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MICROAGGREGATE STABILITY AND SESQUIOXIDES CONTENT OF DEGRADED ULTISOL UNDER DIFFERENT SOIL AND CROP MANAGEMENT PRACTICES IN NSUKKA, SOUTHEASTERN NIGERIA

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ABSTRACT

Evaluating microaggregate stability and sesquioxides content of degraded Ultisol is important for sustainable management and productivity of the soils and our agroecosystem. A research was conducted in the runoff plots at the University of Nigeria Nsukka Teaching and Research Farm, in 2010 and 2011 to evaluate changes in microaggregate stability, and sesquioxides contents of Nkpologu sandy loam soil under different cover and soil management practices. The management practices were bare fallow (BF), grass fallow (GF), legume (CE), groundnut (GN), sorghum (SM), and cassava (CA) cultivation. Soil samples for analysis were taken at 0-20 cm depth at the end of each cropping season and five-month interval. There were significant effect ($p<0.05$) of soil and cover management on the sesquioxides (Fe_2O_3 and Al_2O_3) and the organic matter (O.M.) contents. Fe_2O_3 recorded the lowest value (5.88%) under the BF while the highest value (10.18%) was recorded under SM. However, the lowest value (0.265%) of Al_2O_3 was recorded under GN, and the highest value (0.345%) was recorded under CA. Although, the soil and cover management practices did not have significant effect ($p<0.05$) on the microggregate stability indices; water dispersible silt (WDSi) and clay (WDC), clay flocculation index (CFI), dispersion ratio (DR), aggregated silt and clay (ASC), and clay dispersion index (CDI) measured, there were traces of variability (CV 16-31%) in the microaggregate stability indices under the different soil and cover management practices. The most varied index was WDSi (CV 30.8%) while the least varied index was DR (CV 16%).Both Fe_2O_3 and O.M. had significant high positive correlation with DR (0.6658; 0.7615) and CDI (0.6068; 0.5360), but significant high negative correlation with ASC (-0.7675; -0.6918) and CFI (0.6068; -0.5360) respectively. However, while Fe_2O_3 had significant high positive correlation with WDC, O.M. content had a poor positive correlation with WDC. On the other hand, Al_2O_3 had poor correlation with all the microaggregate stability indices studied. The sesquioxides and O.M. had similar but opposite correlation coefficients with CDI and CFI respectively. It was clear that O.M. and Fe_2O_3 played major role in the microaggregation of the soil studied. A continuous vegetative cover management practices and adequate crop residue management were recommended for this soil, due to its fragile nature to minimize further structural degradation and further leaching of the basic cations in the soil which affects the sesquioxides and O.M. contents.

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INTRODUCTION

Evaluating microaggregate stability and sesquioxides content of degraded Ultisol is important for sustainable management and productivity of the soils and our agroecosystem. Soil structural stability affects the productivity and sustainability of agricultural systems, and natural environments through soil erosion, and consequently loss of soils and nutrients. Soil aggregate structure and aggregate stability are important factors that contribute to sustainable soil quality and soil erosion potential (Barthes and Roose, 2002; Shepherd *et al.*, 2002; Bronick and Lal 2005). Soil aggregate/structural stability may be defined as a measure of the ability of the soil structural units to resist change or the extent to which they remain intact when mechanically stressed by environmental factors (Encyclopedia of Soil Science, 2008) mainly climate and soil characteristics. Microaggregate stability indices serve as sensitive indicators of soil degradation (Boix-fayos, 2001), and are very important in the processes of infiltration, sealing and crust formation, runoff and soil erosion (Levy and Miller, 1997). It has been widely reported that the major microaggregating agents in tropical soils are Fe and Al oxides (Alekseeva *et al.*, 2009; Yan *et al.*, 2008; Igwe, 2005; Igwe *et al.*, 2009). Numerous studies have shown that soil properties can change under various land use (Oguike and Mbagwu 2009) or management techniques.Land use according to Mbagwu and Auerswald (1999) influence structural stability more than other intrinsic soil properties. Some authors adjudged microaggregates to be more stable and less affected by management than macroaggregates (Edwards and Bremner, 1967; Tisdall and Oades, 1982). However, the fact that

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microaggregates are more stable and less affected by management than macroaggregates may hold true due to the sensitivity of the later to organic matter content (Sung *et al*., 2012; Tisdall and Oades, 1982) but not absolute in all cases. An assessment of microaggregate stability under different land use types in some Nigerian tropical soil revealed the strong dependence of soil microaggregation on land use (Opara, 2009; Obi, 1982). This suggests that agents of stabilization of microaggregates in tropical soils are sensitive to land use. While numerous studies may have reported the effect of land use and organic matter on microaggregation, little is known about the effect of crops and soil management practices on sesquioxides contents and microaggregate stability. Growing concerns regarding adverse effects of intensive crop management on soil quality have kindled an interest in identifying cropping systems that maintain desirable soil quality and productivity. The search for the most appropriate combination of crop and or soil management practices suitable for different ecological zones in Nigeria should be intensified especially on fragile Ultisols of southeastern Nigeria. Despite the fragile nature of this soil, indiscriminate deforestation, inappropriate land use and non-sustainable soil management options are common features of agriculture in the region. Better soil management and conservation option for sustainable agricultural production is imperative for restoration of these badly degraded soils. Investigating how different soil and crop management practices affect the microaggregate stabilityand sesquioxides contents of degraded ultisols will give insight on appropriate soil management practices in the region. Thus, the objective of this study is to evaluate the influence of different soil and crop management practices on microaggregate stabilityand sesquioxides contents of a degraded Ultisols and the sensitivity of different microaggregate stability indices to sesquioxides and organic matter contents.

MATERIALS AND METHODS

Site description

The study was carried out at the University of Nigeria Nsukka Teaching and Research Farm located between latitude $06^{o}\ 52^{\prime}$N and longitude $07^{o}\ 24^{\prime}$ E on runoff plots established in 1973. The area is characterized by a humid tropical climate with wet and dry season (Obi, 1982). The rainfall is bimodally distributed with annual total of about 1750mm. The average annual rainfall is estimated to be 800 mm. The mean annual temperature is 27^{o} C with minimum and maximum of 21^{o} C and 31^{o} C respectively (UNN meteorological station). The runoff plots, each 20 x 3 m, were located on a 5% slope with mean elevation of 400m above sea level. The study was established to monitor microaggregate stability and sesquioxide contents of degraded Ultisol under different soil/crop management practices. The soil is an Ultisol (Acrisol, FAO; sol ferrallitique, French system) belonging to the Nkpologu series. It is deep, porous, and red to brownish red and derived from sandy deposit of false bedded sand stones, classified as Typic Paleustult (Nwadialo, 1989).

Field methods/ crop establishment

The experimental layout was a completely randomized design (CRD) and the treatments imposed were replicated four times (Fig 1). Cassava, groundnuts, sorghum and centrosema were used as test crops. The test crops were grown with 10 tons/ha poultry droppings during crop establishment in 2010, while the bare fallow and grass fallow remained untilled with no amendment. Groundnut seeds were sown at a rate of two seeds per hole and at a planting distance of 45 cm by 30 cm. Sorghum seeds were sown at the rate of four seeds per hole at a planting distance of 70 cm by 30 cm and later reduced to two. Cassava cuttings of length 25 cm was planted 15 cm deep into the soil at a rate of one cutting per hole and at a planting distance of 1 m by 1 m. The Centrosema seeds were established by broadcasting the seeds on the soil surface after tillage and fresh supplies were made in areas where germination failed to occur. Groundnut and sorghum were harvested at five and six months after planting respectively and replanted in 2011 without amendments. Cassava was harvested at twelve months after planting while centrosema was not harvested.

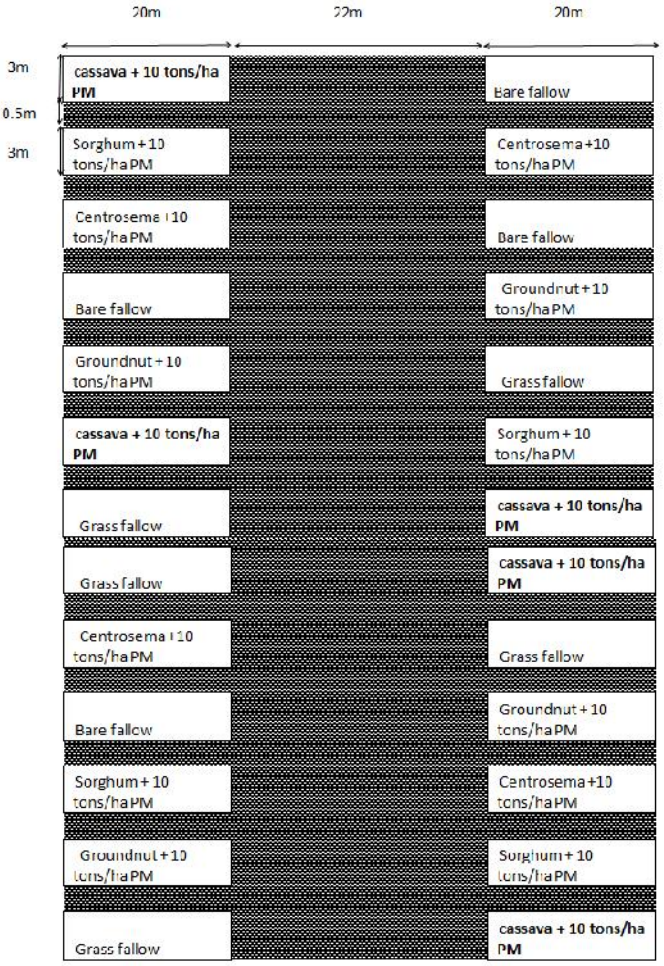

Fig. 1. Field or experimental layout of the runoff plots at the study location
PM= Poultry Manure

Measurement of soil physical properties

Soil samples were collected at the depth of 0-20 cm in each site, air dried, and sieved through a 2 mm mesh. Samples that passed through the 2 mm sieve were used to determine particle size distribution, sesquioxides and organic matter contents.

Laboratory Methods

The particle size distribution of the < 2 mm size fraction of calgon-dispersed soil samples was determined by the hydrometer method described by Gee and Or (2002).Organic carbon was determined on the air dried, 2mm sieved samples at 0-20cm from each location according to the Nelson and Summer (1982) method. The organic matter content was obtained by multiplying values of organic carbon by a factor of 1.724.Dithionite-citrate-bicarbonate Fe and Al were determined by the extraction method of Mehra and Jackson (1960). Water dispersible clay (WDC) and silt (WDSi) was determined by dispersing soils in distilled water only and determining the particle size by the hydrometer method described by Gee and Or (2002). The indices of microaggregate stability were calculated using the relationships stated below:

Dispersion ratio (DR) = [% silt + clay (H_2O)] / [% silt + clay (calgon)]
Aggregated silt and clay (ASC) = [% silt + clay (calgon)] - [% silt + clay (H_2O)]
Clay flocculation index (CFI) = [% clay (calgon) - % clay (H_2O) / % clay (calgon)] X 100
Clay dispersion index (CDI) = [% clay (H_2O) / % clay dispersed)] x100

Statistical Analysis

The analysis of variance (ANOVA) for a completely randomized design (CRD) was carried out using a Genstat Discovery Edition version 5.0 (GENSTAT, 2003) on windows 7 to compare the influence of soil and crop management system on the measured soil properties. The mean difference of the effects of different crop growth on microaggregate stability were separated using the Fischer's least significant difference (F-$LSD_{0.05}$) as described by Obi (2002). Correlation between microaggregate stability indices, organic matter content, and sesquioxides was done to ascertain their contribution to microaggregate stability.

RESULTS AND DISCUSSION

Microaggregate Stability Indices

The water dispersible clay (WDC), water dispersible silt (WDSi) and dispersion ratio (DR) are used as estimates of the rate of dispersibility of the soils. The results show that the soils were moderately stable and moderately dispersive (Table 1). This was confirmed by the report of Igwe *et al.*, (2009) that soils with low WDC, WDSi and low to moderate DR were stable and less erodible. The results also show moderate to high values of ASC and CFI which imply greater stability, and moderate values of DR and CDI indicate moderate stability. The moderate dispersion of the soils was reflected on the relatively high microaggregate stability indices such as CFI (Table 1). The results showed non-significant effect of the various cover management practices on indices of stability such as DR, ASC, WDSi, CDI, WDC and CFI. Oguike and Mbagwu (2009) found significant effect of land use types on these properties. However, the non-significant effect observed in this study could be because these indices to some extent are determined/controlled by the intrinsic properties of soil such as texture especially clay and silt content which rarely change especially within short-term period. This can be further buttressed by the fact that treatment effects on water dispersible clay (WDC) and silt (WDSi) remained non-significant throughout this study. There was no appreciable difference or variability in the structural indices due to cover management as seen from the CV (13.4%). Moreso, all the indices of microaggregate stability were not significantly affected ($P<0.05$) by the interaction of sampling period and cover management practices. This implies that these properties are intrinsic and are therefore, dependent mostly on the nature of the soil rather than the management practices. However, the results show that breakdown of macroaggregates was less under various cover management practices compared to the BF without protection. Thus, most cases of low stability observed in these soils can be linked to a combination of anthropogenic factors such as deforestation and land use, the nature of the soil and the high rainfall regime with high intensity. Mbagwu and Bazzoffi (1998) reported that the sandy nature of most tropical soil parent material, and decreased clay contents militate against their stability. Again, most tropical soils have long weathering history as is often evident in their low silt content (Igwe, 2011), and this also contributes to frustrating aggregation processes in the soils. This is true for the soils as shown from their textures which were mainly sandy loam with low silt content (Azuka and Obi, 2012). Igwe (2011) reported that most soils occurring in areas with heavy rainfall, even when not originally sandy, have been so intensively washed by runoff and leaching that their texture tends toward coarseness. Mbagwu and Bazzoffi (1998) also reported that the resistance of soil aggregates to raindrop impact decreases with a decrease in clay content of the soil. The result also shows that sampling period was significant ($P<0.05$) on ASC, CFI, and DR. This implies that the factor which influences these microaggregate stability indices changes with time, leading to changes in microaggregate stability of the soils with time. This may further influence the rate of formation of macroaggregates from microaggregates.

Sesquioxides (Iron and Aluminium oxide) contents

The concentration of iron oxide (Fe_2O_3) was higher than that of aluminum oxide (Al_2O_3) in the soil studied (Table 1). The values of Fe_2O_3 ranged from 5.88 % to 10.18 % while the values of Al_2O_3 ranged from 0.265 % to 0.345 %. Igwe *et al.* (1999) noted that extensive leaching of the basic cations from the solum resulted in the low concentration of secondary minerals such as Fe_2O_3 and Al_2O_3. This is true more for Al_2O_3rather than Fe_2O_3 as seen from the study. The cover management practices significantly ($P<0.05$) affected the quantity of Fe and Al oxides contents present in the soil. The highest value of Fe_2O_3 (10.18) was obtained under Sorghum plot while the least value (5.88 %) was obtained under the bare fallow. For Al_2O_3content, the highest value (0.345 %) was obtained under the cassava plot while the lowest value (0.265 %) was obtained under the groundnut plot. The sampling period had no significant effect on the quantity/concentration of Fe and Al oxides contents (Table 2). This implies that the sesquioxides are intrinsic properties of soil which rarely changes with time especially within short-term period.

Table 1. `Main effect of cover management on some selected soil properties

MS	O.M (g/kg)	WDSi	WDC	ASC	CDI	CFI	DR	Fe_2O_3 (%)	Al_2O_3 (%)
Bare fallow	9.9	5.28	6.32	14.73	34.7	65.3	0.44	5.88	0.322
Centrosema	13.5	5.28	6.32	12.9	39.7	60.3	0.48	7.56	0.301
Groundnut	13	5.11	6.65	12.23	40.2	59.8	0.5	9.36	0.265
Sorghum	13.8	4.45	6.99	13.23	43.1	56.9	0.47	10.18	0.285
Cassava	11.8	3.95	6.99	12.9	45.5	54.5	0.46	7.77	0.345
Grass fallow	11.9	4.28	6.65	13.57	40.8	59.2	0.45	7.79	0.272
CV%	15	30.8	19.8	20.1	23.4	16	16.1	16.5	22.1
$LSD_{0.05}$	0.15	NS	NS	NS	NS	NS	NS	1.103	0.055

MS= management system, O.M. = organic matter, WDC= water dispersible clay, ASC= aggregated silt and clay, CDI= clay dispersion index, CFI= clay flocculation index, DR= dispersion ratio, Fe_2O_3= Iron oxide, Al_2O_3= Aluminium oxide, $LSD_{0.05}$= least significant difference at 5% probability level, NS= not significant

Table 2. Effects of sampling period and cover management on some selected soil properties studied

S. period	MS	O.M (g/kg)	WDC	ASC	CDI	CFI	DR	Fe_2O_3 (%)	Al_2O_3 (%)
	BF	11.4	6.48	15.49	38.3	61.7	0.42	5.87	0.345
	CE	13.3	6.48	13.24	40.7	59.3	0.45	8.92	0.325
1	GN	10.5	6.98	13.24	41.3	58.7	0.48	9.36	0.272
	SM	15.4	7.48	17.24	40.7	59.3	0.40	10.18	0.336
	CA	12.4	6.98	15.74	41.6	58.4	0.38	7.20	0.263
	GF	9.7	6.98	15.24	40.4	59.6	0.41	7.61	0.273
Mean		1.15	6.90	15.03	40.5	59.5	0.42	8.04	0.302
	BF	10.7	6.48	14.46	35.3	64.7	0.44	5.60	0.325
	CE	13.6	6.48	12.96	43.2	56.8	0.47	7.50	0.302
2	GN	10.5	6.48	10.96	40.9	59.1	0.51	9.52	0.260
	SM	12.8	7.48	10.46	50.6	49.4	0.53	10.44	0.283
	CA	11.9	6.98	10.96	53.5	46.5	0.53	7.73	0.351
	GF	12.3	6.48	12.96	43.6	56.4	0.44	7.75	0.269
Mean		1.29	6.73	12.13	44.5	55.5	0.49	8.09	0.298
	BF	7.8	6.00	14.25	30.5	69.5	0.47	6.16	0.296
	CE	13.6	6.00	12.50	35.2	64.8	0.50	6.27	0.277
3	GN	13.1	6.50	12.50	38.3	61.7	0.50	9.76	0.261
	SM	13.1	6.00	12.00	38.0	62.0	0.48	10.26	0.236
	CA	11.1	7.00	12.00	41.4	58.6	0.48	8.37	0.422
	GF	13.6	6.50	12.50	38.5	61.5	0.49	8.00	0.275
Mean		1.25	6.33	12.62	37.0	63.0	0.49	8.14	0.294
$LSD_{0.05}$	Period(P)	NS	NS	1.542	NS	5.5	0.04	NS	NS
	P x MS	0.262	NS	NS	NS	NS	NS	NS	0.095

S= sampling, MS= management system, O.M. = organic matter, WDC= water dispersible clay, ASC= aggregated silt and clay, CDI= clay dispersion index, CFI= clay flocculation index, DR= dispersion ratio, Fe_2O_3= Iron oxide, Al_2O_3= Aluminium oxide, $LSD_{0.05}$= least significant difference at 5% probability level, NS= not significant

Table 3. Correlation of sesquioxides and O.M. with microaggregate stability indices

CDI	0.1098						
CFI	-0.1098	-1.0000					
DR	-0.4888	0.2658	-0.2658				
Fe_2O_3 (%)	-0.5656	0.6068	-0.6068	0.6658			
O.M. (g/kg)	-0.4961	0.5360	-0.5360	0.7615	0.8283		
WDC	0.0574	0.8739	-0.8739	0.1009	0.6675	0.3413	
WDSi	-0.2159	-0.8172	0.8172	0.2766	-0.2842	-0.0591	-0.8433
ASC	0.3352	-0.6319	0.6319	-0.8887	-0.6918	-0.7675	-0.3936
	Al_2O_3 (%)	CDI	CFI	DR	Fe_2O_3 (%)	O.M.(g/kg)	WDC

Correlation of sesquioxides and organic matter with the microaggregate stability indices

The correlation of sesquioxides and organic matter contents with the microaggreagate stability indices was done to evaluate their contribution or relationship to microaggregate stability. The results showed that the sesquioxides and organic matter contents had significant effect/contribution to macroaggregate stability (Table 3) of the degraded Ultisol. Both Fe_2O_3 and organic matter had significant high positive correlation with DR (0.6658; 0.7615) and CDI (0.6068; 0.5360), but significant high negative correlation with ASC (-0.7675; -0.6918) and CFI (0.6068; -0.5360) respectively. However, while Fe_2O_3 had significant high positive correlation with WDC, O.M. content has a poor positive correlation with WDC. On the other hand, Al_2O_3 had poor correlation with all the microaggregate stability indices studied (Table 3) especially with WDC (0.0574). This could be attributed to its low concentration in the soil studied (Table 1), and mainly caused by the extensive leaching of the basic cations in the soil typical of highly weathered or degraded soils. The results also showed that Fe_2O_3, Al_2O_3 and organic matter had a similar but opposite correlation coefficients with CDI and CFI respectively. For instance, Al_2O_3 has a correlation coefficient value of 0.1098 with CDI and a value of -0.1098 with CFI (Table 3). The above result show that O.M. content and most importantly the Fe_2O_3 oxide content contributed significantly to the microaggregate stability and otherwise of the degraded Ultisol while the Al_2O_3 had little or no contribution. The result from this study confirm the report of Oades (1990) that the concentration of Fe and Al oxides had to be considerably high (10%) before they could exert any aggregating effect on soils. Where the concentration is low (< 10%), humic acids appeared to dominate the charge on oxide surfaces. Oades (1984) reported that in soils with high amounts of Fe and Al oxides, the contribution of organic matter to aggregate stability is diminished. This further explains why Al_2O_3 had poor correlation with microaggregate stability indices, while O.M.reported to be low and significantly ($P < 0.05$) influenced by different cover management for the soil (Azuka and Obi, 2012) and Fe_2O_3 had better correlation with the microaggregate stability indices studied.

Conclusion

Soil microaggregates were stabilized under vegetative cover management practices. The lack of vegetative cover in the bare fallow plot had serious negative impacts on the sesquioxides contents of the soils, and to lesser extent soil microaggregate stability indices. The organic matter content and the Fe_2O_3 played significant roles to the microaggregate stability of the degraded Ultisol while the Al_2O_3 had little or no contribution. Although, the soil and cover management practices had no significant effect on the microaggregate stability indices, they helped to protect the soil, and lessen the rate of its breakdown. Thus, a continuous vegetative cover management practices and adequate crop residue management are recommended for this soil, due to its fragile nature to minimize further structural degradation and further leaching of the basic cations in the soil. Proper management is necessary to position these soil resources for improved and sustainable agricultural productivity without compromising environmental quality. Incorporation of high quality and quantity of organic materials during tillage operations and use of manure are encouraged.

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