soil dispersion, have higher mean values in Abakaliki soils when compared to those of Nando and UNN soils (Table 2); an indication that Abakaliki soils are more prone to dispersion upon contact with water resulting in lower aggregate stability.

3.2. Runoff and Sediment Yield of the Soils Studied

The result of runoff volume and sediment yield in the first cropping season are summarised in Table 3. The result shows that runoff at the first cropping season (RV_1) generally had higher values relative to runoff at the second cropping season (residual, RV_2) at Nando. The trend varied slightly in Abakiliki and UNN. The mean difference between RV_1 at the first cropping season and residual runoff (RV_2) was not significant across the three location soil.

The result of sediment yield in the first cropping season (SD_1) (Table 3) indicates that Nando soil had the highest value (91.1) followed by UNN (66.5) and Abakaliki having the lowest value (61.7). In the residual sediment yield (SD_2) the order of increase in value is 84.5 (Nando) > 65.1 (UNN) > 62.5 (Abakaliki). The value of residual sediment yield (SD_2) was found to decrease with increase in the applied organic treatments in Abakaliki and UNN.

*3.3. Correlation of Aggregate Stability against Granulometric Composition and Organic Matt***er**

The results of the correlation of aggregate stability against granulometric composition and organic matter are presented in Table 4. The results show that water-dispersible silt (WDSi) and aggregated silt + clay (ASC) positively and significantly correlated with coarse sand (CS) at $p < 0.05$ % probability level, while the state of aggregation (SOA) and clay dispersion ratio (CDR) positively correlated with CS. The correlation values of aggregate stability (AS) and mean weight diameter (MWD) against CS value was negative. The result shows that WDSi and ASC have negative-

Table 2: Colloidal stability indices of the three location soils

Treatment (t/ha)	WDC g kg $^{-1}$	WDSi g kg $^{-1}$	CDR %	CFI g g $^{-1}$	DR %	CDI g g $^{-1}$
			Nando			
0	5.04	10.7	0.84	0.54	0.36	0.96
20	7.04	9.3	0.89	0.47	1.77	1.18
40	9.71	14.0	0.58	0.42	1.19	1.17
Mean	7.26	11.3	0.77	0.48	1.11	1.10
			Abakaliki			
0	11.04	22.7	0.49	0.52	0.60	1.23
20	7.04	24.0	0.51	0.51	1.74	1.45
40	6.37	20.0	1.33	0.32	2.34	1.51
Mean	8.15	22.2	0.77	0.45	1.56	1.39
			UNN			
0	6.37	3.3	0.37	0.52	0.39	0.20
20	5.71	12.0	0.39	0.60	1.12	0.78
40	5.04	5.33	0.33	0.56	0.59	0.36
Mean	5.71	6.88	0.36	0.56	0.70	0.45

NB: WDC – water dispersable clay, WDSi - water dispersable silt, CDR – clay dispersion ratio, CFI – clay flocculation index, DR – dispersion ratio, CDI – clay dispersion index

ly high significant ($p < 0.1$) correlation with fine sand (FS), while WDC and CDR correlated negatively significantly ($p < 0.05$) with FS (Table 6). Clay dispersion ratio (CDR) significantly ($P < 0.05$) and positively correlated clay ($r = 0.409$*). When CDR is high, it may lead to clogging of the pores and formation of seal leading to restriction of water movement and changes in the hydraulic properties of the soils (Legout *et al.,* 2005).

Again, it was only WDSi and ASC that showed positive significant ($p < 0.05$) correlation with silt. Amongst all the aggregate stability indices, only CDR negatively significantly ($p < 0.05$) correlated with clay.

In terms of heavy metal correlations, it can be observed in Table 3 that only WDC index that positively significantly ($p < 0.05$) correlated with iron (Fe), At the same time, MWD had negative but significant ($p < 0.05$) correlation with Al^{+3}. All the aggregate stability indices showed an either negative or positive correlation with manganese (Mn). The correlation of SOA, WDC and WDSi against organic matter (OM) was positively significant ($p < 0.05$), while those of ASC ($r = 0.52$**) and CDR ($r = 0.51$**) were positively highly significant.

The significant correlation of organic treatment with WDC shows that organic matter can act as an aggregating agent (Goldberg *et al*., 1990) depending on its composition in the soil. Soil organic matter positively and profoundly significantly ($p <0.1$) correlated with CDR and ASC and this implies that organic matter can increase clay dispersion, that is, act as an disaggregating agent (Goldberg *et al*., 1990). They further noted that decreased organic matter decreases clay dispersivity. However, the well-known positive effect of organic manure on soil structure probably occurs through binding of soil properties by roots and hyphae at the aggregate level. However, at the clay-particle level the negative charge of organic anions enhances clay dispersion.

Table 3: Runoff and sediment yield in first and second cropping seasons of the three location soils studied

Treatment (t ha-1)	RV1	RV_2	SD_1	SD_2
		Nando		
0	35.93	32.90	147.70	128.73
20	35.97	35.40	60.97	65.27
40	37.30	36.07	64.97	59.43
		Abakaliki		
0	23.93	29.60	33.60	34.93
20	33.53	29.73	62.03	63.17
40	24.60	30.20	89.60	90.23
		UNN		
0	34.80	34.40	58.07	57.00
20	33.13	31.50	56.40	59.30
40	36.63	30.87	75.23	78.63
$LSD_{0.05}$	3.06*	Ns	37.61*	32.87*

NB: $LSD_{0.05}$ – least significant value at 5 percent probability, RV_1 – run off volume first cropping season, RV_2 – run off volume second cropping season, SD_1 –sediment yield first cropping season, SD_2 – sediment yield second cropping season,

Some authors have emphasized that the interaction of Fe and Al (amorphous and crystalline oxides) contents of soils play important, stabilizing roles in soil aggregate stability (Goldberg *et al.* (1990; Six *et al.,* 2000; Yin *et al.*, 2016; Zhao *et al.*, 2017). In this study also, iron (Fe) positively and significantly ($p < 0.05$) correlated with water-dispersible clay (WDC) (r = 0.386 *) contents of the soils (Table 4). This agreed with the findings (Seta and Karathanasis 1996) that Fe and Al contents in the soil greatly account for the clay dispersibility of the soils they studied. Emphasizing on the relevance of water-dispersible clay in the dispersibility of soils, Boix-Fayos *et al.* (2001) showed that this type of aggregate deformation was an indicator of the degradation. Extensive dispersion of clay leads to structural breakdown of aggregates, slaking and the subsequent hard setting of the soil upon drying. Goldber *et al.* (1990) noted that this tendency of clay to disperse results in restriction of water movements and changes in hydraulic properties of the soil.

The summarized results of the correlation coefficients for runoff and sediment yield against soil physical and chemical properties in the three soils studied are shown in Table 5. The correlation values between runoff volume (RV_1) for first cropping season 3 months after planting (3 MAP), runoff volume for second cropping season 6 MAP (RV_2), sediment yield 3 MAP (SD_1), sediment yield 6 MAP (SD_2) and the particle size distribution (Cs, FS and silt) were either positive or negative.

The consequence of the high rate of clay dispersion in soils when submerged leads to instability of the micro aggregates. This tendency of the soil may facilitate the movement of the soil particles when saturated with water through runoff and erosion.

The results of runoff volume correlation (Table 5) shows that RV_1 significantly ($p < 0.05$) correlated with clay (r = -0.46*), WDSi (r = -0.52**), and ASC (r = -0.57**). The residual runoff volume (RV_2) had a significantly ($p < 0.05$) negative correlation with clay (r = -0.48*), mean weight diameter (MWD) (r = -0.40*), and CDR (r = -0.49**). A negative significant ($p < 0.05$) correlation between runoff volumes (RV_1), WDC, WDSi, ASC and CDR was obtained, suggesting the possibility of these soils to erode when submerged in water. The water-dispersible clay (WDC) may clog the soil pores and prevent the ease of infiltration and even aeration when the soil is dry. The pore-clogging leads to puddling of the soil when tillage operation is performed in a high-water regime.

Sediment yield (SD_1) and SD_2 correlated negatively and significantly ($p < 0.05$) with WDC (r = -0.43*) and (r = -0.45*), respectively. It was observed that the correlations between RV_1, Rv_2, SD_1 and SD_2 and particle size distribution were mostly not-significant (Table 5) but for soil structural properties.

4. Conclusion and Recommendation

This study sought to understand the influence of granulometric composition and organic matter management on soil stability against water erosion in southeastern Nigeria. The findings show that particle size distribution is influenced by texture and parent materials as observed in the three-location soils studied. Also, the use of organic manure as amendment plays a vital role in improving the aggregate stability of soils and thus determines if the soil is favourable for agricultural activities. Previous reports concluded that very unstable and weakly aggregated soils have low MWD and favour an increase in porosity. It was found in this study that highest water-dispersible clay (WDC) values increased with the increasing rate of organic treatment. The higher value of WDSi at Abakaliki followed by Nando and UNN, suggested that clay and silt leached more in Abakaliki soil than in other soils. Also, soil structural indices such as clay dispersion ratio (CDR) serve as micro aggregate stability of the soil. From the results, organic manure and soil structural properties affect soil aggregation positively or negatively depending on the texture of the soil.

Long-term field trials at a broader scale of southern Nigeria should be conducted to validate the potential of organic treatments in improving aggregation and aggregate stability indices of soils to resist erosivity of rainfall (reduced runoff) and erodibility of the soils by runoff (soil erosion), increased water infiltration into the soil, possibly leading to higher drought tolerance; and ultimately improve the potential productivity of the soils.

Table 4: Correlation coefficients for the relationship between aggregate stability indices and granulometric compositions, heavy metals, micronutrients and organic matter in the three soils studied

	CS	FS	Silt	Clay	Fe^{+3}	Al^{+3}	Mn^{+2}	OM
AS	-0.006	0.111	-0.274	-0.015	-0.019	0.201	-0.311	0.417
SOA	0.032	0.088	-0.254	-0.074	-0.062	-0.294	-0.300	0.381*
MWD	-0.209	0.270	-0.368	0.058	0.100	-0.042*	-0.088	-0.145
WDC	0.330	-0.426*	0.348	0.291	0.386*	-0.112	0.241	0.437*
WDSi	0.453*	-0.554**	0.442*	0.206	0.097	0.227	0.273	0.471*
ASC	0.475*	-0.588**	0.468*	0.248	0.174	0.174	0.296	0.515**
CDR	0.355	-0.447*	0.366	0.409*	0.301	0.152	0.375	0.514**

NB: AS – aggregate stability, SOA – state of aggregation, MWD – mean weight diameter, WDC – water-dispersible clay, WDsi – water-dispersible silt, ASC – aggregated silt + clay, CDR – clay dispersion ratio, CS - coarse sand, FS – fine sand, Fe – iron, Al – aluminium, Mn – manganese, OM – organic matter, * and ** - significant at 0.05 and 1.0 percent probability level, respectively

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Table 5: Correlation coefficients for runoff and sediment yield against soil physical and chemical properties in the three soils

Particle size distribution

	CS	FS	Silt	Clay
RV_1	-0.256	0.380	-0.247	-0.466*
RV_2	0.146	0.251	-0.056	-0.481*
SD_1	0.086	0.003	-0.007	-0.280
SD_2	0.049	0.027	-0.026	-0.237

Soil structural properties

	AS	SOA	MWD	WDC	WDSi	ASC	CDR
RV_1	-0.028	0.028	0.043	-0.487*	-0.520**	-0.569**	-0.668**
RV_2	-0.005	0.027	-0.403*	-0.333	-0.202	-0.254	-0.490**
SD_1	-0.045	-0.017	0.042	-0.432*	-0.169	-0.248	-0.240
SD_2	-0.041	-0.041	0.082	-0.454*	-0.194	-0.276	-0.220

Soil chemical properties

	Fe	Al	Mn	OM
RV_1	-0.323	0.114	-0.121	-0.425*
RV_2	-0.441*	0.316	-0.107	-0.402*
SD_1	-0.073	-0.047	0.192	-0.366
SD_2	-0.072	-0.057	0.177	-0.395*

RV1 – runoff volume for first cropping season 3 months after planting (3 MAP), RV2 - runoff volume for second cropping season 6 MAP, SD1 – sediment yield 3 MAP, SD2 - sediment yield 6 MAP, CS - coarse sand, FS – fine sand, AS – aggregate stability, SOA – state of aggregation, MWD – mean weight diameter, WDC – water-dispersible clay, WDsi – water-dispersible silt, ASC – aggregated silt + clay, Fe – iron, Al – aluminium, Mn – manganese, OM – organic matter, * and ** - significant at 0.05 and 1.0 percent probability level, respectively

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