

DISCRIMINANT FUNCTIONS FOR CLASSIFYING EROSION DEGRADED LANDS AT OTAMIRI, SOUTH EASTERN NIGERIA

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ABSTRACT

This study was conducted to evaluate the effect of natural in-situ erosion on soil physico-chemical properties and to identify indicator variables associated with various degrees of erosion on a Southern Nigeria Ultisol. A preliminary survey conducted in 1997 had delineated four erosion phases on a contiguous sloping land within a watershed. The erosion classes were Non-eroded (NE), Slight (S), Moderate (M) and Severely eroded (Sv) based primarily on Ap horizon thickness. Field experiments and laboratory analysis were done in 1998/99. Definite consistent relationships that were statistically significant were observed between erosion class and some soil physical and chemical properties of surface 0 – 10 cm layer. Among these were silt/clay ratio which ranged from 0.29 in NE to 0.19 in Sv; fine sand/coarse sand ratio were 0.33 (NE), 0.31 (S), 0.17 (M) and 0.19(SV). Soil organic carbon (SOC) declined from 1.01% in NE to 0.60% in Sv, and (Ca + Mg)/(Al + H) ratio, used to infer nutrient imbalance, also decline from 1.23 in NE to 0.43 in Sv. Aluminum saturation percentage increased from 33% in NE to 60% in Sv, and Ca/Mg ratio from 1.14 (NE) to 1.62 (Sv). Pedotransfer functions suggested that erosion – induced soil alterations are more process based than simple factor dependent. It is therefore recommended that in this environment the prediction of erosion hazard and the identification of erosion classes be based on discriminant analysis derived from silt/clay, fine sand/coarse sand, Ca/Mg, and (Ca + Mg)/(Al + H) ratios. Soil organic carbon and Al⁺⁺⁺ saturation are equally important indicator variables.

Key words: Erosion, Degradation, Pedotransfer Functions and Classification

INTRODUCTION

Soil erosion is a major limitation to sustainable production in most farmlands of Africa (Lal, 1995). In West Africa in general and southeastern Nigeria in particular, it ranks as one of the most serious problems on agricultural lands, threatening large populations with starvation. Water erosion is the most active erosion process in the ultisols of SE Nigeria, which cover more than 70% of the total land area (Mbagwu, 1992). While literature on the extent and severity of erosion in soils of the tropics is voluminous, there is paucity of information on specific erosion-- induced alterations of soil properties that can be used to classify eroded soil phases or included in erosion-- crop productivity decline models for these soils.

In developed countries, the degree of erosion on soils is recorded on National soil survey maps as phases of soil series. The phase of the eroded soil is identified on the basis of the properties of the original soil that remains (USDA Soil Survey Manual, 1993). Generally, classes of erosion are assigned on the bases of the percentage of the original A horizon that has been lost. While this is a simple approach, by depending solely on A-horizon thickness other soil changes induced by erosion which impact directly on crop yields are ignored. The inclusion of simple soil properties changed

by erosion in national soil databases and their use in the identification and delineation of eroded soil phases, will be a superior approach to erosion studies. The main objective of this study therefore, was to identify specific physico-chemical soil properties altered by various degrees of erosion that would serve as reliable indicator variables for clacking erosion classes of a tropical ultisol. It is also aimed at providing basic benchmark information on naturally eroded environments that will aid model development.

MATERIALS AND METHODS

Study Environment

The study area, covering the Otamiri watershed in Imo State, lies between latitudes 4° 15" and 7° and longitudes 5 50" and 9 30"E. It is a humid tropical environment. Temperatures are high and change only slightly during the year (mean daily temperature is about 27° C). The night and day, and monthly variations in temperature are minimal. The average annual rainfall is about 2400 mm. There is a distinct 3 months of dryness.

The predominant parent material underlying Imo State, from which most of its soils are formed are the

Table 1
Some physico-chemical properties of eroded sites at Oramiri Southern Nigeria

Erosion Phase	pH (1:1-H ₂ O)	N (%)	BS (%)	CEC (mequiv./100g)	P (ppm)	AWC (v/v%)	Total aggregation (%)	Bulk density (g/cm ³)
A. 0 – 10cm depth								
Non eroded	4.8	0.092	56	6.3	8.25	14.65	88.09	1.39
Slight	4.9	0.071	50	4.5	6.43	18.66	86.36	1.50
Moderate	4.9	0.061	52	4.3	6.95	13.90	87.92	1.48
Severe	4.7	0.057	43	3.6	10.25	18.77	87.07	1.47
LSD (0.05)	NS	0.006	06	0.6	0.20	1.40	0.31	0.04
B. 10 – 20 cm depth								
Non eroded	4.9	0.107	52	4.6	5.30	17.49	88.26	1.51
Slight	4.9	0.049	51	4.0	3.95	20.46	84.01	1.59
Moderate	4.9	0.042	46	3.3	6.60	17.20	84.87	1.51
Severe	4.6	0.023	44	4.3	9.25	15.75	87.04	1.53
LSD (0.05)	NS	0.020	NS	0.2	0.28	0.41	0.20	0.03

NS = not significant at $p = 0.05$; N = total nitrogen; BS = base saturation; CEC = cation exchange capacity; P = available phosphorus; AWC = available water capacity; Table 2

Particle size distribution, silt/clay and finesand/coarse sand ratios of natural erosion degraded Ultisol in Southeastern Nigeria.

Erosion phase	Particle Size Distribution (%)				Coarse sand	Textural class	Silt/clay	Ratios	
	Clay	Silt	finesand					Finesand/coarse	
A. 0 – 10 cm depth									
Non-eroded	12	4	20		64	Loamy sand	0.33		0.31
Slight	13	7	16		64	Loamy sand	0.54		0.25
Moderate	14	6	12		68	Loamy sand	0.43		0.18
Severe	14	2	12		72	Loamy sand	0.14		0.16
B. 10 – 20 cm depth									
Non-eroded	16	6	14		64	Loamy sand	0.38		0.22
Slight	14	6	16		64	Loamy sand	0.43		0.25
Moderate	12	4	18		66	Loamy sand	0.33		0.27
Severe	12	4	08		76	Loamy sand	0.33		0.11

Coastal Plain Sands also known as "Acid Sands". They are acidic, have low CEC, low base saturation and low fertility status, usually suffering from multiple nutrient deficiencies. Farming is mainly practised at the subsistence level with the traditional slash and burn system. Soil fertility is maintained by the use of perennial fallow a fast disappearing practice in most communities. Rotations consist of mixed cropping/ relay cropping of yams, cassava, cocoyam as main crops with telfaria, pepper, plantains and banana as minor crops.

Field Survey

Field survey was conducted within the Otamiri watershed of Imo State, Nigeria, during the dry season of 1997. Using the guideline of USDA's Soil Conservation Service (1989) and USDA Soil Survey Manual (1993), four categories of erosion phases were identified and delineated as follows:

Non-eroded sites (NE): virgin soil under forest in wooded lots. A horizon thickness is about 40 cm.

Slightly eroded sites (S): soils that have lost 25% of the original A horizon. A horizon thickness is about 30 cm.

Moderately eroded sites (M): soils that have lost between 25 and 75% of the original A horizon. The A in most cultivated areas is a mixture of the A horizon and underlying material. A horizon thickness is about 18 cm

Severely eroded sites (Sv): soils that have lost 75% or more of the original A horizon. Material below the A horizon is exposed at the surface in cultivated areas. A horizon thickness about 9 cm

Soil Sampling and Analysis

All selected sites were Typic Trophumult under a 5-year fallow. After land clearing activities, 2 profiles, each measuring 1 m x 1 m x 2 m were dug at random within each of the already delineated erosion classes. A total of 8 profile pits were excavated and examined. For this aspect of the series of studies, soil samples were collected at 2 depths: 0–10 and 10–20 cm. Soil bulk density (BD) was measured by the core method using cores of 7.5 cm (diameter) and 7.5 cm depth. The water stable aggregates (WSA) were determined on 5 to 8 mm aggregates using the wet sieving procedure of as described by Kemper and Rosenau (1986). Available water capacity was computed as the difference between the moisture retained at 0.10 and 15 bars tension. Disturbed soil sam-

ples, were air-dried and sieved through a 2 mm mesh. The < 2 mm fraction was then used to determine particle size distribution by the hydrometer method (Day, 1965).

Soil pH was measured in 1:1 soil-water suspension, exchangeable cations (Ca and Mg) displaced in NH_4OAC solution by emission spectroscopy, available P by the Bray-I method, CEC by the summation of exchangeable cations, exchangeable acidity by the 1 N KCl extraction method (Jackson, 1958), soil organic carbon by the method of wet combustion (Walkley–Black, 1934) and total nitrogen by the micro Kjeldahl method.

Statistical analyses included analysis of variance (ANOVA), mean separation of significant treatments effect, and computer based step-wise regression analysis to determine pedotransfer functions (PTF's). Pedotransfer functions are step-wise regression equations that relate properties of importance to production and resource management to basic, easily measured soil properties (Larson and Pierce, 1991).

RESULTS AND DISCUSSION

Effects of Erosion on Soil Properties

Physical Properties and Ratios

The effect of erosion on some soil properties is shown in Table 1. There was no adverse effect of erosion on the available water capacity of these soils, contrary to results obtained in temperate soils where erosion is nearly always accompanied by drought stress in years with inadequate rainfall (Eck, 1987; Ellsworth et al., 1990; Fahnestock et al., 1995). Whereas total aggregation decreased with erosion, bulk density tended to increase with severity of erosion and ranged from 1.39 to 1.47 g/cm³ for the 0–10 cm depth and 1.51 to 1.59 g/cm³ for the 10 to 20 cm layer. Increase in bulk density attributed to erosion is usually caused by the direct compacting effect of heavy raindrops on unprotected surface soil layers with diminished SOC levels, in addition to surface sealing and slaking of structurally weak macro aggregates. Even though erosion altered some of these soil properties, yet the trends appear irregular and therefore not easily predictable.

Data on particle size distribution and soil fraction ratios of the non-eroded and three eroded sites are shown in Table 2. Erosion led to consistent decrease in fine sand fraction (< 0.5 mm) of the surface 0–10 cm layer, and coarse sand (2.0–1.5 mm) enrichment due to the preferential removal of the former particles as also reported by Mbagwu (1988) in a tropical ultisol. The response of silt/clay ratio was not consistent in the two

Table 3.

Soil organic carbon, (SOC) Aluminum saturation, (Al Sat.) Ca/Mg and (Ca + Mg)/(Al + H) ratio for different erosion classes of an Ultisol. In Southern Nigeria

Erosion phase	Soil organic Carbon (%)	Al Sat. (%)	Ca/Mg ratio	(Ca + Mg)/(Al + H) ratio
A. 0 – 10cm depth				
Non – eroded	1.01	33	1.14	1.23
Slight	0.75	50	1.33	0.69
Moderate	0.64	49	1.25	0.69
Severe	0.60	60	1.62	0.43
LSD (0.05)	0.02	-	-	0.06
B. 10 – 20cm depth				
Slight	1.22	38	0.83	0.92
Moderate	0.51	45	1.22	0.83
Severe	0.39	52	1.14	0.63
LSD(0.05)	0.20	45	1.25	0.64
	0.08	-	-	0.04

Table 4

Pedotransfer functions relating water stable aggregation (WSA) of 0 – 20 cm layer with soil properties, 1998.

Independent variable (predictors)	Regression equation	R	R ²	n
Organic matter (OM)	WSA = 85.362 + 2.52 OM	0.32ns	0.10	20
Percentage clay (PC)	WSA = 85.106 + 0.152PC	0.37ns	0.13	20
Percentage Silt (PSilt)	WSA = 89.511 – 0.525PSilt	0.41ns	0.17	20
Percentage fine sand (PFS)	WSA = 88.196 – 0.073PFS	0.21ns	0.04	20
Percentage coarse sand (PCS)	WSA = 81.274 + 0.087PCS	0.23ns	0.05	20
Total porosity (%) (TP)	WSA = 94.710 – 5.163 TP	0.24ns	0.07	20
OM, PC, PSilt, PFS, PCS, and TP	WSA = 81.740 + 3.72 4OM + 0.268 PC – 0.366 PSilt – 0.159 PFS – 0.025 PCS + 0.113 TP	0.62**	0.38	20

Dependent variable: % water stable aggregation (WSA); ** Significant at P = 0.01, ns = not significant

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soil layers examined. However, there was more variation in silt/clay ratio among the four erosion treatments at the 0 – 10 cm layer (10 units). At the 10 – 20 cm depth, the severely eroded phase had the same silt/clay ratio of 0.33 as the upper 0 – 10cm layer of the non-eroded field. Silt/clay ratio is a reflection of the weathering stage of the parent material and erosion tends to distort the interpretation of this parameter. Caution should, therefore, be exercised in the use of this indicator in erosion degraded environments.

At the top 0– 10 cm layer, the fine sand/coarse sand ratio was 0.31 (NE), 0.25 (S), 0.18 (M) and 0.16(Sv), a progressive decrease with increase in the severity of erosion. Mbagwu (1988) had also reported similar findings for a tropical ultisol. At the severe erosion phase this parameter was half the value of the undisturbed reference site.

Chemical Properties and Ratios

The effect of natural *in situ* erosion on selected soil chemical properties is also shown in Table 1. Soil pH was the only soil attribute not altered by erosion. Total nitrogen, base saturation and CEC decreased significantly with increasing severity of erosion. For the surface 0 – 10 cm layer, total nitrogen was 0.092, 0.071, 0.061 and 0.077 for the non-eroded, slight, moderate and severely eroded phases, respectively and the relative values were 100:77:66:62, accordingly. The impact of erosion on total nitrogen content was more pronounced at the 10 – 20 cm depth where reductions of 54, 60 and 79% were observed in the slight, moderate and severely eroded fields, respectively. Several studies have documented decreases in soil chemical fertility status of cultivated lands, but the results are normally confounded by improved management practices like fertilizer and resi-

due applications (Ketcheson and Webber, 1978; Bowman et al., 1990; Verity and Anderson, 1990). Phosphorus response to erosion showed irregular trend.

The data of the effect of erosion on soil organic carbon, aluminum saturation, exchangeable Ca/Mg ratio and (Ca + Mg)/(Al + H) (an indicator used to infer nutrient balance) are shown in Table 3. There were drastic reductions in SOC and (Ca + Mg)/(Al + H) ratio associated with various degrees of erosion. For SOC, the relative values were 100:74:63:59 for non-eroded: slight: moderate: severely eroded phases, respectively. In general (Ca + Mg)/(Al + H) ratio was in the order non-eroded > slight ≥ moderate > severe (Table 3). The trend was similar for the 10 – 20 cm depth.

Even though the magnitude and direction of change in soil properties induced by erosion is environment and management dependent, its effect on some soil properties like SOC and nutrient balance appears consistent as documented by similar works in both temperate and tropical regions (Ebeid et al., 1995; Nezeyimana and Olson, 1988; Mbagwu, 1988; Fahnestock et al., 1995). Aluminum saturation and Ca/Mg ratio increased consistently with increased severity of erosion in the order Sv > M ≥ S > NE. The range of values for aluminum saturation was between 33% in the non-eroded field to 60% in the severely eroded plots. Erosion therefore, intensified aluminum toxicity by a factor of 2 without altering soil pH. High level of soluble Al concentrations is toxic to most plants and becomes a serious constraint to productivity when it reaches 60% or more (Styczen, 1992). Calcium/Magnesium ratios were highest in the non-eroded phase and decreased progressively with increasing severity of erosion. Tegene (1992) observed similar patterns in a south Ethiopian Nitosol. A decrease of Ca/

Mg ratio to a level below 3 results in unavailability of calcium and phosphorus (Landon, 1984) and this effect is especially serious in acidic soils.

Because erosion effects on fine sand/coarse sand ratio, soil organic carbon, aluminum saturation, Ca/Mg and $(Ca + Mg)/(Al + H)$ ratio are consistent, progressive and the pattern predictable, they can be used as reliable markers to identify and delineate erosion degraded environments.

Pedotransfer Functions

Pedotransfer functions relating water stable aggregation (WSA) to selected soil properties are shown in Table 4. Decline in WSA, the basic unit of soil structure, may be both the cause and consequence of soil erosion (Lal, 1987). Most soils with weakly developed structural units and aggregates are unstable to raindrop impact and therefore slake and disintegrate readily. This predisposes such soil to severe erosion. Water stable aggregation was therefore, used as a key indicator of "proneness" to erosion.

Reliable, easy-to-measure predictors were used in a computer based stepwise regression analysis that only selected sensitive predictor variables. Whereas all the single factors tested showed weak bivariate correlation with WSA, the combination of factors – SOC, clay, silt, fine and coarse sand percentages and total porosity had a significantly positive r value of 0.62. However, only a maximum of 38% of the variability in WSA could be attributed to these properties.

CONCLUSION

The study of naturally eroded environments from the point of view of the impact of past erosion on productivity decline has only just begun. Whereas it is well known that erosion alters a number of soil functions in a manner that diminishes the productive capacity of the soil/crop system, yet only a few soil physico-chemical properties are impacted in a consistent and predictable manner in most soils. For tropical ultisols, the following factors – fine sand/coarse sand, Ca + Mg, $(Ca + Mg)/(Al + H)$ ratios, soil organic carbon and aluminum saturation are recommended as reliable predictors for the identification and delineation of erosion classes. However, this should be used in conjunction with the A horizon depth approach. More work is needed to set critical limits for these factors.

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