Research Journal of

Forestry

ISSN 1819-3439

Academic
Journals Inc.

www.academicjournals.com

Research Journal of Forestry 1 (2): 73-79, 2007
ISSN 1819-3439

Lithosequential Variability and Relationship Between Erodibility and Sodium Concentration in Soils of a Rainforest

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Abstract: This study was conducted in 2004 to investigate variability and relationship between sodium concentration and erodibility of soils formed over different lithologies. A free survey technique guided by the geological map of the study area was adopted in field sampling, which was followed by routine laboratory analyses. Soil data were subjected to Analysis of Variance (ANOVA) using PROC Mix-model of SAS computer software and correlation analysis. Results showed that soil groups had very low sodium concentration (Exchangeable Sodium Percentage = 0.3-1.4) and this trend was followed by depth distribution (Exchangeable sodium percentage = 0.5-1.2). Soils were highly erodible spatially (Dispersion Ratio = 28.7-83.7%) and with depth (Dispersion ratio = 62.7-65%). While soil dispersability had good relationship with bulk density ($R = 0.51$; $p = 0.05$), clay ($R = -0.62$; $p = 0.05$) and sand ($R = 0.66$; $p = 0.05$), it had non-significant relationship with exchangeable sodium percentage at the same level of probability. It becomes necessary to consider other edaphic and soil-related factors for more reliable assessment of erodibility factors in studied soils.

Key words: Erosion, parent materials, rainforest salinity, tropical soils

INTRODUCTION

Among several forms of enviroumental degradation occurring in the rainforest belt of the humid tropics, soil erosion by water is the most prevalent. It has reduced the productive capacity of soil through unfavourable changes in soil texture and nutrient losses. Soil erosion is associated with high silt-clay ratio of soil since it does not promote weathering and pedogenesis (Igwe *et al*., 1995). Physical damages caused by soil erosion include increased gravel and decreased silt and clay contents, increased bulk density, reduced total and macro-porosity, infiltration capacity and saturated conductivity (Mbagwu, 1988). Loss of soil productivity following soil erosion by water also manifested in unfavourable change in soil chemical fertility. Plant essential nutrients, such as nitrogen, phosphorus, potassium, calcium, magnesium and others are lost with runoff and sediments.

Biological parameters of soil fertility are adversely affected by soil erosion, Eroded soils contain less micro-and macro-organisms (Mbagwu, 1988) and this drastically reduces activity and transformations within the pedosphere.

Vulnerability of soils to erosive forces depends on among other factors the nature of soils (Igwe *et al*., 1995; Wang *et al*., 2001), land use and soil management practices (Fu *et al*., 1999; Hontoria *et al*., 1999) and a combination of land use and lithological formations (Kosmas *et al*., 2000). Organic matter is also considered a major binding agent that stabilizes soil structure (Haynes *et al*., 1991) and this is possibly achieved by chemical bonding of soil particles by fungal

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hyphae and plant Roots (Miller and Jastrow, 1990; Angers, 1998), a combined bonding mechanisms between clay and organic matter (Mikha and Rice, 2004). The above interactions and relationships with soil erodibility have been well documented in soils of southeastern Nigeria by Akamigbo (1983) Mbagwu (1988) Igwe *et al*. (1995) Igwe *et al*. (2002) Mbagwu and Auerswald (1999) and Igwe and Stahr (2004). While literature on the extent and severity of erosion of soils of southeastern Nigeria is voluminous, there is paucity of information on specific relationships between soil erodibility and sodium concentration of soils and their variability among different soil groups of the rainforest agroecosystem. But this knowledge would be helpful and fundamental in introducing effective and corrective measures aimed at preventing and minimizing catastrophic soil losses in the region. Based on the above, we investigated the differences and relationships between sodium concentration and soil erodibility in lithologically different soils of southeastern Nigeria. We hypothesized that these soils vary in their susceptibility to erosion due to variability in sodium concentration.

MATERIALS AND METHODS

Study Area

The study was conducted at central southeastern Nigeria comprising Abia and Imo States in 2004 and 2005. The site lies between latitudes $4°40^{1}10^{11}$ 210 and $8°15^{1}20^{11}$.110 N and longitudes $6°40^{1}05^{11}$. 210 and $8°15^{1}30^{11}$.310 E. The area is dominated by lowlands with few scarpy landscapes in a Northeast orientation. Soils are formed over six major parent materials namely Alluvium, Coastal Plain Sands, Falsebedded Sandstones, Lower Coal Measures, Shale and Upper Coal Measures. Annual rainfall ranges from 1800 to 2500 mm and characterized by 9 months of rainy season and 3 dry months. Rainforest vegetation dominates the study area with patches of marshlands along natural water bodies. Low-Input-low-output agriculture is the main socio-economic activity.

Field Studies

A reconnaissance study of the site was conducted in the early months of 2004 and this was quickly followed by field sampling which was guided by a base map derived from a geological map of the study area. A free survey approach involving a target sampling was used. On each soil group, 5 profile pits were dug, described and sampled according to the procedure of FAO (1990). Soil samples were collected from both surface and subsurface horizons although ‘soil erosion is more of a surficial phenomenon. Collected soil samples were air-dried, gently crushed and sieved using 2 mm sieve.

Laboratory Determination

Particle size distribution was determined by hydrometer method according to the procedure of Gee and Or (2002) using both water and sodium haxametaphosphate as dispersants. Exchangeable sodium was obtained through inductively coupled plasma spectroscopy on 1: 10 soil/Mehlich-3 extracts (Mehich, 1984) while cation exchange capacity was estimated using the procedure of Darmody *et al*. (2000).

Calculations

Dispersion ratio was used as an indirect measure of soil erodibility (Middleton, 1930) and computed as follows:

$$DR = \frac{\%\ \text{Silt} + \%\ \text{clay in water} - \text{Dispersed samples}}{\%\ \text{Silt} + \%\ \text{clay in sodium hexametaphosphate dispersed samples}} \times \frac{100}{1}$$

Where,
DR = Dispersion Ratio

Exchangeable sodium percentage was used as an index of sodium concentration and was calculated as follows:

$$ESP = \frac{\text{Exchangeable Na}}{\text{CEC}} \times \frac{100}{1}$$

Where,
ESP = Exchangeable Sodium Percentage
CEC = Cation exchange capacity (NH_4OAC)
Na = Sodium

Statistical Analyses

Soil data were subjected to Analysis of Variance (ANOVA) using the PROC Mix-model of SAS (Little *et al*., 1996). Means were separated using Standard Error of the Difference (SED) at 5% level of probability. Thereafter values of DR were correlated with some soil properties to ascertain degree of relationship.

RESULTS AND DISCUSSION

Soil Physical Properties

Soils were generally sandy although sandiness varied significantly ($p<0.0001$) among parent materials (Table 1). Similar variations were found in silt-and clay-sized particles (Table 1) and in their Silt-Clay Ratio (SCR). Soils were highly weathered as indicated in their low SCR (SCR = 0.023-0.64) (Table 1). There was non-significant ($p = 0.05$) relationship among soil groups in Bulk Density (BD) values (Table 1). Particle size distribution varied possibly due to differences in lithological materials at the regional scale while recorded similarities in sandiness and bulk density can be attributed to climate, land use and land use history of the study area. Least SCR encountered in soils derived from. Upper Coal Measures implies higher weathering and stability in line with the observation of Igwe *et al*. (1995) that the higher the SCR, the younger the soils and that higher SCR values are associated with landscapes devastated by soil erosion. But the SCR of Upper Coal Measures is in contrast with its BD value which is the highest among soil groups (BD = 1.47 mg m^{-3}), suggesting higher possibility of aggregate instability and erosive impact. This is because higher BD values suggests reduced porosity and higher build-up of runoff water and consequent deterioration of macro-aggregates (Park and Smucker, 2005) and intraaggregate pores (Paustian *et al*., 1997).

Sodium Concentration

Sodium saturation in soil groups differed but were generally very low in studied soils (Exchangeable Sodium Percentage <1.5%), while soils are said to be saline if ESP is greater 15% (Michael, 1985). Low sodium content of soils is attributable to the high rainfall amount and duration.

Table 1: Selected physical properties of studies soils (n = 150)

Parent material	Sand	Silt	Clay	SCR	BD (mg m^{-3})
	----------------------	($g\ kg^{-1}$)	----------------------		
Alluvium	808.4	42.0	149.6	0.28	1.45
Coastal plain sands	693.2	73.2	233.6	0.31	1.41
Falsebedded sandstones	744.0	72.8	183.2	0.39	1.45
Lower coal measures	485.6	201.6	312.8	0.64	1.42
Shale	376.8	131.2	492.0	0.26	1.45
Upper coal measures	835.2	31.6	133.2	0.23	1.47
SED (p = 0.05)	32.8	25.2	45.8	0.08	0.03
(Pr > t)	<0.0001	<0.0001	<0.0001	<0.0001	NS

SED: Standard Error of the Difference ; SCR: Silt-Clay Ratio; BD: Bulk Density; NS: Not Significant

Table 2: Distribution of ESP among soil groups (n = 15)

Parent material	ESP (%)	SED	Pr > (t)
Alluvium	1.4	0.45	0.0055
Coastal plain sands	1.1	0.45	0.0199
Falsebedded sandstones	1.2	0.45	0.0147
Lower coal measures	1.2	0.45	0.0112
Shale	0.3	0.45	0.4765
Upper coal measures	0.4	0.45	0.3172

ESP = Exchangeable Sodium Percentage, SED = Standard error of the difference in means

Table 3: Change in distribution of ESP with depth (n = 150)

Depth (cm)	ESP (%)	SED	Pr > t
0-20	1.1	0.21	<0.0010
20-40	0.5	0.21	0.0183
40-60	0.9	0.21	<0.0001
60-80	1.2	0.21	<0.0001
80-100	1.0	0.21	<0.0001

ESP = Exchangeable Sodium Percentage, SED = Standard error of the difference in means

Table 4: Parent material-depth interactions in ESP of soil of the study site (n = 150)

	Depth (cm)				
Statistics	0-20	20-40	40-60	60-80	80-100
Alluvium	1.5	0.3	1.5	1.6	1.7
SED	0.52	0.52	0.52	0.52	0.52
Pr > (t)	0.0042	0.5029	0.0048	0.0036	0.0014
Coastal plain sands	1.2	0.5	1.2	1.6	1.3
SED	0.52	0.52	0.52	0.52	0.52
Pr > (t)	0.00350	0.2120	0.0415	0.0065	0.0221
Falsebedded sandstones	1.2	0.5	1.2	1.6	1.3
SED	0.52	0.52	0.52	0.52	0.52
Pr > (t)	0.00203	0.3229	0.0211	0.0037	0.0172
Lower coal measures	1.2	0.5	1.2	1.6	1.3
SED	0.52	0.52	0.52	0.52	0.52
Pr > (t)	0.0051	0.0444	0.0353	0.0157	0.0359
Shale	1.2	0.5	1.2	1.6	1.3
SED	0.52	0.52	0.52	0.52	0.52
Pr > (t)	0. 4792	0.6249	0.05297	0.4585	0.5906
Upper coal measures	1.2	0.5	1.2	1.6	1.3
SED	0.52	0.52	0.52	0.52	0.52
Pr > (t)	0.1686	0.6143	0.5248	0.3285	0.3829

SED: Standard error of the difference in means

As rainwater percolates through the pedosphere, it dissolves and leaches away sodium cations which may accumulate in ground water, implying that the amount of Na-concentration in ground water may be proportional to the amount of soluble Na-cations leached out of top and sub soils. This is consistent with the observation of Dupriez and Deleener (1992) that rain water falling on the surface of a field causes soils to hardly be associated with any saltness.

Comparatively, soils formed over Alluvium had the highest ESP value, (Table 2) possibly due to marine influences, as sampled sites belong to the River Niger delta region of Southeastern Nigeria thus proximal to the influences of the Atlantic Ocean. Generally, Na-concentration varied and increased significantly ($p<0.05$) with depth (Table 3). Variability in depth distribution of Na-concentrations could be attributed to precipitation-dissolution reactions (Khoshgoftar *et al*., 2004). The distribution of pore sizes in the soil and boundary conditions (Hamlen and Kachanoskil, 2004), presence of restrictive zones (Shaw *et al*., 1997) and orientation of tubular pores in soils (Ezeaku and Anikwe, 2006).

Exchangeable sodium percentage values were mainly ouly significant ($p<0.05$) at epipedons when parent materials interacted with depth (Table 4) except in soils derived from Shale and Upper Coal Measures, possibly due to high micro-porosity of Shale derived soils and high bulk density in soils formed over Upper Coal Measures.

Table 5: Distribution of dispersion ratio among soil groups (n = 150)

Parent material	DR (%)	SED	Pr > (t)
Alluvium	68.0	6.98	<0.0001
Coastal plain sands	74.9	6.98	<0.0001
Falsebedded sandstones	83.7	6.98	<0.0001
Lower coal measures	43.1	6.98	<0.0001
Shale	28.7	6.98	0.0004
Upper coal measures	83.1	6.98	<0.0001

DR = Dispersion Ratio, SED = Standard error of difference in means

Table 6: Changes in dispersion ratio with depth (n = 150)

Depth (cm)	DR %	SED	Pr > t
0-20	62.8	3.06	<0.0001
20-40	64.0	3.06	<0.0001
40-60	63.5	3.06	<0.0001
60-80	62.7	3.06	<0.0001
80-100	65.0	3.06	<0.0001

DR: Dispersion Ratio; SED: Standard error of difference in means

Table 7: Parent material-depth interactions erodibility of soils of the study site (n = 150)

	Depth (cm)				
Statistics	0-20	20-40	40-60	60-80	80-100
Alluvium	68.2	63.0	69.2	68.8	71.0
SED	7.5	7.5	7.5	7.5	7.5
Pr > (t)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Coastal plain sands	77.2	76.4	77.2	74.0	70.0
SED	7.5	7.5	7.5	7.5	7.5
Pr > (t)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Falsbedded sandstones	76.2	89.4	86.2	79.4	87
SED	7.5	7.5	7.5	7.5	7.5
Pr > (t)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Lower coal measures	41.6	38.8	41.8	43.2	50.4
SED	7.5	7.5	7.5	7.5	7.5
Pr > (t)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Shale	29.8	20.8	27.0	28.2	27.8
SED	7.5	7.5	7.5	7.5	7.5
Pr > (t)	<0.0004	<0.0003	<0.0011	<0.0007	<0.0008
Upper coal measures	84.2	85.6	79.6	82.6	83.8
SED	7.5	7.5	7.5	7.5	7.5
Pr > (t)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

SED = Standard error of the difference in means

Erodibility

All investigated soils were erodible since dispersion ratio was greater than 15% in all soil groups (Table 5). Highest mean erodibility value was recorded in soils formed over Upper Coal Measures although it had least SCR (SCR = 0.23) and ESP (ESP = 0.4%) in line with reports from Mbagwu and Auerswald, 1999) indicating that the concentration of Na is not a major determinant in dispersion and erodebility of soil of the study area. In a similar study Mbagwu and Auerswald (1999) attributed soil structural instability and vulnerability to erosive forces to land use. However, the presence of various forms of sesquioxides in the region may be main factors determining erodibility of soils since iron, aluminum and manganese form bridges between clay and organic matter in the formation of stable aggregates (Igwe and Stahr, 2004).

Most studies in the area investigated surficial soil erodibility (Mbagwu, 1988; Igwe *et al*., 2002; Mbagwu and Auerswald, 1999), but results of this study (Table 6) show that sub-surficial layers are erodible and that erodibility increased somewhat with depth ($p>0.0001$). These values suggest that removal of epipedal layers paves way for rapid dispersion and erosion of deeper soil layers and this could be responsible for deep gullies in Southeastern Nigeria. There were significant ($p<0.0001$) interactions between parent materials and depth in erodibility of soils (Table 7), pointing to the need

Table 8: Correlation coefficients for linear relationships between dispersion ratio and some soil properties (n = 150)

Factors correlated	R
DR Vs BD	0.51*
DR Vs ESP	0.15NS
DR Vs Clay	-0.62*
DR Vs Sand	0.66*

DR: Dispersion Ratio; BD: Bulk Density; *: Significant at p = 0.05, NS = Not Significant

for both aspects in soil conservation modelling in the study area. However, there was non-significant relationship between DR and ESP in contrast to values obtained when DR related with BD, clay and sand, (Table 8) showing that particle size influences erodibility with clays being aggregating agents (Igwe and Stahr, 2004).

In conclusion, this study has revealed that low SCR may not serve as a good indicator of structural stability in the study area. Secondly the study has shown that ESP is not the major component determining variable in the erodibility of studied soils Again soils differed in their vulnerability to erosive forces in both space and depth, suggesting the need for their considerations in conservation modelling ventures. Large scale studies may be necessary in future investigation for increased accuracy of predictions. Finally, more attributes of soil resource should be investigated to create greater confidence.

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