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Relative Structural Developments and Crop Yields in Two Landforms of an Ultisol in Southeastern Nigeria

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Abstract Aggregate stability is an important factor in the functioning of soil due to its ability to controlling plant growth, influence on root penetration, soil temperature, and water transport and seedling emergence. Some soil characteristics play important role in improving soil aggregation and hence soil structure. This study evaluated the aggregates between soils of Beach Ridge Sand (BRS) and Coastal Plain Sand (CPS) as well as relating the stable aggregates to variability in soil properties and crop yields. Twelve soil profiles were sunk for the study. The relationship between structural indices; Mean weight diameter (MWD) and Water-stable aggregate from one side and some soil properties on the other side were assessed to compare the relative stable aggregates between the landforms. Structural development of CPS improved maize yield by 67.5 % and cassava 35.3 %. However, significant difference in the aggregate stability between the two landforms was a function of organic C and hydrated Fe oxides. Differences in sand and silt content are not a probable cause of differences in aggregation of these landforms, because these particles usually have low-activity surfaces and very low surface areas compared with clay particles. Calcium contents also influence aggregation, but do not correlate well with any of the aggregation indices in these landforms.

Keywords: *landform, crop yield, stability, erosion, mean weight diameter development*

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1. Introduction

Soil aggregates are formed as a result of flocculation, cementation and arrangement of soil particles [1] and it varies with landform. Understanding soil Aggregation is important because it affects infiltration capacity, hydraulic conductivity, water retention capacity, tilth, gas exchange, organic matter decomposition and erodibility [2].

Soils with stable aggregates at the surface are more resistant to water erosion than soils with less stable aggregates both because soil particles are less likely to be detached and because the rate of water infiltration tends to be higher on well aggregated soils [3]. Soil structure is very important in the top soils because it increases permeability, cut down run off and decreases erosion. It enhances root growth by giving a more permeable soil through which root can move, by increasing the permeability to roots, it increases the effective water holding capacity and give better air relationship in soil aggregate stability [4].

The stabilizing effect of Fe stems from the fact that soluble Fe species act as flocculants while the gelatinous materials act quite independently as cement and thereby stabilizes the aggregates. Aina et al., [5] observed that soils that exhibited oxide characteristics and with high to intermediate free oxide contents were structurally stable to rain drop impact, such soils were not dispersed on quick wetting because of the stability effect of iron oxide. This will reduce erosion, loss of top soils and nutrients, hence increase soil productivity. Most studies investigating soil structural changes compare particle-size distribution after vigorous shaking in standard dispersion solution with treatments that dissolve hydrated Fe oxides. structural bonds between Fe oxides and other soil particles from different landforms are obvious not a subject of such studies.

In recent times, as a result of increased pressure on land in most parts of the zone, the prevalent farming system of intercropping followed by bush fallow that lasts 5 to 10 years or more is no longer the common practice. It has given way to shorter bush fallow that lasts 2 to 3 years and continuous cropping system that are more resource demanding, this has affected crop production significantly, thus resulting in deterioration of the resource base of the soil.

The present experiment was conducted to evaluate indices of soil structural development in different landforms as influences macro aggregation and crop yield. Two landforms of beach reach sand (BRS) and coastal plain sands (CPS) were selected because of differences in

Fe oxide crystalinity to test the hypothesis that differences in oxidation state between the selected soils could cause poorly crystalline oxides which facilitate formation of stable macroaggregates (> 0.25 mm). This test gives a reliable description and ranking of the behavior of soils under the effect of water, wind and soil management. Soil structure is one of the main factors controlling plant growth and crop yields. Therefore, our objectives were (i) to assess the aggregate size distribution under the influence of water erosion between and (ii) to relate stable aggregate to variability in soil properties as its affect crop yield.

2. Materials and Methods

2.1. Experiment of the Study Area

The study was conducted in the beach ridge sands (BRS) and coastal plain sands (CPS) in Akwa Ibom State; which lies between the latitudes $4^0 30^1$ N and longitude $8^0 20^1$ East. Akwa Ibom State is characterized by two seasons, a wet seasons that last for nine (9) months (April – October), and dry season (November-March). The annual rainfall ranges from 2000-3000 mm, while annual temperature varies between 26^0C and 28^0C. Relative humidity is high varying and lowest values in July and January [6].

Akwa Ibom State is subdivided into five (5) contrasting landform region: i) the mangrove swamps and flood plains with recent alluvial accumulations, ii) beach ridge sands; iii) level of gently undulating sandy plains; iv) sandstone hill and ridges with steep- sided valleys; and v) the Obotme Steep-sided isolated hills. The State geomorphic unit consists of long-lying plain and riverine areas with no part greater than 175m above sea level [7]. The geological materials found in Akwa Ibom State belong to three periods namely: Recent, tertiary and Getaceous. In the Recent are alluvial deposits and in the tertiary are coastal plain sands. The Cretaceous contain the late Gretaceous Nsukka formation.

2.2. Field Studies

A total of six (12) sites were selected, six each from the Beach Ridges Sands (BRS), and Coastal Plain Sands (CPS). Two profile pits of 2 x 1 m^2 dimension and 1.5 m depth were dug at each of the study sites of BRS- Ette (ETT), Ikot Ibiok (IKB), Okoromboko (OKM) and CPS- Abak (ABK), Nsukara Offot (NSO), Ikot Osokpong (IKO). Soil samples were collected at A and B horizons with metal core cylinders of 785 cm^3 . Each core cylinder was carefully driven into the soil using mallate before the samples were collected. Bulk and aggregate samples were also collected for physico-chemical and structural analyses.

2.3. Laboratory Analyses

Soil samples used to evaluate aggregate stability were air dried and sieved so that only air-dry aggregates > 4 but < 8mm remained. The samples used for all other physical and chemical analyses were gently crushed and sieved to 2mm. Water stable aggregation was determined in duplicate by the procedures of Yoder [8] using a nest of sieve with openings of 4.00, 2.00, 1.00, 0.50 and 0.25 mm. Result of the duplicates were averaged before performing linear regression and aggregate size distribution analyses. The sieve set was rapidly immersed in distilled water and oscillated at 37 rpm for10 min. In addition, the 0.25-mm fraction was wet sieved by hand through a 0.125 and 0.053-mm sieve. All fractions were dried at 105^0C and weighed .In the case of the soils from A horizon , the WSA were dispersed in 50 gL sodium hexameta phosphate after drying and weighing, so that a coarse-fraction correction could be made for these soils. First, the dry weight of the aggregate plus coarse fragments remaining on each sieve was determined, after which the aggregates on the sieve were dispersed with sodium hexameta phosphate. Subsequently, the dry weight of the coarse fragments remaining on the same sieve was determined.

Percentage of WSA was calculated as oven-dry soil remaining on all sieves with openings 0.25mm after sieving in water minus oven dry soil remaining on the same sieves after dispersion in sodium hexameta phosphate divided by oven-dry weight of original sample minus oven dry soil remaining on the same sieves as above after dispersion in sodium hexametaphosphate. Mean weighted diameter was calculated as $w_i x_i$ where w_i is the mean diameter of each size fraction and x_i is the proportion of total sample weight in the corresponding size fraction, where the summation is performed overall size fractions, including the one that passes through the finest sieve [9] For the calculation of MWD, the size of the smallest fraction was calculated as 0.053mm/2.

Standard sieving and pipette procedures determined particle-size distributions after dispersion and overnight shaking in 50 gL^{-1} solution sodium hexametaphosphate [10]. Soil color of wet samples was measured with a Munsell colour chart. The redness ratio (RR) was calculated as: RR= (10-H) C/V, where H is the numerical value of YR hue, C is chroma, and V is the value of the Munsell notation [11]. Soil chemical analyses were conducted on the < 2mm fraction, however, all samples extracted with acid ammonium oxalate [12] and citrate/bicarbonate/dithionite were first pulverized in a mechanical shaker. The concentrations of Fe and Al in solution were determined by atomic absorption spectrophotometry [13]. Silica concentration was measured colorimetrically with the blue silicomolybdous acid procedure [14]. Soil OC content was determined with a LECO-CN-2000 analyzer (Leco Corp., St. Joseph, MI) at 1000 ^oC. The C measured in this way equaled the OC content, because the carbonate content was zero in all samples (measured with a pressure-calcimeter apparatus). Exchangeable cations were determined following extraction with 1 N ammonium acetate at pH 7.0 with atomic absorption spectrophotometry. The pH was measured in a 1:2.5 soil/water suspension [15]. Results were analyzed statistically with the Statistical Analysis System [16].

3. Results and Discussion

3.1. Basic Properties of Investigated Landforms

The textural groups of the tested soils diversify from sandy (BRS) and sandy clay soil (CPS). Their reactions were strongly acidic to slightly acidic. Organic matter is moderate and low in EC which ranged from 14.9-31.7 % and 17.8-25.1 %, and 0.02-0.09 dSm^{-1} and 2.56- 3.28 dSm^{-1}. The colors of the soils used in this study (Table1) range from 7.5YR3/2 to 10YR7/1. The content of hematite increases with the redness rating of the soils. Samples devoid of hematite have redness ratings <1 to 2. Nevertheless, a soil with a high redness rating can also contain goethite, but because of the dominance of the red color of hematite [17], the redness rating does not allow estimation of the amount of goethite in a sample .Thus, based on redness ratings (Table1), the A horizon of BRS has the highest hematite content in OKM soil, followed by IKB - A, ETT - A, ETT - B, and IKB - B. The other soils mostly CPS contain essentially no hematite, judged by their color. The redness rating increases as natural drainage improves in the soils from both BRS and CPS landforms. Among the soils from BRS, natural drainage conditions improve in the order OKM > IKB > ETT, whereas among the soils from CPS the order is ABK < NSO < IKO, corresponding to the order of redness rating in both cases.

Table 1. Some morphological and physical characteristics of soil in two landforms

Soil	LF	Horizon	Colour	Redness ratio	Ks (mm hr^{-1})	BD (gcm^{-3})	Sand	Silt g kg^{-1}	Clay
ETT	BRS	A	10YR3/2	3.45	29.5	1.01	953.8	1.8	44.4
	BRS	B	10YR5/4	2.38	12.59	1.07	913.18	21.8	65.02
IKB	BRS	A	10YR7/1	3.50	38.45	1.22	893.8	41.8	64.4
	BRS	B	10YR3/2	2.85	52.71	1.28	853.8	61.8	84.4
OKM	BRS	A	7.5YR/3/2	3.75	32.48	1.22	913.8	21.8	64.4
	BRS	B	10YR3/2	0.75	44.42	1.19	893.8	21.8	84.4
ABK	CPS	A	7.5YR5/8	1.56	38.45	1.42	853.8	41.8	104.4
	CPS	B	7.5YR5/8	1.56	1.04	1.57	793.8	21.8	184.4
NSO	CPS	A	7.5YR4/6	1.67	13.25	1.24	853.8	21.8	124.4
	CPS	B	7.5YR4/6	1.67	0.88	1.43	813.8	1.8	184.4
IKO	CPS	A	7.5YR3/4	1.88	13.59	1.36	813.8	21.8	164.4
	CPS	B	7.5YR4/6	1.67	22.54	1.45	853.8	2.2	144

LF = land form

The mean contents for saturated hydraulic conductivity (Ks) for BRS and CPS are respectively presented in Table 1. For A horizon, Ks ranged from 29.5 to 38.45 mm hr^{-1} with a mean value of 33.47 mm hr^{-1} and 13.25 to 38.45 mm hr^{-1}, averaging 21.76 mm hr^{-1}. In the B horizon, Ks ranged from 12.59 to 52.71 mm hr^{-1} (average 36.57 mm hr^{-1}) and between 0.88 to 22.54 mm hr^{-1} (average 8.15 mm hr^{-1}). This described water movement under saturated conditions in the two soil groups studied. Resulting from low Ks in CPS, the soils have low infiltration rates and during intense rains, nutrients loss is mostly unidirectional through surface runoff, whereas in the BRS, nutrients, colloids are transported through surface runoff and leaching because of its preponderance of capillary pores.

The values of bulk density (BD) on the A horizon ranged from 1.01 to 1.22 g cm^{-3} with an average of 1.15 g cm^{-3} (BRS) and from 1.24 to 1.42 g cm^{-3} averaged 1.34 g cm^{-3}. For B horizon, it ranged from 1.07 to 1.28 g cm^{-3} with mean value of 1.18 g cm^{-3} and 1.43 to 1.57 g cm^{-3} with a mean of 1.48 g cm^{-3}. BD as an index of soil structural stability revealed that CPS is more structurally stable and the density of both landforms allowed plant optimal root development. The mean contents of sand, silt and clay were similar to those obtained by Edem et al., [18] for100 representative soil samples collected in Ultisol under slash-and-burn method of farming during early farming season.

The soils from BRS have citrate/bicarbonate/dithionite extractable Fe (Fe_c) contents that range from 765.31 mg kg^{-1} in the Ette to 961.28 mg kg^{-1} in the OKM A-horizon (Table 2). The B horizon of the IKO soil also has the lowest Fe (Fe_c) concentration among the soils from CPS. The low Fe content of the IKO soil is not unconnected to the poor natural drainage of this soil, which contributes to the reduction, mobilization and loss of Fe from the soil profile. The soils from BRS landform have average Fe_c contents of 856.96 mg kg^{-1}, whereas CPS content averaged 908.66 mg kg^{-1} and 6.54 % content higher than A horizon and 4.83 % than B horizon in BRS landform.

As presented in Table 2, hydrated Fe (Fe_x) contents of the soils from BRS range from 198.4 mg kg^{-1} to 266.4 mg kg^{-1} and from 215.01 mg kg^{-1} to 370.42 mg kg^{-1} in CPS. In the A horizons from CPS there is no significant difference in Fe_x contents. But in the B horizons, ABK location has the highest Fe_x content, also its A horizon has the second highest, and the B horizon of NSO has the lowest concentration of Fe_x. This is contrary to the initial expectation (based on drainage characteristics) that the order of Fe_x contents would be OKM > IKB > ETT .Evidently landscape position and natural drainage of the soils are not good predictors of Fe_x content. The soil from BRS have much lower Fe_x contents than those from CPS. This indicates that the hydrated Fe oxides in the soils from CPS are more crystalline than those in the soils from BRS. Furthermore, the RR indicates that the crystalline Fe oxide hematite is present in substantial quantities in Soils BRS, whereas goethite is the dominant crystalline Fe oxide in Soils from CPS.

The crystalline Al (Al_c) contents range from 198.4 to 266.4 mg kg^{-1} in the soils from BRS, and from 98.71 to 1.9135.8 g kg^{-1} in the soils from CPS. The hydrated Al (Al_x) concentrations are most lower than Al_c for both soil groups, whereas the soils from A horizon of BRS tend to have slightly greater average concentrations of Al_x than the soils from CPS (120.47 mg kg^{-1} and 114.52 mg kg^{-1}).

For B horizon, Al_x concentration averaged 127.39 mg kg^{-1} and 120.90 mg kg^{-1} in the respectively landform.

The pH values of the soils from BRS range from 4.5 to 5.1, whereas the pH of the soils from CPS yields a range from 5.2 to 6.6 (Table 3). The predominant landuse of the soils from both landforms is arable mixed cropping after a short fallow period, resulting in relatively high OC contents in their A horizons compared with the OC content of the B horizons. Organic C contents in the A horizons of the soils from BRS 14.9 to 31.7 g kg^{-1} and B horizon range from 15.9 to 22.8 g kg^{-1} (Table 3). The predominant exchangeable cation is Mg in all soils of both landforms (Table 2). The Mg content of soils from BRS ranges from 2.0 to 5.76 cmol Mg kg^{-1}, and the soils from CPS from 3.12 to 7.44 cmol Mg kg^{-1}. Calcium is the next most abundant cation after Mg. Potassium and Na are present in low concentrations in all soils.

3.2. Relationship between water-stable aggregation and soil organic C

As shown in Figure 1 and Figure 2, Regression analysis shows the absence of a relationship between OC and MWD in both horizons of BRS (r^2 = 0.055 and 0.02 respectively, not signicant with $p > 0.05$). Conversely, OC content was significantly related with WSA in the B horizon (r^2 = 0.485). On the other hand, there is a significantly positive correlation between WSA and Na in the BRS (Table 4). It is likely that Na is the major factor explaining the reduction in macro aggregation in the A and B horizons of BRS because specific aggregating agents have been related to specific levels in a hierarchy of aggregation [19] in the multiple correlation of the predicted model. Therefore, in these geological units, aside from OC, plant roots and fungal hyphae were considered to be largely responsible for the stability of aggregates 0.25mm.

Table 2. distributions of crystalline and hydrated oxides of Fe and Al

Location	Landforms	Horizons	Crystalline oxides		Hydrated oxides	
			Fe	Al	Fe	Al
			mg/kg		mg/kg	
ETT	BRS	A	765.31	102.11	240.2	67.8
	BRS	B	862.64	120.21	198.4	33.96
IKB	BRS	A	817.33	125.16	230.6	40.5
	BRS	B	864.81	135.67	250.6	96.47
OKM	BRS	A	961.28	134.14	266.4	60.56
	BRS	B	870.44	126.28	242.06	42.8
ABK	CPS	A	871.21	134.2	361.31	80.4
	CPS	B	960.32	135.8	370.42	60.14
NSO	CPS	A	890.67	101.21	260.4	60.73
	CPS	B	964.2	98.71	215.01	50.44
IKO	CPS	A	960.2	108.14	340	78.6
	CPS	B	805.4	128.2	316.1	89.4

Table 3. Some chemical characteristics of soils in BRS and CPS

Soil locations	Landforms	Horizons	pH	OC	Ca	Mg	K	Na
				→		g/kg	←	
ETT	BRS	A	4.5	26.7	1.92	4.8	0.11	0.6
	BRS	B	4.5	15.9	2.4	3.84	0.12	0.5
IKB	BRS	A	4.6	14.9	3.36	5.76	0.08	0.08
	BRS	B	4.8	16.8	1.44	4	0.09	0.09
OKM	BRS	A	5.1	31.7	2.88	2.4	0.1	0.1
	BRS	B	5.0	22.8	1.68	4.58	0.11	0.11
ABK	CPS	A	5.3	24.9	2.88	3.12	0.07	0.06
	CPS	B	5.2	22.9	3.6	3.84	0.07	0.04
NSO	CPS	A	5.3	24.9	1.92	4.8	0.09	0.06
	CPS	B	5.6	17.9	1.44	4.8	0.1	0.06
IKO	CPS	A	6.6	25.1	3.6	6.48	0.1	0.04
	CPS	B	5.4	17.8	4.08	7.44	0.06	0.03

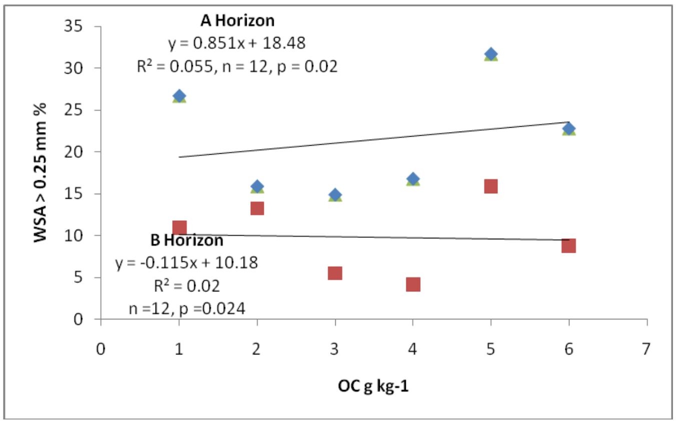

Figure 1. Relationship between water-stable aggregation and soil organic C for A and B horizon in BRS

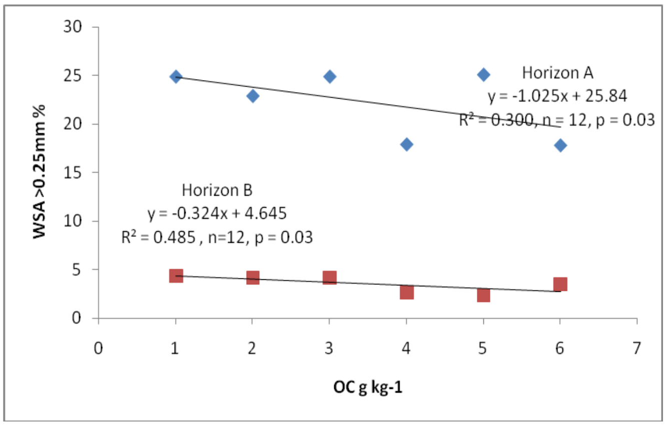

Figure 2. Relationship between water-stable aggregation and soil organic C for A and B horizon in CPS

Table 4. model summary of multiple correlation of MWD and soil properties

Correlation coefficient (R)	R^2	Adjusted R^2	Standard error of the estimate
0.966	0.933^{a}	0.916	1.3087
0.998	0.995^{b}	0.992	0.4060

a= predictors (constant), 2.0 mm aggregate , b= predictors (constant), 2.0 mm aggregate, Na

3.3. Changes in Cassava-maize Intercropped BRS and CPS

Table 5 shows the changes in yield of cassava-maize intercropped in the BRS and CPS landforms of Akwa Ibom State. The results revealed that, structural development of CPS improved maize yield by 67.5 % and cassava 35.3 % relative to BRS. Maize yield from BRS ranged between 1.18 to 1.64 Mg ha^{-1} averaged 1.37 Mg ha^{-1}, whereas cassava range from 3.68 to 6.25 Mg ha^{-1} with an average yield of 5.25 Mg ha^{-1}. In CPS landform, maize yield range from 3.55 to 4.67 Mg ha^{-1} and cassava from 8.05 to 8.19 Mg ha^{-1} with average yields of 4.22 Mg ha^{-1} and 8.12 Mg ha^{-1} respectively. This increase in both crops in CPS might be attributed to increasing ECEC, and associated binding agents of cations which slows leaching out of bases from the soil surface [20] by keeping those elements in the rooting zone.

Table 5. Changes in yields of Cassava-maize intercropped in two landforms

Soil locations	Landforms	Yields (Mg ha^{-1})	
		Maize	Cassava
ETT	BRS	1.64	6.25
IKB	BRS	1.28	5.81
OKM	BRS	1.18	3.68
	Average	1.37	5.25
ABK	CPS	4.44	8.05
NSO	CPS	4.67	8.19
IKO	CPS	3.55	8.12
	Average	4.22	8.12
	LSD $_{0.05}$	0.16	0.34

4. Conclusions

In this study, the correlation of Organic carbon and some soil properties were rather weak, even when statistically significant. The weaknesses of the correlations may be due to the joint effect of several properties that may aid or inhibit their influence and/or low content. Despite the known role of organic carbon (organic matter) in increasing MWD, the estimated values are not as large as required to improve hydro-physical soil properties due to its lower content. The role of Ca and Mg on MWD was similar to organic carbon in CPS landform. Therefore, the increase in sand and Na contents leads to dispersion of soil aggregate in the BRS and bad effect on soil drainage system and crop yield. So, application of organic and inorganic amendments annually is a must especially on soils from BRS.

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