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Variability of some soil properties along a toposequence in a basaltic parent material of Vom, Plateau State Nigeria

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ABSTRACT

Topography influences the distribution of some soil physical and chemical properties. This study assessed some variation in soil properties resulting from the topographic effect on Basaltic parent material at Vom Jos Plateau State in the Southern Guinea zone of Nigeria. Soil samples were collected at an interval of 20 m and at depths of 0 to 15cm and 15 to 30 cm, parceled, labeled and taken to the laboratory for analysis of selected soil properties. The results from the study revealed that variations in soil properties along the landscape segments were probably due to their positions on the toposequence in the soil studied. Clay, silt and gravel contents varied moderately (CV = 22.9, 15.42 and 32.55% respectively), while sand did not vary much (CV = 8.47%). Organic carbon showed high variability (CV = 38.08%) while soil pH in (H_2O and $CaCl_2$) showed less spatial variability (with CV = 4.91 and 6.45% respectively). Available phosphorus has high variability (CV = 37.59%). Magnesium, K and Ca showed high spatial variability (CV = 42.60, 35.85, and 35.84% respectively), while Na and exchange acidity were moderately variable (CV = 24.39 and 24.27% respectively). Generally, some of the soil chemical properties were varied with topographic positions.

1. Introduction

The spatial variation of soil properties is significantly influenced by some environmental factors such as topographic position, microclimatic differences, parent materials, and vegetation communities (Chen *et al*., 1997; Sharma *et al*., 1999; McKenzie and Ryan, 1999; Johnson *et al*., 2000; Ollinger *et al*., 2002; Yimer *et al*., 2006). Topography as a soil-forming process is affected by erosion and deposition, thus leads to differentiation in soil properties and hydrological conditions (Lawal *et al*., 2014). Topography plays a major role as one of the factors that influence pedogenesis and in the process that dictates the distribution and use of soils on the landscape (Esu *et al*., 2008). The concept of toposequence results in soil properties differentiation along hill slope and within soil horizons, which have improved evaluating the interaction of pedogenic and geomorphic processes (Gessler *et al*., 2000). The influence of topography as a variant in soil properties has accounted for between 26 and 64% total variation in soil properties (Cox *et al*., 2002; Wilson *et al*., 2004; Samndi and Mahmud 2014). Variation in soil properties has been known and has been the subject of much research, as horizons may differ in organic matter content, structure, texture, pH, base saturation, cation exchange capacity (CEC), bulk density and water holding capacity, as well as many other soil physical and chemical properties. Variability of soil pH, for example, increases with depths (Lark and Wheeler, 2000).

In Nigeria, an increase in population growth has posed an increasing demand on land resources, leading to the cultivation of soils on slopes and tilling soil without proper soil management. Studies on the variation of soil properties along toposequence were conducted much in Forest ecologies compared to savanna biomes. Therefore, this study evaluates the status and distribution of the soil properties along toposequence on Basaltic parent materials in the Southern Guinea savanna of Nigeria.

2.0 Materials and methods

The Study Area

The study location was Vom, Jos Plateau State situated between longitude 08^0 45' 01 to 8^0 47' 56E'' and latitude 9^0 43' 17 to 9^0 45' 15N, with an elevation of about 1270m above sea level. It has a mean annual rainfall of about 1258mm and temperature of 24^{0}C. The soils of the study area were derived from Newer Basalts material with Ustic soil moisture and Isohyperthermic temperature regime, respectively (Eswaran *et al*., 1997).

Sample Collection and Preparation:

Geographic Position System (GPS) was used to obtain the coordinates of the respective sampling sites, which were identified using the stratified purposive sampling procedure. Soil sampling was carried at 20m intervals, at depth of 0-15cm and 15-30cm at each sampling points. Soil samples were obtained along the North-Eastern axis in three replicates.

Laboratory Analysis

The bulk soil samples collected were air-dried, gently crushed, and passed through 2mm sieve to remove coarse fragments. The soil pH was determined in water in the ratio of 1:2.5 soil-water suspensions and read with a glass electrode pH meter (Blackmore *et al*., 1987). Particle size analysis was carried out by the use of hydrometer (Bouyoucos, 1951). Available P was determined using Bray ascorbic acid method (Bray and Kurtz, 1945). Organic Carbon percentage was determined using Walkley and Black method as described by (Nelson and Sommer, 1982). Exchangeable C and Mg were determined using EDTA titration methods as outlined by (Chang and Bray, 1951) while exchangeable Na and K were determined using flame photometer following procedure by (Chapman, 1965). Exchangeable acidity was determined by saturating the soil samples with potassium chloride solution and titrated with sodium hydroxide (Mclean, 1965).

Statistical Analysis

The data was subjected to descriptive statistics, analysis of variance (ANOVA) and correlation analysis using SAS 9.0 statistical software. Coefficient of variability was used for the variability analysis where CV < 15% classified as less variable, CV between 15 to 35% classified as moderately variable, and CV > 35% classified as highly variable.

3.0. Results and Discussion

Status, Variability and Distribution of Soil Particle Size and Gravel Content

From Table 1, irrespective of the slope location sand is the dominant particle size fraction (ranged from 49.20 to 70.60 %), followed by silt (19.40 to 33.40%), with clay been the lowest (7.40 to 25.40%). The gravel content ranged from 15.56 to 67.53%, with a mean of 34.5% (Table 1). Clay, silt and gravel content are moderately spatially variable (CV = 22.9, 15.42 and 32.55% respectively), while sand showed less variability (CV = 8.47%). Clay content was highly skewed (skewness = 1.43) with silt, sand, and gravel approximately symmetrical (Table 1). The analysis of variance in Table 2, showed a highly significant difference in gravel content and significant difference in clay content along a toposequence, while sand and silt were at far. Although there was no regular pattern of distribution along the slope in clay and gravel contents, the highest mean value was observed at uppermost slope location (1348masl) and similar/lower values observed at 1341 and 1327masl respectively. All the sampling points along the toposequence were sandy loam (Table 2).

The dominant of sand fraction over silt and clay could be due to the sorting of the soil materials and biological activities, clay eluviation and surface erosion or combination of both as reported by (Malgwi *et al*., 2000; Voncir *et al*., 2008). The dominance of sand fraction might result in low or poor moisture retention capacity of the soil, especially if organic matter content is low.

Status, Variability and Distribution of Soil pH, Organic Carbon and Available Phosphorus

Generally, pH (H_2O) was higher than pH ($CaCl_2$). The values of pH (H_2O) were between 5.75 to 7.40, while pH ($CaCl_2$) ranged from 5.13 to 7.30. Organic carbon ranged from 0.76 to 3.11%, with a mean of 1.92% (Table 3). The soil available phosphorus (Table 1) ranged from 4.82 to 25.00mgkg^{-1}). Soil pH in (H_2O and $CaCl_2$) showed less spatial variability (with CV = 4.91 and 6.45% respectively) with organic carbon and available phosphorus being highly variable (CV = 38.08 and 37.59% respectively). Available Phosphorus data were moderately skewed (skewness = 0.55) with pH (H_2O), pH ($CaCl_2$), and organic carbon content skewed symmetrically in Table 1.

The Analysis of Variance showed a highly significant difference in pH ($CaCl_2$), with pH (H_2O) and organic carbon content being statistically similar along the toposequence (Table 2). Soil pH (H_2O) values along the slope were slightly acid to neutral. There was no regular distribution pattern in pH ($CaCl_2$), along the slope despite values being significant. Similarly, soil pH (H_2O) and pH ($CaCl_2$) were statistically higher in surface (0 to 15cm) than the subsurface (15 to 30cm) horizons. The distribution of available phosphorus (Table 3) along the slope was statistically significant ($P \leq 0.05$). Highest mean of available phosphorus was observed on middle slope position (1327masl, and lower values were observed on (1315masl). Organic carbon (Table 2) and available phosphorus (Table 3) contents decreased with soil depth even though values were at par. All the pH values were within the acceptable range for normal crop growth and development (Brady and Weil, 2006). Therefore, no potential acidity or alkalinity problem along the sequence. The organic carbon content was moderate to very high in status, while available phosphorus was moderate.

Table 1: Descriptive Statistics of the Studied Soil Parameters

Property	Mean	Max	Min	STD	Skewness	Kurtosis	CV (%)
Gravel (%)	34.50	67.58	15.56	11.22	0.39	-0.25	32.55
pH (H_20)	6.60	7.40	5.75	0.32	-0.10	0.40	4.91
pH ($CaCl_2$)	5.99	7.30	5.13	0.39	0.50	0.72	6.45
OC (%)	1.92	3.11	0.76	0.73	0.10	-1.25	38.08
Av. P (mg/kg)	11.93	25.00	4.82	4.49	0.55	-0.13	37.59
Na (cmol/kg)	0.16	0.29	0.08	0.04	0.96	2.44	24.39
K (cmol/kg)	0.35	0.92	0.10	0.13	1.36	4.33	35.85
Ca (cmol/kg)	3.27	5.50	1.00	1.17	0.26	-0.99	35.84
Mg (cmol/kg)	0.68	2.10	0.42	0.29	1.66	6.15	42.60
Ex. Acidity (cmol/kg)	1.70	3.17	0.33	0.41	0.59	3.91	24.27
Clay (%)	13.04	25.40	7.40	2.99	1.43	3.64	22.90
Silt (%)	25.96	33.40	19.40	4.00	0.10	-0.91	15.42
Sand (%)	61.00	70.60	49.20	5.16	-0.50	-0.22	8.47

Max = maximum, Min = minimum, Av. P = available Phosphorus, Na = exchangeable sodium, K = exchangeable potassium, Ca = exchangeable calcium, Mg = exchangeable magnesium, Ex. Acidity = exchangeable acidity, STD = standard deviation, CV = coefficient of variation, OC = organic carbon

Status, Variability, and Distribution of Exchangeable Bases and Exchangeable Acidity

Exchangeable calcium was the dominant basic cation in the exchange complex with a range of 2.17 to 4.00cmol/kg, followed by exchangeable Mg (ranged between 0.50 to 0.83cmol/kg), then exchangeable K (ranged between 0.27 to 0.52cmol/kg) and Na (varied between 0.12 to 0.21cmolkg^{-1}). Exchangeable acidity ranged from 0.33 to 3.17cmol/kg with a mean value of 1.70cmol/kg. Exchangeable Mg, K and Ca showed high spatial variability (CV = 42.60, 35.85, and 35.84% respectively), while Na and exchange acidity values were moderately variable (CV = 24.39 and 24.27%). Exchangeable K and Mg were highly skewed (skewness = 1.66 and 1.36). Exchangeable Na and acidity were moderately skewed (skewness = 0.96 and0.59), while Ca skewed symmetrically (skewness = 0.26).

The Analysis of Variance showed significant differences in the contents of exchangeable Na and K along a toposequence (Table 3), while exchangeable Ca, Mg, and acidity were at par. There was no regular pattern of along a slope position in terms of exchangeable Na and K distribution, the highest mean values were observed at uppermost slope location (1348masl) and the lowest at (1315masl) for exchangeable Na, while K has the highest mean value at (1304masl) and lowest at (1333 and 1315masl). Distribution with depth, exchangeable Na was statistically higher in the subsurface horizon compared to the surface, which was contrary to exchangeable K distribution along the two depths.

The exchangeable bases (Ca, Mg, Na, and K) were rated as low to moderate; similar results were also obtained in soils from Bauchi and Gombe, respectively (Kparmwang, 1993). This might be attributed to low CEC, indicative of leaching/ erosion and presence/dominance of 1:1 Kaolinitic and Fe and Al oxide clays. Exchange acidity values were high (more than 1cmol/kg) across all the depths and slope positions, which surprising because all the pH values were above the critical level 5.5 below which acidity problem could be potential. In general, the physical properties of the sampled soils were less variable than the chemical properties. The findings of this study are similar to the outcome of (Amuyou *et al.*, 2013), who also observed that soil physical properties tend to be less variable than the chemical properties.

Table 2: Distribution of particle size fractions, gravel content, pH and organic matter along a slope and soil depth

Treatment	Clay (%)	Silt (%)	Sand (%)	Textural class	Gravel (%)	pH (H_2O)	pH ($CaCl_2$)	OC (%)
Slope (S)								
1348m	16.00a	26.73	57.30	SaL	30.29c	6.80	6.39a	1.75
1343m	15.63ab	28.40	55.97	SaL	37.10bc	6.33	5.89cde	2.00
1341m	10.43c	27.10	62.50	SaL	29.61c	6.60	5.99bcde	1.12
1339m	13.90abc	27.73	58.40	SaL	32.04bc	6.61	6.03bcd	2.02
1333m	11.83bc	24.10	64.10	SaL	29.34c	6.50	6.13abc	2.43
1327m	11.70c	26.73	61.60	SaL	32.12bc	6.81	6.30ab	1.70
1320m	12.43abc	24.73	62.83	SaL	33.79bc	6.50	5.66e	1.77
1315m	14.33abc	23.10	62.60	SaL	32.90bc	6.35	5.79cde	2.12
1311m	14.23abc	26.73	59.03	SaL	35.80bc	6.48	5.69de	2.40
1304m	12.23abc	24.73	63.03	SaL	54.99a	6.59	6.10abc	2.07
1298m	12.13abc	26.10	61.80	SaL	44.92ab	6.66	5.96bcde	1.75
1292m	11.73bc	25.40	62.87	SaL	25.97c	6.58	5.92cde	1.95
SE±	1.18	1.56	1.89		4.04	0.11	0.11	0.29
	*	NS	NS		**	NS	**	NS
Depth (D)								
Surface	13.10	26.40	60.53		35.13	6.64a	6.20a	2.03
Subsurface	13.02	25.51	61.50		33.84	6.50b	5.78b	1.82
SE±	0.48	0.64	0.77		1.65	0.05	0.04	0.12
	NS	NS	NS		NS	*	**	NS
Interaction								
S*D	NS	NS	NS		NS	NS	NS	NS

Means followed by the same letters are not significantly different (significant differences at $P < 0.05$ and 0.01, * and ** indicate the significance levels at $P < 0.05$, and $P < 0.01$ respectively, SaL = sandy loam, SE = standard error, NS = not significant, S = slope, D = depth,

Table 3: Available phosphorus, Exchangeable bases and Acidity along a Slope and Soil depth

Treatment	**Av. P (mg/ kg)**	**Na (cmol/ kg)**	**K (cmol/kg)**	**Ca (cmol/kg)**	**Mg (cmol/kg)**	**Ex. Acidity (cmol/kg)**
Transect (T)						
A(0m)	13.98a	0.21a	0.40ab	2.96	0.76	1.60
B(20m)	12.20ab	0.14bc	0.40ab	3.33	0.76	1.81
C(40m)	13.59a	0.17bc	0.38b	3.50	0.69	1.72
D(60m)	7.63b	0.18ab	0.29b	2.96	0.69	1.61
E(80m)	10.95ab	0.13c	0.27b	3.42	0.60	1.42
F(100m)	15.58a	0.16bc	0.40ab	2.17	0.50	1.40
G(120m)	12.10ab	0.17abc	0.30b	4.00	0.76	1.97
H(140m)	7.30b	0.12bc	0.27b	3.71	0.69	1.83
I(160m)	10.40ab	0.15bc	0.32b	3.67	0.60	1.61
J(180m)	13.52a	0.16bc	0.52a	3.25	0.83	1.89
K(200m)	13.40a	0.15bc	0.37b	3.75	0.69	1.83
L(220m)	12.70ab	0.16bc	0.33b	2.63	0.69	1.80
SE±	1.74	0.01	0.04	0.47	0.13	0.18
	*	*	*	NS	NS	NS
Depth (D)						
Surface	11.82	0.15b	0.40a	3.32	0.66	1.70
Subsurface	12.05	0.17a	0.32b	3.23	0.71	1.72
SE±	0.71	0.01	0.02	0.19	0.05	0.07
	NS	*	**	NS	NS	NS
Interaction						
T*D	NS	NS	NS	NS	NS	NS

* and ** indicate the significance levels at P < 0.05, and P < 0.01 respectively

Summary and conclusion

The result revealed that topography influences the distribution of soil physical and chemical properties across the different slope positions. Soil pH was within the optimum range for normal crop growth and development, organic carbo, and available phosphorus were moderate to high in status, exchangeable bases were low to moderate. Sodium found to increase with increasing soil depth as opposed to pH and potassium, which significantly decreased with increasing depth. For optimum crop production, moderate application of phosphorus and exchangeable bases are required, and more in-depth research should be conducted to understand the pattern of distribution of soil properties along toposequence in the studied area.

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