Pedogenesis of calcium in degraded topical rangeland soil

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ABSTRACT: Studies were conducted in 2006 at a degraded forest- savanna rangeland in Uturu, Abia State, Southeastern Nigeria to investigate Calcium abundance and distribution in relation to some soil properties. A transect was used to link 4 soil profile pits dug for the study, representing summit (SM), upper slopes (US), middle slope (MS) and valley bottom (VS). Soil sampling was done based on degree of horizon differentiation. Soil samples were air-dried, and sieved using 2-mm sieve. Data were subjected to simple averages, analysis of variance (ANOVA) and regression analysis. Results indicated narrow calcium magnesium ratios showing predominance of leaching in influencing distribution and abundance of soil calcium. Bivariate and multivariate analyses identified organic Carbon, Clay, silt and soil pH as good predictors. There is need to increase number of samples for analysis to increase prediction certainty and reliability. [The Journal of American Science. 2007;3(2):23-29]. (ISSN: 1545-1003).

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INTRODUCTION

The spate of land degradation in the sub-Saharan Africa is a tropical issue especially in Southeastern Nigeria where soil erosion by water has been dissecting the landscape including rangeland. Land degradation is one of the consequences of mismanagement of land (Reich *et al*., 2001) and low –input low-output African farming (Badiane and Delgado, 1995). Inappropriate and conservation practices, such as continuous use of ammonium sulphate and potassium chloride fertilizers in the absence of magnesium fertilization threaten magnesium availability in these soils (Kayode, 1985).

Soil calcium is one of the macronutrients adversely affected in degraded soils of forest ranges in the Southeastern Nigeria. High rainfall amount and duration in the area encourage leaching of the basic cations, such as soil calcium from upper horizons thereby making them unavailable to arable crops and grasses. Even in undegraded rainforest soils, decline in soil calcium is evident. Similar findings in decline in exchangeable calcium were reported in European forest soils (Thimonier *et al*., 2001) and North American forest soils (Lawrence *et al*., 1997; Raben *et al*; 2000). It is possible that a lot of organic acids in these forest soils resulted in acidification and acid leaching of the forest soils.

Unavailability of sufficient soil calcium in the root zone has been associated with low productivity of some soils of Nigeria (Osemwota *et al*., 2003). Most arable and forage crop in the study area show symptoms of soil infertility while the trees look luxuriant. It is postulated that the variation is due to current status of soils calcium predogenesis especially as it affects the element's vertical distribution in the rangeland soils of the Southeastern Nigeria. Based on the above, we investigated the relationships between calcium abundance (CAB) and some properties of rangeland soils if southeastern Nigeria.

MATERIALS AND METHODS

Study area: The study was conducted in 2006 at a forest-Savanna rangeland in Uturu, Southeastern Nigeria. The Study site lies on latitude 5^0 59'27" N and longitude 7^0 40' 38" E, and with an altitude of 330 metres (Handheld Global Positioning System-GPS) Receiver (Garmin LTD, Kansas, USA). Soils were derived from the Lower Coal Measures (Mamu Formation) of the maestrichtian age and on rugged hills of the Nsukka-Okigwe Cuesta. Total annual rainfall ranges from 1750-2000 mm, and with a mean annual temperature range of 26-28^{0}C.It is of highly altered rainforest vegetation. Arable crops farming and nomadic animal husbandry are common. Farmers still hold tenaciously to clearing forest debris by burning. Mixed cropping is common. Soils are allowed to regain their fertility by bush fallow although few farmers apply inorganic fertilizer when available and affordable.

FIELD WORK

Soil samples were collected in 2005 from 4 pedons. In each horizon, 10 soil samples were collected to improve results of laboratory tests. Soil samples were collected based on the degree of horizon differentiation. Pedons were linked with the aid of a transect at an inter- pedon distance of 100 metres. The pedons covered the Summit (SM), Upper slopes (US) , Middle slope (MS) and Valley bottom (VB) on a leeward side of the hilly landscape. These physiographic units represented 4 morphologically distinct vegetation types, namely grassy summit, sparsely grassy upper slope, overgrazed midslopes, and thickly vegetated valley bottom. Five core samples were collected from each horizon and then averaged to obtain representative data as given in Table 2. Soil samples were air –dried, crushed and sieved using 2-mm sieve, preparatory to laboratory analysis.

Laboratory analysis: Particle size distribution was estimated by hydrometer method (Gee and Or, 2002). Results of particle size analysis were used to calculate silt-clay ratio. Bulk density was determined by core method according to the procedure of Grossman and Reinsch, 2002. Soil organic carbon (OC) was measured by wet digestion (Nelson and Sommers, 1996). Cation exchange capacity and exchangeable cat ion were determined with neutral I N ammonium acetate (Thomas, 1982). Soil pH was measured with an electrode on a 1:2 soil –water solution (Headershot *et al*., 1993). Total nitrogen was determined by microkjeldal method (Bremner, 1996).

Data analysis: Soil data generated were subjected to simple averages, analysis of variance (ANOVA), mean separation of significant treatment effects and computer based step-wise regression analysis (Little *et al*., 1996) to determine predotransfer functions (PTFs). The PTFs are step-wise regression equations that relate soil properties of importance to production and resource management to basic easily measured soil properties (Larson and Pierce, 1991)

Results

Calcium abundance (CAB) was related to some soil properties and results are shown in Table 5, indicating moderate to strong bivariate correlation ($p<0.05$) with calcium abundance, while bulk density (BD) was insignificant.

Pronounced human activities were observed in upper and middle slopes. Prominent morphological features are given in Tables 1and 2. Least horizon thickness was reported in the MS unit (0-4cm) while the thickest A-horizon was found in VB (0-17 cm). Soils were generally sandy and with weak granular structures, and friable soil consistence dominated the study site.

Results of physical properties of soil samples from profile pits are shown in Table 3.Soils of the study site were deep (greater than100 cm). Sand- sized particles dominated other particle size fractions while silt was the least and most stable throughout the study site. Clay content increased with depth. Parent materials have been exposed to the weathering processes for a long period based on very low silt- clay ratios. Generally, bulk density increased with depth of soils, with highest values recorded in MS soil unit. (pedon3) and least in VB soil unit (Pedon 4).

Soil chemical characteristics of the study site are presented on Table 4. Soils were strongly acidic with soil pH ranging from 3.5 to 4.9. Middle slope soils (Pedon 3) exhibited the strongest soil acidity and thus was strongest in eluvial horizon-s while lowest acidity values were recorded in deeper layers. Highest CEC values were recorded soil OC ranged from 20 to 80 g kg-1 on surface soils. Soil OC decreased with depth in all the pedons. The same trend was allowed by soil total nitrogen (TN) , carbon – nitrogen ratios were highest at surface horizons and decreased with dept in all investigated soils.

Generally, higher values of Ca were found in the deeper horizons, especially in MS and VB soil units represented by Pedons 3 and 4, respectively. In all, narrower ranges of calcium magnesium ratios were observed in the surface horizons (A- horizons). Calcium abundance (CAB) was related with some soil properties and results are shown in Table 5

Showed moderate to strong bivariate correlation (p<_0.05 with calcium abundance, with bulk density (BD) insignificant. The combination of predictors that showed significance (P<_0.05) with calcium abundance (CAB) resulted to in a fairly good prediction (R^2 =0.45; P<_ 0.01)

Soil classification: Soils of the study site represent typical ultisols with udic moisture regime. Slight variations were abound as soils of SM (Pedon 1)which had sandy particle size class throughout a layer extending from the mineral soil surface to the top of an argillic horizon at a depth greater than 100 cm, hence classified as Grossarenic Paleudults (Soil Survey Staff 2003). Based also on the criteria of Soil Survey Staff (2003), other units went classified as Arenic Rhodic Paleudults (Pedon 2 and 3) and Typicpaledult (Pedon 4).

Table 1. Brief description of sampling points

Pedon	Physigraphic position	Description
1	Summit (SM)	Mainly grasses few Acica, barteri, and Bambusa Valganis Zero ills erosion.
2	Upper Slop (US)	Mainly grasses but scanty minimal ills erosion
3	Middle Slopes (MS)	Bare surface, few sparsely distributed rhizomatous grasses sheet and rill erosion. Grazing tracks Trees, Shrubs and few grasses zero rill erosion
4	Valley bottom (VB)	Trees, shrubs and few grasses zero rill erosion.

Table 2. Selected near –surface features of soils of the study site

Pedon	Depth of a horizon cm	Colour (moist)	Texture	Structure (Type)	Consistence (Moist)	Horizon Boundary
1	0 -11	RB(5yr ^{8}/4)	LS	Weak granular	Very friable	Clear
2	0 –9	DR(2.5 YR ^{3}/6)	SL	Weak granular	Friable	Gradual
3	0 –4	R (2.5 yr^4/6)	SCL	Weak sub angular blocky	Friable	Gradual
4	1 –17	DR (2.5 yr ^{3}/6)	SL	Crumbs	Very friable	Distinct.

Colour: RB =reddish brown, DR = dark red, R = red
Texture: Ls =Loamy sand, SL = Sandy Loam, SCL = Sandy clay loam

Table 3. Selected soil physical characteristics

Horizons	Depth (cm)	Sand (g kg $^{-1}$)	Clay (g kg $^{-1}$)		SCR	BD (m gm $^{-3}$)
Pedon 1 (Grossarenic Paleudults)						
A	0 –11	850	20	130	0.2	1.42
E	11 –75	850	30	90	0.3	1.46
Bt_1	75 –118	750	20	230	0.1	1.49
Bt_2	120-169	670	20	310	0.1	1.51
Pedon 2 (Arenic Rhodic Paleudults)						
A	0 –4	720	20	260	0.1	1.51
Bt_1	4 – 90	610	30	360	0.1	1.58
Bt_2	90-185	620	20	360	0.1	1.61
Pedon 3 (Typic Paleudults)						
A	0 –17	700	40	260	0.2	1.36
E	17 -48	710	50	240	0.2	1.39
Bt_1	48 –88	680	30	290	0.1	1.43
Bt_2	88 –110	670	20	310	0.1	1.44
Bt_3	110 –140	775	10	215	0.1	1.46

SCR = Silt clay ratio, BD = bulk density (Mg m-3)

Table 4. Selected Soil Chemical characteristics

Depth (cm)	pH (0.1 N KCl)	CEC (cmo 1kg^{-1})	Ca (cmo1 kg^{-1})	Mg (cmo1 kg^{-1})	Ca: Mg	OC g kg-1	TN (g kg^{-1})	C/N
Pedon 1 (Grossarenic Paleudults)								
0 –11	4.2	6.0	0.5	0.3	1.67	60	5	12
11-75	4.0	4.0	0.4	0.3	1.33	20	2	10
75 –118	4.3	6.2	0,4	0.4	1.00	10	1	10
118-170	4.4	6.8	0.3	0.2	1.50	5	1	5
Pedon 2 (Arenic Rhodic Paleudults)								
0-9	4.1	5.0	0.5	0.4	1.25	40	4	10
9-79	3.9	4.1	0.2	0.7	0.28	15	3	5
79-120	4.2	5.2	0.4	0.4	1.00	10	2	5
120-169	4.3	5.7	0.6	0.3	2.00	3	1	3
Pedon 3 (Arenic Rhodic Paleudults)								
0-4	3.8	4.0	0.3	0.3	1.00	20	2	10
4-90	3.5	3.6	0.6	0.3	2.00	10	1	10
90-185	4.5	4.5	0.6	0.2	3.00	4	1	4
Pedon 4 (Typic Palendults)								
0-17	4.5	6.8	0.3	0.1	3.00	80	7	11

17-48	4.2	4.6	0.3	0.2	1.50	45	4	11
48-88	4.6	6.3	0.8	0.2	4.00	13	2	6
88-110	4.9	7.0	0.9	0.3	3.00	10	2	5
110-140	4.4	6.0	0.4	0.1	4.00	5	1	5

CEC =cat ion exchange capacity, Ca =Calcium, Mg =magnesium.
OC = organic carbon, TN =total nitrogen.

Table 5. Pedotransfer functions relating calcium abundance and some soil properties at surface horizon

Predictor(s)	Regression equation	R	R^2	N
OC	CAB =86.109+3.13 OC	0.55	0.28	40
BD	CAB =81.006-4.181 Bn	0.19^{ns}	0.04	40
CC	CAB =92.216+1.21CC	0.68	0.46	40
SC	CAB =85.371+0.52 SC	0.45	0.20	40
P^H	CAB =48.125+0.85 pH	0.77	0.57	40
OC, CC, SC, pH	CAB =82.670+1.780C +1.36CC 1.12 pH +0.61SC –0.97	0.67	0.45	40

OC = Organic carbon, BD = Bulk density, CC =Clay content, SC= Silt content, CAB = calcium abundance. Significant at P<_ 0.01,x significant at P =0.05, ns not significant.

DISCUSSIONS

Translocatory pedogenic process involving loss of silt and clay-sized particles from upper horizon may have influenced their redistribution and illuviation in deeper horizons. Clay- sized particles are negatively charged on which cationic calcium (Ca^{2+}) adsorbs, and this adsorption is substantial, since clay has large surface area (Kaiser *et al*., 1996). Because soils were deep, there was considerable leaching and eluviations towards the deeper horizons in the study area (Esu, 2005). Higher values of exchangeable Ca in the illuvial horizons with argillation which resulted from losses encountered in the eluvial and epipedal horizons; Ca values were low but were deposited downward. This may have caused the low Ca/Mg ratio in surface horizons.

However, Pedons 2 and 3 representing US and MS, soil units respectively had the narrowest Ca/Mg ratios, possibly due to poor vegetative cover. Generally, it was observed that Ca/Mg ratio values were below 3.0, suggesting unavailability of calcium and phosphorus (Landon, 1984) and this effect is especially serious in acidic soils (Oti 2002). These results indicate soil infertility, and consequent low yield of plant biomass. This becomes critical since most of the plants are grassed forage with fibrous root system and lack the capacity to extend to deeper horizons in the search for leached nutrients, including exchangeable calcium.

Soil acidity had a positive significant correlation (P=0.05) with calcium abundance implying that the higher the pH, the greater the CAB. The soil pH acidity was buffered by the destruction of silicates, and adsorption of basic cations (Schwertmann *et al* 1987). Relatively higher values of total nitrogen in VB soils could be due to deposition of sediment from higher physiographic position of the study site. Effect of nitrogen on soil calcium is obvious, since negatively charged nitrates attract positively charged calcium cations, forming calcium nitrates in soils. Nitrogen deposition adds nitrate as a mobile anion and leads to cation loss (Jandl *et al*., 2004), and consequent illuviation in deeper horizons. The mobile nitrate bound Ca may be adsorbed in deeper horizons say by ferrihydrites (Lilienfein et al., 2004) while dissolved nitrogen joins the surface and ground waters (Lawis, 2002).

CONCLUSION

Soil calcium loss is evident in the site based on the results of the study, and below critical levels. The study also concluded that leaching is the predominant translocatory, pedogenetic process since narrow Ca/Mg ratios were recorded at surface horizons. A good prediction of calcium abundance is possible in the area using organic carbon, clay content, silt content and soil pH in a multivariate analysis. More intensive sampling and inclusion of more variables as predictors will certainly improve model reliability for pedotransfer functions in the soils of study area.

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