Nigerian Journal of Soil Science

journal homepage:www.soilsjournalnigeria.com

Micro-aggregate Indices and Structural stability of Soils under Different Management

B. E. Udom and H. Anozie

Department of Crop and Soil Science, Faculty of Agriculture, University of Port Harcourt, Port Harcourt, Rivers State, Nigeria.

ARTICLE INFO

Article history:
Received: 28th June, 2018
Received in revised form: 30th July, 20018
Accepted: 2nd August, 2018
Available online: 1st December, 2018

Keywords:
Clay dispersion,
aggregated silt and clay
clay flocculation index
soil health

Corresponding Author's e-mail Address:
ebassidy@yahoo.com

https://doi.org/10.36265/njss.2018.280208
ISSN-1597-4488 ©publishingrealtime.

ABSTRACT

Low water stability of soil micro-aggregates accentuated by increased intensity of cultivation and soil degradation are among the significant issues that draw the attention of Soil Scientists due to their effects on soil physical conditions. The study was carried out to quantify changes in micro-aggregate stability indices of soils on coastal plain sands under contrasting land use and management. Soil samples were collected from cassava plots, plantain, maize, rubber plantation, oil palm and 2-season fallow plots with *Calapogonium mucunoides*. Results revealed significant changes in micro- and macro-aggregate stability indices. Clay dispersion index (CDI) was 0.46 and 0.39 g g^{-1} respectively in cassava and maize plots. Parameters such as aggregated silt and clay (ASC), clay flocculation index (CFI) and saturated hydraulic conductivity (Ksat) used as estimates of soil structural stability were significantly ($p < 0.05$) increased due to 2-season fallow and 10-year oil palm plantation. Two-year fallow increased ASC and CFI by 57 % and 86.5% respectively compared with continuous maize cultivation. Ten-year cultivation to cassava and maize increased sand content by 18 and 9% respectively and decreased the mean weight diameter (MWD) of water stable aggregates and Ksat. Relationships showed significant ($p < 0.05$) positive correlation between ASC and CFI and Ksat. Two-year fallow with *Calapogonium mucunoides* and 10-year oil palm plantation improved the soil micro- and macroaggregate indices. They could be used to conserve the soil and reduce the degradation of soil resources.

1. Introduction

Soil aggregate stability influences many physical and biogeochemical processes in agricultural lands (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 the soil. Soil aggregates are, therefore , soil structural unit of which classical soil research recognize two major size-based categories: macro- and micro-aggregates, formed by both aggregation and fragmentation processes (Opara, 2009).

Micro-aggregate is the collapse of macro-aggregate and is regarded as soil aggregates less than 250 µm in size. They are more typically found in disturbed or cultivated soils (Yan *et al.,* 2009). Aggregate stability and aggregate size information may be used to evaluate or predict the effects of various agricultural practices, such as tillage and organic matter additions, including soil erosion. Soil aggregate stability is the ability of the aggregate to remain undisrupted under stress or slaking. It 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).

The concept of aggregate stability depends on both the forces that bind particles together in nature and the magnitude of the disruptive stress (Beare *et al.,* 1994). Factors that influence aggregate stability are essential in evaluating the ease with which soils erode by water and/or wind, the potential of soils to crust and/or seal, soil permeability, quasi-steady state infiltration rates, and seedling emergence and in predicting the capacity of soils to sustain long-term crop production (Udom *et al.,* 2016). Aggregate stability of soils can be measured by the 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). Therefore, soil aggregates structure and aggregate stability are important factors that contribute to sustainable soil quality and soil erosion potential (Barthes and Roose, 2002). The moisture content of the soil aggregates before wet sieving controls the severity of the disruption. On the other hand, soil structural stability is a potential indicator of a wide range of decisions on soil management such as cultivation or engineering considerations (Dikinya *et al.*, 2006). To a great extent, it determines the ability soil to resist erosion, rupture, disintegration, or be puddled during mechanical manipulation (Abrishamkesh *et al.*, 2011).

The derivation of many aggregate stability indices involves all aggregate size classes, and as a result, such indices provide information on the overall stability of the soil. A typical example and perhaps the most used of such indices is the mean weight diameter (MWD) of aggregate, geometric mean diameter (GMD) (An *et al.*, 2010). Clay dispersion index and flocculation have been used to measure micro-aggregation of soils after long-term application of organic manures (Udom *et al*., 2013).

The primary mechanism of aggregate breakdown for macro - and micro-aggregate are slaking and dispersion respectively, slaking is the first water caused by pressure due to entrapped air and by differential swelling. It liberates the colloidal particles that are more transportable during erosion. Hence, micro-aggregate stability is often referred to as colloidal stability (Sequl, 2013), which controls soil air, water movement into and within the soil, soil sealing and biochemical reactions in the soil.

In a typical tropical ecosystem, information on the effects of land use systems on the maintenance of soil aggregate and their degradation will help in the management of soil structure following land use options. Thus, the objective of this study was to evaluate the micro-aggregate indices of soils under different stages of forest cultivation and cropping. The study will improve our understanding of the changes in soil stability indices that may serve as early indicators of soil recovery or degradation.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study was carried out on soils under selected land use/ management at the University of Port Harcourt environment (Land 4^0 45^1 N, long 7^0 15^1 N). The soil is derived from the Coastal plain sands and classified as Arenic acrisol (USDA, 2012), dominated by kaolinite and oxides of Fe and Al. The climate is of the tropical hot, humid climate. The mean annual minimum and maximum temperatures are 28°C and 30°C respectively, with total annual rainfall of about 2400 mm (NIMET, 2014).

Site Selection and Sampling

Site selection was based on the overall land use type and management common in the area, and each land use occupied an area not less than 25 hectares. Five (6) land use/ management types were selected viz: (1) 10-year cultivated cassava plots (Cassava), (2) 10-year cultivated maize plots (Maize), (3) Plantain plantation, characterized with guinea grass (P*anicum maximum*) as undergrowth (Plantain), (4) 10-year rubber plantation dominated by siam weed (C*hromoleana odorata)*, goat weed (*Ageratum conyzoides*) and guinea grass (Rubber), (5) 10-year oil palm plantation, characterized with *Imperata cylindrica* and siam weed (*Chromoleana odorata*) (Oil palm) and (6) Plots under Calapo (*Calapogonium mucunoides*) fallowed for 2- cropping seasons (Cover crop). Based on landform characteristics, such as the influence of slope, each land use area was divided into four (4) replicates measuring 50 m x 50 m.

Ten (5) disturbed, and undisturbed soil samples were collected from each replicate plots at random on the surface 0-15 cm and grouped to obtain 5 replicate composite bulk samples. The undisturbed soil samples were collected at similar depth using a 6 cm × 5 cm (height x diameter) metal ring. A total of 120 bulk and core samples were collected and taken to the laboratory for analyses.

Determination of Particle-size Distribution and Micro-aggregate Stability Indices

Particle-size distribution was determined by the hydrometer method of Gee and Bauder (1986), using sodium hexametaphosphate as a dispersion agent. The clay and silt obtained from particle-size analysis after complete dispersion with sodium hexametaphosphate was regarded as total clay (TC) and total silt (T silt), while clay and silt obtained with water were water-dispersible clay (WDC) and water dispersible silt (WDS) respectively.

Micro-aggregate stability indices were measured by the procedures of Dong *et al*., (1983) calculated as:

$$\text{Dispertion ratio (DR)} = \frac{WDS+WDC}{Tsilt+Tc} \quad (1)$$

$$\text{Clay dispersion index (CDI)} = \frac{WDS}{Tc} \quad (2)$$

Aggregated silt and clay (ASC) = (TC + Tsilt) - (WDC + WDS) (3)

$$\text{Clay flocculation index (CFI)} = \frac{(TC-WDC)}{TC} \quad (4)$$

The higher the values of DR and CDI, the greater is the tendency of the soil to disperse upon contact or slaking with water, i.e ., aggregate stability is lower when dispersion ratio (DR) and clay dispersion index (CDI) are high. The higher the value of CFI and ASC, the greater the soil aggregation at micro-aggregate level (Igwe and Nwokocha, 2006).

Determination of Saturated Hydraulic Conductivity and Water-stable Aggregates

Saturated hydraulic conductivity was measured by the constant-head permeability test procedure of Klute and Dirkksen (1986) and calculated using the transport Darcys equation for vertical flow of liquid and calculated as:

$$\text{Ksat} = \frac{Q}{AT} \ x \ \frac{L}{\Delta H} \quad (5)$$

Where, Ksat is the saturated hydraulic conductivity, Q the volume of water that flows through a cross-sectional area, A the cross-sectional area of the core , T is the time elapse, L the length of core and ΔH the hydraulic head difference.

Aggregate stability was measured by the mean weight diameter (MWD) of water stable aggregates as described by Kemper and Rosenau (1986), and calculated as:

$$\text{MWD} = \sum_{i=0}^{n} \text{XiWi} \quad (6)$$

Where X_i is the mean diameter of any particular size range of aggregation separated by wet-sieving and Wi the weight of aggregates in that size range as a fraction of total dry weight of sample analyzed. Soil samples for measurement of aggregate stability were sieved through 4.75 mm mesh and wet-sieved using a nest of sieves of diameter 2, 1, 0.5, and 0.25 mm.

Determination of Bulk Density, Water Holding Capacity, Total Porosity, and Organic Carbon

Bulk density was determined using the method of Grossman and Reinsch (2002) after oven-drying the soils at 105° C with and calculated as:

$$\text{Bulk density} = \frac{\text{Mass of oven-dried soil}}{\text{Volume of bulk soil}} \quad (7)$$

Water holding capacity at saturation (0 kPa) tension after 24hours was calculated using the formula:

$$WHC = \frac{Mw - Md}{MD} \quad (8)$$

Where WH·C is the water holding capacity, M_d is the mass of oven-dried soil and M_w the mass of wet soil. Total porosity was determined using the method described by Flint and Flint (2002) using the equation:

$$\%\ Total\ porosity = \frac{\text{volume of water at 0 kPa}}{\text{volume of bulk soil}} \times \frac{100}{1} \quad (9)$$

Soil organic carbon (SOC) was measured by digestion in chromic acid, and the excess was titrated against ferrous ammonium sulphate after the addition of concentrated phosphoric acid (Nelson and Sommers, 1996).

2.2 Data Analysis

Analysis of variance (ANOVA) was used, followed by multiple comparisons on the measured parameters using the SAS Software (SAS, 2001). Means were separated according to the least significant difference using Fisher's protected test (Gomez and Gomez, 1984) at 5% probability.

3. Results and Discussion

The soil is sandy loam to sandy clay loam (Table 1). Mean sand, silt, and clay contents are 624, 197 and 179 g kg $^{-1}$ respectively. Bulk density ranged between 1.41 g cm^{-3} in a cover crop to 1.64 g cm^{-3} in oil palm soils. In the whole, bulk density was in the order of cover crop < cassava < maize < plantain < rubber < oil palm. The 2-year fallow with *Calapogonium mucunoides* showed significant ($p < 0.05$) improvement in the soil bulk, consistent with the previous knowledge that build up of organic matter when the land was allowed to rest increased soil aggregation and reduced soil bulk density (Tisdall, 1996; Sung, 2012).

Table 1: Some Physical Properties of Soils under the Land use Types

Land use	**Sand (g kg^{-1})**	**Silt (g kg^{-1})**	**Clay (g kg^{-1})**	**Textural class**	**Bulk density (g cm^{-1})**
Oil palm	638	174	188	SL	1.64
Rubber	618	234	148	SL	1.61
Cassava	658	174	168	SL	1.54
Maize	608	184	208	SCL	1.56
Cover crop	558	234	208	SCL	1.41
Plantain	668	184	148	SL	1.58
LSD (0.05)	114	NS	NS		0.22

NS- non-significant at $p > 0.05$

Micro Aggregate Stability Indices

The highest value of aggregated silt and clay (ASC) which is a measure of soil aggregation was found in cover crop (*Calapogonium mucunoides*) soils, followed by the soils under oil palm (Table 2). Higher values of ASC indicate greater micro-aggregate stability. The trend was in the order of cover-crop > oil palm > Plantain > Rubber > Cassava > Maize. Furthermore, the highest clay dispersion index (CDI) value of 0.61 g g-^{1} was found in Rubber soils followed by cassava plots with mean CDI value of 0.46 g g-^{1}. These values were 85% and 39.4% respectively, higher than values obtained in continuously cultivated maize plots.

Clay flocculation index (CFI) which indicates micro-aggregate stability was significantly ($p < 0.05$) higher in cover crop plots than the other land use types. Values ranged between 0.41 g g^{-1} in plantain soils and 0.69 g g^{-1} in cover crop. This explained that *Calapogonium mucunoides* used as cover crop improved micro-aggregate stability through enhancement of ASC and CFI. The low CFI values of 0.41 g g^{-1} and 0.54 g g^{-1} found in plantain and 10-year maize cultivation soils respectively, further explained their insignificant roles in improving the micro-aggregate stability of soils. Significant low values of ASC and CFI, and higher values of CDI and DR found in maize and cassava soils were indications of adverse effects of continuous cultivation on soil structural indices. This is consistent with studies of Biswas and Mukherzee (2014); Udom *et al.* (2013).

Higher values of ASC and CFI found in cover crop soils confirmed the beneficial roles of *Calapogonium mucunoides* in short-season fallow when the soil was continuously cropped to maize and cassava. This is because parameters such as ASC, CFI and saturated hydraulic conductivity (Ksat) are commonly used as estimates of soil structural stability. On the other hand, CDI and DR, are estimates of soil dispersion (Udom *et al.,* 2016; Udom *et al.*, 2018). The higher values of CFI and ASC found in *Calapogonium mucunoides* and oil palm soil were indications of higher or better stability of the soils (Igwe *et al.*, 2006) while a higher value of DR found in rubber, cassava and plantain soils were an indication of low structural stability. In the whole, CFI values > 50 % and relatively low DR in Table 2 showed that the soils were moderately stable and less prone to dispersion.

Table 2: Micro-aggregates Stability indices and Saturated Hydraulic Conductivity of the soils

Land use	ASC (%)	CDI (gg^{-1})	CFI (gg^{-1})	DR (%)	Ksat (cm hr^{-1})	Permeability class
Oil palm	20	0.33	0.69	44	27.91	Moderately rapid
Rubber	17	0.61	0.61	58	4.94	Very slow
Cassava	16	0.46	0.54	53	34.9	Rapid
Maize	14	0.39	0.52	37	24.7	Moderately rapid
Cover crop	22	0.35	0.69	21	34.3	Rapid
Plantain	18	0.39	0.41	55	9.73	Slow
LSD (0.05)	3.88	0.16	0.14	12.11	13.41	

ASC- aggregated silt and clay, CDI- clay dispersion index, CFI- clay flocculation index, DR- dispersion ratio, Ksat- saturated hydraulic conductivity

Aggregate Stability, Organic Carbon, Water content and Total Porosity

Water stable aggregates (> 0.25 mm) were 73, 56, and 55 % in cover crop, continuous cultivated cassava and maize plots respectively (Table 3). Mean weight diameter (MWD) of water stable aggregates was significantly ($p < 0.05$) higher in soils under short-term fallow with cover crops. Previous studies (Udom *et al.,* 2018; Udom *et al.,* 2013) discussed the positive roles of soil cover on hydraulic and structural properties of soils and found that fallow periods help the soil to recover nutrient that was lost due to continuous cropping.

Results in Table 4 showed that the soil was generally highly porous to extremely porous with values ranging from 46.3% to 28.5%. Total porosity was significantly higher in cover crop soils. The contrast observed between total porosity and Ksat, and bulk density was not surprising, because pore-size distribution rather total porosity was adequate to relate these properties. This study agreed with Igwe and Wokocha (2006), and Udom and Adesodun (2016), that aeration capacity of soils was related the ratio of macro- to micro-porosity showed a positive trend with Ksat and bulk density.

Table 3: Water stable Aggregates and Aggregate Stability of the Soils

	Aggregate size class (mm)					
Land Use	**4.75-2.0**	**2.0-1.0**	**1.0-0.5**	**0.5-0.25**	**<0.25**	**MWD (mm)**
Oil palm	5.0	9.0	17.0	31.0	38.0	0.643
Rubber	4.0	7.0	10.0	38.0	41.0	0.560
Cassava	7.0	7.0	11.0	30.0	45.0	0.649
Maize	6.0	8.0	10.0	32.0	44.0	0.590
Cover crop	10.0	19.0	21.0	23.0	27.0	0.933
Plantain	6.0	9.0	17.0	37.0	31.0	0.682
LSD (0.05)	3.67	2.81	2.66	9.63	19.8	0.114

MWD- Mean weight diameter

Table 4: Total Porosity, Water holding Capacity and Organic matter content of the Soils

Land use	**Total porosity (%)**	**WHC (g g^{-1})**	**OC (g kg^{-1})**	**Remarks[a]**
Oil palm	28.5	0.22	17.8	Highly porous
Rubber	32.6	0.24	14.4	Highly porous
Cassava	44.7	0.32	18.1	Extremely porous
Maize	41.2	0.28	17.9	Extremely porous
Cover crop	46.3	0.39	18.8	Extremely porous
Plantain	33.2	0.31	17.2	Highly porous
LSD (0.05)	9.41	NS	2.35	

a- Pagliai (1988) classification, WHC- water holding capacity, OC- organic carbon

Relationships among Micro- and Macro- Aggregate Stability Indices

Relationships showed that water stability of aggregates measured by the mean weight diameter (MWD) and ASC was positively related with CFI and Ksat (r = 0.684, 0.611 and 0.527) respectively ($p < 0.05$) (Table 5). Significant positive correlation between MWD and ASC implied that soil air capacity and water movement within the soil would be improved. Clay dispersion index (CDI) showed significant ($p < 0.05$) negative relationships with MWD, Ksat and CFI (r = -0.624, -0.592, and -0.601) respectively, ($p < 0.05$). Similarly, DR showed a negative correlation with MWD and Ksat, confirmed that the higher the CDI and DR, the greater the tendency of the soil to disperse. Reduced values of CDI would mean increased soil aggregation, macro-aggregate stability, and improved soil air diffusion. Clay flocculation index (CFI) was highly correlated with ASC, contributing more than 70 % in micro-aggregate stability.

Table 5: Relationships between Some Structural and Micro-aggregate Stability indices

Correlation coefficient (r) N = 30						
Soil properties	**ASC (%)**	**CDI ($g\ g^{-1}$)**	**CFI ($g\ g^{-1}$)**	**DR (%)**	**Ksat ($cm\ hr^{-1}$)**	**MWD (mm)**
MWD (mm)	0.684*	-0.624*	0.611*	-0.651*	0.527*	--
Ksat ($cm\ hr^{-1}$)	0.658*	-0.592*	0.638*	-0.596*	--	
DR (%)	-0.537*	0.642*	-0.474	--		
CFI ($g\ g^{-1}$)	0.710**	-0.601*	--			
CDI ($g\ g^{-1}$)	-0.494	--				
ASC (%)	--					

*Significant at $p < 0.05$, ** significant at $p < 0.01$

4. Conclusion

Conclusions drawn in this study are that land use and management affected micro-aggregate stability indices and distribution of size fractions. The small aggregate fractions formed large aggregate fractions by combining with organic matter. Increased soil organic carbon concentrations were closely linked with the formation of macro-aggregates. In relation to land use and management, 10-year rubber plantation and 10-year continuous cassava cultivation decreased micro-aggregate stability by 85 % and 39 % respectively compared to 2-season fallow with *Calapogonium mucunoides*. Total porosity and saturated hydraulic conductivity as ecological indices were significantly improved after 2-year fallow of the soil with *Calapogonium mucunoides*. 10-year continuous cultivation did not show a significant decrease in micro-aggregate stability indices. Oil palm plantation maintained increases in structural and hydraulic indices of the soils. Therefore, 2-year fallow with *Calapogonium mucunoides* and 10-year oil palm plantation significantly maintained the soil micro- and macroaggregate stability indices. They could be used for arable crop production to conserve the soil and reduce the degradation of soil resources

References

Abrishamkesh, S., Gorji, M. and Asadi, H. (2011). Long-term effects of land use on soil aggregate stability. *International Agrophysics* 23:103-108.

An, S. S., Mentler, A., Mayer, H. and Blum, W.E.F. (2010). Soil aggregation, aggregate stability, organic carbon and nitrogen in different soil aggregate fractions. *China* 81: 226-233.

Barthes, B. and Roose, E. (2002). Aggregate stability as an indicator of soil susceptibility to runoff and erosion: Validation at several levels. *Catena* 47, 133–149.

Beare, M. H., Hendrix, P .F. and Coleman, D. C. (1994). Water-stable aggregates and organic matter fractions in conventional and no-tillage soils. *Soil Sci. Soc. Amer. J.* 58:777-786.

Dikinya, O, Hinz, C., Aylmore, G. (2006). Dispersion and re-deposition of fine particles and their effects on saturated hydraulic conductivity. *Aust. J. Soil Res.* 44:47-56.

Dong, A., Chesten, A. and Simsiman, G. V. (1983). Soil dispersibility . *Soil Science* 136:208-212.

Flint, L. E. and Flint, A. L. (2002). Pore Size- Distribution. In: Dane, J. H., and Top, G.C.(ed) *Methods of Soil Analysis Part 1. Physical Methods*. Soil Science Society of America. Madison, W.I. pp 246- 253.

Gee, G. W. and Bauder, T. W. (1986). Particles-size analysis. In: Klute, A. (editor). *Methods of Soil Analysis. Part I. Physical and Mineralogical Methods,* (2nd ed.) Agronomic Monograph 9, pp 91-100. ASA and SSSA, Madison, WI

Grossman, R. B. and T. G. Reinsch, (2002). Bulk density and linear extensibility. In: *Methods of Soil Analysis, Part 4: Physical Methods,* Dane, J.H. and G.C. Topp (Eds.). Chapter 2, ASA and SSSA., Madison, WI., USA., pp: 201-228.

Gomez, K. A. and Gomez, A. A. (1984). Statistical Procedures for Agricultural Research, 2nd ed. Int. Rice Inst. John Wiley and Sons, New York, Toronto , Singapore, pp 643.

Igwe, C. A., Zarei, M. and Stahr, K. (2006). Clay disper sion of hard setting Inceptisols in Southern Nige ria as influenced by soil components. *Communi cations in Soil Science and Plant Analysis* 37:751 -760

Kemper, W. D. and Rosenau. R. C. (1986). Aggregate Stability and Size Distribution. In: Klute, A. (ed.). *Methods of Soil Analysis. Part* 1. 2nd ed. Agron. Monogr . 9. ASA, Madison, WI. p. 425-442.

Klute, A. and Dirksen, C. (1986). Hydraulic conductivity and diffusivity, laboratory methods. In: Klute, A. (ed.). *Methods of Soil Analysis, Part I. Physical and Mineralogical Methods*. *Agron. Monogr*. 9:687-734.

Lal, R. and Stewart, B. A. (2012). Aggregate stability and aggregate size information. In: Lal, R. (Ed.), *Encyclopedia of Soil Science* (2nd ed.), Taylor and Francis, 40-44.

Nelson, D. W., and Sommers, L. E. (1996). Total Carbon, Organic Carbon and Organic Matter. In: *Methods of Soil Analysis. Part 3. Chemical Methods*, Sparks, D.L. (Eds.). American Society of Agronomy/Soil Science Society of America, Madison, WI. p. 961-1010.

NIMET- Nigeria Metrological Agency (2014). Annual report 2014- Port Harcourt , Nigeria pp539-579

Obalum, S. E.. Igwe, C. A., Obi, M. E. and Wakatsuki, T. (2012). Using selected structural indices to pin point the field moisture capacity of some coarse-textured agricultural soils in Southeastern Nige ria. *Journal of Tropical Soil* 6:151-159.

Obi, M. E, Salako, F. K. and Lal, R. (1989). Relative sus ceptibility of some Southeastern Nigeria soils to erosion. *Catena*, 16: 215-225.

Opara, C. C. (2009). Soil-microaggregates stability under different land use types in South-eastern Nigeria. *Catena* 79:103-112.

Pagliai, M. (1988). Soil porosity aspects. *Int. Agrophysics*, 4:215-232.

SAS- Statistical Analysis system (2001). Institute SAS/ *STAT Users Guide,* 4th ed. Vol.1.InstituteCary, N.C., USA

Sung, C. T. B. (2012). Aggregate stability of tropical soils in rela tion to their organic matter constituents and other soil properties. *Pertanika Journal of Tropical Agricultural Science*. 35:135-148.

Tisdall, J. M. 1(996). Formation of soil aggregates and accumu lation of soil organic matter. In: *Structure and Organic Matter Storage in Agricultural Soils* (eds. Carter, M. R., Stewart, B. A.). Advances in Soil Science. CRC Press, Boca Raton, FL. Pp. 57-96.

Udom, B. E., Omovbude, S. and Wokocha, C. C. (2013). Effects of organic wastes applications on macro and micro-aggregate stability indices of a sandy soil and maize performance. *Niger. Agric. J*. 44:15-23.

Udom, B. E. and Adesodun, K. A. (2016). Soil penetrating quali ty in cultivated and forested coastal plain sands of Southern Nigeria. *Archives of Agronomy and Soil Sci ence.* 62(7): 963-971.

Udom, B. E., Omovbude, S. and Abam, P. O. (2018). Topsoil removal and cultivation effects on structural and hydrau-lic properties. *Catena* 165:100-105

USDA (United States Department of Agriculture) (2012). Soil Taxonomy, USDA-NRCS, Washington, D.C.

Yan, F., Shi, Z., Li, Z. and Cai, C. (2009). Estimating inter rill soil erosion from aggregate stability of Ultisols in sub tropical China. *Soil Till. Res*. 100:34-41.