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Pedology of Near Gully Sites and its Implications on the Erodibility of Soils in Central South Eastern Nigeria

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Abstract: Near gully sites in southeastern Nigeria were investigated from April to July 2005 to ascertain their erodibility potentials. Soils were sandy and of low Silt-Clay Ratio (SCR) but were eroding. Exchangeable Sodium Percentage (ESP), carbon content, silt, clay and Calcium-Magnesium Ratio (CMR) tended to influence erodibility of these soils. They correlated significantly with Dispersion Ratio (DR) ($p \leq 0.05$). Exchangeable sodium percentage was higher in pedons near gully sites (ESP = 1.4-5.1) compared with results of non-gully site (ESP = 0.1-0.3). Calcium-magnesium ratio (CMR) was generally narrow (0.3-3.0). Organic matter content was very low in pedons near gully sites (less than 11%). Cation exchange capacity was lower in sites affected by gullying (CEC = 3.50-7.00 cmol kg^{-1}). Low base saturation (less than 40%) shows very strong leaching of basic cations in the study area.

Key words: Degradation, erodibility, gully erosion, pedology, southeastern Nigeria

INTRODUCTION

Soil erosion is a predominating soil degradative agent in southeastern Nigeria and is believed to be related to soil properties among other non-soil contributors. Currently, the spate of soil erosion which comes in various forms is so aggravated that it threatens life and property in the sub-region. In addition to non-human factors, such as climate man has been implicated as facilitating soil erosion by inappropriate land use practices (Eremie, 1990). All these manifest in reduced productivity of agricultural lands (Oti, 2002) and increased poverty (Mbagwu and Obi, 2003).

Indices have been proposed to assess potential soil loss in soils of southeastern Nigeria. Obi *et al.* (1989) observed that in southeastern Nigeria, the soil aggregate stability technique was the least satisfactory index for determining erodibility of soils. Mbagwu (1986) evaluated the relative erodibility values of soils formed on a toposequence by use of various erodibility indices and observed that clay ratio, dispersion ratio and dispersion index gave better estimation of soil loss. Igwe *et al.* (1995) reported that Dispersion Ratio (DR), Wishmeier's erodibility (K), Clay Dispersion Index (CDI) and Clay Flocculation Index (CFI) ranked higher in predicting soil loss. However, they noted that organic carbon and Fe_2O_3 control flocculation and deflocculation properties of these soils in southeastern Nigeria.

In all these, the pedology of soils proximal to sites of various forms of soil erosion has not been widely studied. The major objective of this study was to investigate influence of pedological processes on soils near gully sites as such may be instrumental to the formation of adjoining gullies and consequent reduction in cultivable land.

MATERIALS AND METHODS

Location

The study area comprises Imo and Abia States of southeastern Nigeria lying between latitudes 4°40[1] and 8°15[1] North and longitudes 6°40[1] and 8°15[1] East (Federal Department of Agricultural Land

Resources, 1985). The geological materials are mainly alluvial deposits, coastal plain sands (Benin formation), shale (Bende-Ameki formation), upper coal measures (Nsukka formation) and falsebedded sandstones (Orajaka, 1975). Its relief is between 50-400 m (Ofomata, 1987). Geomorphologically, it is a lowland with north-lying hills (Ofomata, 1975). The study site is in the humid tropics with annual rainfall reaching 3000 mm in some parts and having rainfall intensities up to 200 mm h^{-1} (Obi and Asiegbu, 1980). There are two main categories of vegetation which are being rapidly deforested by increasing human population and attendant activities. Farming is a major socio-economic activity, with soil fertility regenerated by bush fallows whose length is drastically reduced due to demographic pressure (Onweremadu, 1994).

Field Studies

Field studies are conducted from April to July 2005 in the study area. Six sites, namely Mbaise, Umuahia, Bende, Okigwe, Orlu and Owerri were chosen after a reconnaissance visit. Gullies were found in the first 5 locations while Owerri was used as a control site for the study. Pedons were dug at the edges of the gullies and the control site. These pedons were described according to the FAO Guidelines for profile pit description (1998) while soil classification of was done according to the rules set out in soil taxonomy (Soil Survey Staff, 2003). Soil samples were collected from pedons based on the degree of horizon differentiation and slope was measured using Abney level. All sample points were located on a gentle to undulating topography.

Laboratory Analyses

Soil samples were air-dried and sieved using 2 mm sieve mesh. Particle size distribution was determined by hydrometer method (Gee and Bauder, 1986). Soil pH was estimated by the method of Hendershot *et al.* (1993). Soil organic carbon was measured by Walkley and Black method (Nelson and Sommers, 1982). Total nitrogen was obtained by microkjeldahl method (Bremner and Mulvaney, 1982). Exchangeable bases and cation exchange capacity was determined by with neutral 1N NH_4OAc (Jackson, 1962). Dispersion ratio (Middleton, 1930) was used to assess erodibility of studied soils. Dispersion Ratio (DR) was computed as follows:

1. Dispersion ratio (DR) $$\frac{\%\ \text{Silt} + \%\ \text{clay}\ (H_2O)}{\%\ \text{Silt} + \%\ \text{clay}\ (\text{calgon})}$$

Data Analysis

Soil data were subjected to correlation analysis using SAS version 8.2 (SAS Institute, 2001).

RESULTS AND DISCUSSION

Soil Properties

Table 1 and 2 summarize physical and chemical properties of studied pedons. Generally, soils were sandy. This implies that these soils are least susceptible to erosion (Dupriez and Deleener, 1992) as they have abundant macropores capable of allowing entry and movement of water into the deeper layers of the pedon. Contributing, Obi and Asiegbu (1980) reported low transportability of sand-sized fractions. These notwithstanding, deep gullies were developed in the sites except at Owerri. All soils studied are erodible, having Dispersion Ratio (DR) greater than 15% (Table 1), although Owerri site is currently not eroding. However, these non-eroding status of Owerri site could be attributed to lower volume of runoff water that enters the site.

Table 1: Selected physical properties of soils of the studied sites

Location	Depth (cm)	Description/slope	Total sand (%)	Silt (%)	Clay (%)	Silt/clay	D.R. (%)
Mbaise	0-18	Gully edge, 5%	88	2	10	0.20	60
	18-90		82	2	16	0.12	63
	90-130		80	1	19	0.05	62
	130-190		86	2	12	0.16	61
Orlu	0-15	Gully edge, 6%	60	2	38	0.05	50
	15-80		86	2	30	0.06	53
	80-140		60	9	39	0.23	51
	140-195		68	4	19	0.21	56
Okigwe	0-16	Gully edge, 4%	52	4	30	0.13	42
	16-78		66	3	20	0.15	48
	78-120		77	3	30	0.10	46
	120-180		67	2	31	0.06	47
Bende	0-18	Gully edge, 7%	67	6	48	0.12	38
	18-90		46	6	46	0.13	42
	90-135		48	10	37	0.27	45
	135-193		53	10	41	0.24	44
Umuahia	0-18	Gully edge, 5%	85	3	12	0.25	65
	18-40		86	3	11	0.27	68
	40-120		82	2	16	0.12	62
	120-188		80	1	19	0.05	63
Owerri	0-19	No gully, 1%	86	5	9	0.55	36
	19-75		88	2	10	0.20	56
	75-125		85	2	13	0.15	50
	135-200		86	1	13	0.07	46

DR = Dispersion Ratio

Table 2: Selected chemical properties of soils of the studied sites

			Exchangeable bases											
	Depth	pH (KCl)	Na	Mg	K	Ca	CEC	ESP	B.S	C	OM	T.N		
Location	(cm)	1:2.5	c mol kg^{-1}						%				C/N	Ca/Mg
Mbaise	0-18	3.8	0.11	0.09	0.30	0.20	4.50	15	2.4	0.30	0.52	0.03	10	1.5
	18-90	3.9	0.12	0.10	0.30	0.20	4.00	18	3.0	0.20	0.34	0.02	10	1.5
	90-130	4.0	0.11	0.11	0.40	0.40	4.10	24	2.6	0.09	0.15	0.01	9	1.0
	130-190	4.0	0.10	0.12	0.40	0.40	4.00	25	2.5	0.06	0.10	0.01	6	1.0
Orlu	0-15	4.0	0.15	0.11	0.30	0.20	6.50	11	2.3	0.40	0.68	0.03	11	1.5
	15-80	4.1	0.16	0.11	0.30	0.20	6.00	12	2.6	0.20	0.34	0.02	10	1.5
	80-140	4.2	0.14	0.12	0.20	0.10	6.50	8	2.1	0.09	0.15	0.01	9	2.0
	140-195	4.2	0.14	0.12	0.40	0.30	5.30	18	2.6	0.02	0.05	0.01	3	1.3
Okigwe	0-16	4.1	0.10	0.11	0.50	0.40	6.00	18	1.6	0.35	0.60	0.04	9	1.2
	16-78	4.0	0.12	0.09	0.40	0.20	5.30	15	2.2	0.09	0.15	0.02	3	2.0
	78-120	4.1	0.11	0.08	0.50	0.40	6.00	18	1.8	0.03	0.05	0.01	3	1.2
	120-180	4.1	0.11	0.08	0.40	0.30	5.60	15	1.9	0.03	0.05	0.01	3	1.3
Bende	0-18	4.2	0.13	0.12	0.30	0.30	7.00	12	1.8	0.40	0.68	0.04	10	1.0
	20-90	4.0	0.12	0.14	0.40	0.30	6.50	14	1.8	0.30	0.52	0.01	10	1.3
	90-135	4.3	0.11	0.15	0.50	0.30	7.00	15	1.5	0.10	0.17	0.01	10	1.6
	135-193	4.2	0.10	0.16	0.40	0.20	7.00	12	1.4	0.03	0.05	0.01	3	2.0
Umuahia	0-18	3.7	0.17	0.10	0.20	0.10	3.50	16	4.8	0.30	0.52	0.03	10	2.0
	18-40	3.9	0.18	0.08	0.03	0.10	3.50	16	5.1	0.20	0.34	0.02	10	3.0
	40-120	4.0	0.14	0.06	0.30	0.10	4.00	15	3.5	0.08	0.13	0.01	8	3.0
	120-188	4.1	0.13	0.05	0.04	0.20	3.50	22	3.7	0.03	0.05	0.01	3	2.0
Owerri	0-19	4.2	0.03	0.10	0.70	2.00	5.60	32	0.3	1.85	3.18	0.15	12	0.3
	19-75	4.2	0.02	0.14	0.50	0.90	6.25	25	0.3	1.05	1.81	0.09	11	0.5
	75-135	4.5	0.02	0.15	0.70	1.50	8.05	29	0.2	0.95	1.64	0.09	10	0.4
	135-200	4.4	0.01	0.16	0.70	2.00	8.00	35	0.1	0.16	0.27	0.03	5	0.3

CEC = Cation Exchange Capacity, B.S. = Base Saturation, ESP = Exchangeable Sodium Percentage, C = Carbon, OM = Organic Matter, TN = Total Nitrogen

Morgan (1978) suggested the use of potential soil loss, stating that an increasing value trend to erodibility but results of the study show low values (Table 1), implying that soils have been exposed to weathering for a long period. Values (SCR<1.2) suggest high weatherability of soils (van Wambeke, 1962) which according to Morgan (1978) means low erodibility, but soils were actually eroding.

The foregoing clearly shows that sandy textural classes may not have influenced erodibility (Bazzoffi and Mbagwu, 1986) as much as organic components of the soils. Organic matter content of soils was low and C/N ratio narrow (Table 2) pointing to high mineralization (Eshett *et al*., 1989). This suggests poor aggregation and high vulnerability to erosion. Organic matter has the capacity to chelate metal ions, such as Fe^{3+} and Al^{3+} but these chelates are temporarily withdrawn from soil system leading to pronounced erosion (Tan, 1978). Igwe *et al*. (1995) observed that dispersion and flocculation are influenced by status of metal-organic complexes in tropical soils.

Values of Ca-Mg ratio (Table 2) show increased leaching and this varied among soils as least values were found in soils of Owerri site. Inter-and intra-pedal variabilities are possibly due to differential land use and rapidity of pedogenesis, respectively. The low values of Ca/Mg in the entire study point to high levels of loss of these basic cations and this leads to phenomenal decrease in Ca and P (Landon, 1984). The above effect is worst in acidic soils (Oti, 2002).

Exchangeable Sodium Percentage (ESP) was higher in near gully sites than in non-gully sites (Table 2). Values of ESP were higher in lower horizons of pedons near gully sites especially in Mbaise and Umuahia. This could be responsible for the deepening nature of these gullies. Earlier, Imeson and Kwaad (1980) used the ESP to estimate the dispersive nature of lower horizons proximal to gully sites, concluding that lower horizons close to gully sites are more dispersive than those away from gullies.

Lower values of CEC experienced in pedons near gullies are suggestive of predominance of 1:1 type clay minerals (Igwe *et al*., 2002) which are more dispersive that 2:1 clay mineral like montmorrillonite. This means that aggregative power of clays depends on type.

Results of correlation analyses of erodibility and soil properties are shown in Table 3. Exchangeable Sodium Percentage (ESP) was correlated significantly with DR (R = 0.89; $p \leq 0.05$) and the same trend was followed by soil carbon (R = 0.88; $p \leq 0.05$). Other significant correlation coefficients were found between silt and DR (R = 0.82, $p \leq 0.05$), clay and DR (R = 0.38, $p \leq 0.05$), CMR and DR (R = -0.73; $p \leq 0.05$). The results show that ESP, soil carbon, silt, clay and CMR could be used for prediction of erodibility potential of soils of the site. Similar findings have been made by some researchers (Igwe *et al*., 1995).

Table 3: A correlation matrix of indicators of erodibility and other soil properties

Indicators	Total sand	Silt	Clay	Carbon	pH	ESP	CMRDR	SCR
SCR	0.52*	0.23ns	0.44*	0.53*	0.25ns	0.71*	0.68*	0.77*
DR	0.21ns	0.82*	0.38*	-0.88**	0.44*	0.89**	-0.72*	-
CMR	- 0.42*	0.56*	0.79*	0.76*	-0.65*	-0.61*	-	
ESP	0.48*	0.43*	0.55*	0.57*	0.25ns	-		
pH	0.70*	0.30ns	-0.60*	0.22ns	-			
Carbon	0.20ns	0.32ns	0.28ns	-				
Clay	- 0.80*	0.40*	-					
Silt	- 0.60*	-						
Total sand	-							

SCR = Silt-clay ratio, DR, Dispersion Ratio, CMR = Calcium-Magnesium Ratio, ESP = Exchangeable Sodium Percentage, * = Significant at p = 0.05, ** = Significant at p = 0.01, ns = non Significant

Table 4: Classification of studied soils

Location	Soil taxonomy	FAO/UNESCO
Mbaise	Inceptic Hapludults	Arenic Acrisols
Orlu	Typic Plinthaquox	Haplic Plinthosols
Okigwe	Typic Plinthaquox	Vertic Plinthosols
Bende	Typic Paleustults	Dystric Nitisols
Umuahia	Typic Haplustox	Arenic Ferralsols
Owerri	Arenic Hapludults	Dystric Nitisols

Classification

Soils were classified as shown in Table 4, indicating that soils are highly weathered. The pedogenic status of these soils is attributed to the combined and interactive effects of climate and organisms in the region plus the localized impact of topography and lithology.

CONCLUSIONS

Soils are sandy and would seem to resist soil erosion but have chemical nature predisposing them to soil erosion. Non-soil factors like climate promote inability of these soils to resist erosion.

Exchangeable Sodium Percentage (ESP), carbon, silt, clay and CMR are highly correlated with erodibility of soils. Values of SCR were low against the popular belief that highly erodible soils have high SCR. Finally soils data should be subjected to Principal Component Analysis (PCA) to help find out the most influential pedological factors in erodibility of soils.

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