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Spatial Changes in the Distribution of Exchangeable Cations in Soils of a Forested Hilly Landscape

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Abstract: The study quantified spatial variability in exchangeable basic cations in soils of forested hilly terrain in 2006. A transect technique was used in aligning profile pits along three physiographic units of interfluve, colluvial footslope and channel bed. Collected soil samples from the profile pits were analysed using routine and special laboratory techniques. Soil data were subjected to conventional and geostatistical analyses. Exchangeable cations varied spatially and vertically irrespective of physiographic position. Strong degree of spatial dependence was exhibited by these cations in epipedal horizons while moderate degree of spatial dependence dominated in their subsurface distribution using nugget values. Values of coefficient of variation confirm pronounced anisotropy among these attributes in their vertical distribution. Studies in exchange chemistry and other related edaphic properties using other multivariate techniques will enhance knowledge gained in this study.

Key words: Cations, geostatistics, pedometrics, terrain, variability, vegetation

INTRODUCTION

Soil ions vary in time and space. Such temporal and spatial variability in ion and nutrient content of soils could be in response to landscape and landuse (Wang *et al*., 2001; Tan *et al*., 2003; Onweremadu, 2007a), parent material (Kosmas *et al*., 1993), local carbon distribution (Hobbie, 1996), pedogenesis (Brubaker *et al*., 1993), deforestation activities (Mainville *et al*., 2006) and the extent of these changes is scale-dependent (Stutter *et al*., 2004). These differences in soil properties are also related to environmental processes (Park and Vlek, 2002) which vary according to physiographic position. Variability in soil properties and the relevance of its knowledge for sustainable management of soil and other ecological resources aroused the interest of scholars in using geostatistical approaches such as variogram (Webster, 1985) and kriging (Yost *et al*., 1982), because the concept of variability has attracted controversies (Neal, 1996). Studies on spatial distribution and chemistry of ions have been published (Mallarino, 1996; Anderson-Cook *et al*., 1999; Paz-Gonzalez *et al*., 2000). While Paz-Gonzalez *et al*. (2000) reported significant differences in soil properties in response to manipulations of intensive management, anisotropy could be a product of pedogenesis over time (Birkeland, 1999). In micro-morphological studies, Weisenborn and Schaetzl (2005) observed an eluviation and microerosion of soil constituents and this can influence re-distribution of exchangeable ions in soils.

Landscape studies in southeastern Nigeria and other developing areas are scanty. Few existing studies (Eshett *et al*., 1989; Onweremadu, 2007b) were holistic or did not investigate exchangeable cations. Onweremadu (2007b) evaluated soil carbon in soils of a hilly landscape. But landscape studies in the rainforest belt of southeastern Nigeria is important considering the spate of soil erosion in the

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area (Igwe, 2003) and possibility of increased re-distribution of cations by runoff and leaching activities. Billett and Cresser (1996) reported relationships between runoff from stream catchment, buffering capacity and solute transport in an agroecology different from rainforest belt of southeastern Nigeria. This could be why Suarez and Goldberg (1994) modelled soil solution to soil forming processes. Based on the above we investigated the variability of exchangeable cations in soils of a forested hilly landscape in Ohafia, Southeastern Nigeria, hypothesizing that they varied among physiographic positions.

MATERIALS AND METHODS

Study Area

This study was conducted at Ebem Ohafia, Southeastern Nigeria in 2006. Ohafia is in Abia State, southeastern Nigeria and lies on latitude $5^{0}52^{1}29.670^{11}$ N and longitude $7^{0}54^{1}25.240^{11}$ E. Soils of the study site are derived from Lower Coal Measures (Mamu Geological formation) of the maestrichtian age. The geological material contains sandstones, shales, mudstones and marine intercalations. It lies within the Nsukka-Okigwe Cuesta which swings southwards, terminating at Arochukwu. It is characterized by rugged hills. Soils of the area were classified as Dystropeptic Tropustults (USDA Soil Taxonomy) (Onweremadu *et al*., 2006). It lies within the humid tropical climate, with annual rainfall ranging from 1750-2000 mm and a mean annual temperature range of 26-28°C. It has a rainforest vegetation, having multiple tree species of herbs, shrubs and trees in geographical association. Farming is a major income-generating activity of inhabitants, who stick almost tenaciously to traditional farming technologies.

Field Sampling

Aided by the transect technique, thirty six pedons representing 3 physiographic units, namely Interfluve (IF), Colluvial Footslope (CF) and Channel Bed (CB) were dug and described according to the procedure of FAO (1990). In each land unit, 12 pedons were dug at 20 m interval. In a similar study, Brubaker *et al*. (1993) used six categories of landscape positions including upper interfluve, lower interfluve, shoulder, upper linear, lower linear and slope. All field studies were conducted before the rains in 2006. Soil samples were collected from the pedons starting from bottommost horizon upwards based on the degree of horizon differentiation. Two major horizons namely surface and subsurface horizons were used for the study. Collected soil samples were air-dried, crushed gently and sieved with 2 mm sieve in readiness for Laboratory analyses. Core samples, measuring 15 cm long with a diameter of 10 cm were used to collect soil samples from both surface and subsurface horizons for bulk density and hydraulic property studies.

Laboratory Techniques

Bulk density was measured by core method (Grossman and Reinsch, 2002). In this determination, undisturbed cores (10 cm diameter; length 15 cm) excavated from surface and subsurface horizons were used. In the laboratory, the polyvinyl chloride casing used for packing and transporting soil cores were carefully removed from each column. Then each column was coated with 5-8 mm layer of paraffin to seal the column walls against side flow and creation of crevices between the wall of the casing and soil. This approach would equally circumvent possible overestimation of saturated hydraulic conductivity (Ks) in each column. The soil column were gradually wetted from the bottom. After wetting, two 10 cm staiuless steel probes were inserted horizontally to monitor the volumetric water content by using time domain reflectometry (Carlan *et al*., 1985) while saturated hydraulic conductivity (Ks) was determined using the constant-head method (Klute and Dirksen, 1986). A 0.025 mol L^{-1} of KNO_3 solution was used to minimize clay dispersion in this study.

Particle size distribution was determined by hydrometer method according to the procedure of Gee and Or (2002). Soil pH in water was measured potentiometrically using 1:1 soil-solution ratio as described by Hendershot *et al*. (1993). Cation Exchange Capacity (CEC) was determined using the method of Anderson and Ingram (1998a). Concentrations of K and sodium extracted using neutral ammonium acetate were estimated by flame photometry while exchangeable Ca and Mg were measured using atomic absorption spectroscopy which employed suitable matrix matching. Organic matter was determined according to the procedure of Anderson and Ingram (1998b). Exchangeable acidity was measured titrimetrically (Mclean, 1982). Base Saturation (BS) was computed as a sum of exchangeable basic cations divided by CEC and multiplied by 100.

Data Analyses

Descriptive statistics: mean, coefficient of variation (standard deviation divided by mean×100%) were used in data studies. Variability among soil properties were ranked according to the procedure of Aweto (1982). Exchangeable basic cations were also calculated on the basis of their proportion to the total exchange capacity, since their weighting allows simpler comparisons between soils of contrasting cation exchange capacity (Billett and Cresser, 1996). Data were tested for normality at $p \geq 0.05$ and non-normal data were transformed and significant differences between populations were determined using unpaired t-tests. Variograms were also constructed to investigate the mean rate of change in soil properties with distance using GS+ software (Gamma Design Software, Plainwell, MI). Models for geostatistical analysis were chose on the basis of best fit to the data set using coefficient of determination (R^2) values. Nugget values expressed in percentage were computed as follows:

$$\text{Nugget} = \frac{\text{Nugget variance}}{\text{Total variance}} \times 100$$

Nugget values were used to estimate spatial dependence and were ranked according to the procedure of Cambardella *et al*. (1994).

RESULTS AND DISCUSSION

Soil Morphology

Soil macromorphological features are indicated in Table 1, showing differences in elevation and slope attributes. However at horizon levels A-horizon thickness was least in soils of the interfluve. Soil structure was weakly developed in soil of the interfluve and colluvial footslope and this is

Table 1: Morphology of studies pedons

Pedons	1	2	3
Location	Ebem Ohafia	Ebem Ohafia	Ebem Ohafia
Parent material	LCM	LCM	LCM
Elevation	320 m	153 m	56 m
Slope attributes	Steep (18%)	Undulating (8%)	Almost flat (1%)
Aspect	NE	NE	NE
Physiography	Interfluve	Colluvial footslope	Channel bed
Vegetation	SF	SF	SF
A horizon	0-5 cm	0-15	0-22
Colour	Gray (5 Year 5/1) moist	Reddish brown (5 Year 4/3) moist	Reddish brown (5 Year 5/6) moist
Proximity to lithic contact	Less than 20 cm most	Not discernable	Not discernable
Surface soil structure	Weak, angular blocky	Weak, granular coarse	Crumb
Surface consistence	Friable	Very friable	Firm
Subsurface drainage	Poorly drained	Well drained	Well drained

Pedon 1 = Soils of interfluve, Pedon 2 = Soils of colluvial slope, Pedons 3 = Soils of channel bed, NE = Northeast, SF = Secondary Forest

Table 2: Properties of studied soils

Horizon	Depth (cm)	Sand	Silt	Clay	OC	BD ($mg\ m^{-3}$)	Ks ($mm\ sec^{-1}$)
		----------------------	($g\ kg^{-1}$)	-------------------------			
Interfluve							
Surface	0-5	890	50	60	16.70	1.68	4.4×10^{-3}
Subsurface	5-105	900	70	30	30.00	1.72	3.3×10^{-3}
Colluvial flootslope							
Surface	0-15	860	20	120	17.10	1.61	4.1×10^{-3}
Subsurface	15-170	880	80	40	3.40	1.64	3.9×10^{-3}
Channel bed							
Surface	0-22	710	90	200	25.60	1.36	7.2×10^{-3}
Subsurface	22-185	680	110	210	6.11	1.41	6.8×10^{-3}

OC = Organic Carbon, BD = Bulk Density, Ks = Saturated hydraulic conductivity

consistent with the findings of Weisenborn and Schaetzl (2005) in soils of a Summit in Michigan, United States of America. Soils of the interfluve were grayish, typical of results of Schaetzl (2002) in a Spodosol-Entisol transition in Northern, Michigan, while soil colours downslope were redder. These results could be in response to drainage differences in the site. Soils of the interfluve were proximal to the consolidated bedrock and this is impermeable causing some capillarity irresespective of seepage characteristic of the site. The is in contrast to other soil groups which are deeper, thereby allowing a wider range for soil water re-distribution. Soils of the site are very geomorphically unstable, as erosive activities may have resulted in differential A-horizon thickness. This is in contrast to the findings of Williams (1998).

Soil Characteristics

Soils are sandy, of high bulk density and low organic carbon. These properties are in response to parent material climate and land use (Table 2). Values of saturated hydraulic conductivity (Ks) (Table 2) are similar to reports of Ezeaku and Anikwe (2006) on soils of Ukpabi-Nsukka in the northernmost part of southeastern Nigeria. Values of Ks were higher in epipedal samples and this could be attributed to greater aggregation caused by higher organic matter values at surface soils (Igwe and Stahr, 2004) or increased biological channels (Bouma, 1991). It is hypothesized that bioturbation includes the filling in of very coarse voids left by tree roots and burrowing animals (Ezeaku and Anikwe, 2006) and as a consequence, Ks values were higher in surface soils, irrespective of physiographic position. The implication of this is that more exchangeable cations will be leached out of the surface horizons.

Cation Exchange Characteristics

Cations distribution in soils are given in Table 3 and 4 indicating results of surface and subsurface soil, respectively. Surface and subsurface soil horizons differed significantly (t-tests; $p<0.001$) in all chemical parameters measured (Table 5) except in Na Mean basic cation concentrations increased downslope while Exchangeable Acidity (EA) decreased in the direction of channel bed soils. Means of exchangeable basic cations in both horizons occurred in the order of abundance as follows:

$$Ca > Mg > K > Na$$

Also, these basic cations had higher values in the subsurface horizons irrespective of geomorphic setting. In contrast, EA values were lower in subsurface horizons, suggesting pronounced pedogenic processes of leaching and eluviation in surface horizons and consequent illuviation of translocated basic cations in deep subsurface soils. While leaching and eluviation leave a preponderance of acidic cations (aluminium and hydrogen) hence higher EA values in surface soils, the basic cations (Ca, Mg, K and Na) are readily transported and deposited in the illuvial layers. Exchangeable Ca was the highest in

Table 3: Epipedal (Surface) distribution of selected soil properties (N = 36)

Soil property	Mean	CV (%)	Ranking	Maximum	Minimum
Inter fluve					
pH (water)	3.90	12	LV	4.18	3.63
Ca (cmol kg^{-1})	1.64	36	MV	1.86	1.43
Mg (cmol kg^{-1})	1.01	29	MV	1.16	0.87
K (cmol kg^{-1})	0.09	35	MV	0.12	0.07
Na (cmol kg^{-1})	0.02	29	MV	0.04	0.01
EA (cmol kg^{-1})	7.07	41	MV	8.16	6.02
CEC (cmol kg^{-1})	9.83	22	MV	10.03	9.66
BS (%)	28.07	24	MV	33.24	23.00
Alsat (%)	61.18	10	LV	70.12	53.02
Colluvial footslope					
pH (water)	4.30	18	LV	4.40	4.20
Ca (cmol kg^{-1})	1.89	42	MV	1.95	1.82
Mg (cmol kg^{-1})	1.26	33	MV	1.41	1.10
K (cmol kg^{-1})	0.34	31	MV	0.39	0.30
Na (cmol kg^{-1})	0.02	32	MV	0.05	0.01
EA (cmol kg^{-1})	6.44	45	MV	8.13	4.74
CEC (cmol kg^{-1})	9.95	25	MV	10.55	9.38
BS (%)	35.27	24	MV	40.15	30.40
Alsat (%)	56.23	16	LV	57.00	55.48
Channel bed					
pH (water)	5.60	35	MV	5.70	5.50
Ca (cmol kg^{-1})	5.71	45	MV	5.78	5.66
Mg (cmol kg^{-1})	2.62	31	MV	2.70	2.55
K (cmol kg^{-1})	0.58	34	MV	0.61	0.54
Na (cmol kg^{-1})	5.05	36	MV	0.07	0.02
EA (cmol kg^{-1})	5.09	51	HV	5.11	4.99
CEC (cmol kg^{-1})	14.05	28	MV	15.12	12.96
BS (%)	63.77	26	MV	65.00	62.55
Alsat (%)	28.64	19	LV	29.33	27.56

EA = Exchangeable Acidity, CEC = Cation Exchange Capacity, BS = Base Saturation, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, LV = Little Variation, MV = Moderate Variation, HV = High Variation, Al sat: Aluminum saturation

soils irrespective of physiography, possibly due to low adsorption capacity of exchangeable Mg to the exchange site (Foth, 1984) while exchangeable K has low values in sandy soils (Brady and Weil, 1999). Higher values of aluminium saturation in surface horizons were recorded when compared with their subsurface counterpart, implying possibility of Al-toxicity for shallow-rooted crops. In addition to this, soil of the study site are strongly to moderately acidic (Table 3 and 4) in both horizons and this accentuates a greater possibility of Al-toxicity in soils. Earlier, Yamaguchi *et al.* (2004) reported that soluble aluminium is phytotoxic but phytotoxicity of aluminium depends on its chemical form (Rayan *et al.*, 1995; Ma *et al.*, 1997; Ginting *et al.*, 1998). Aluminium preferentially occupies exchange sites with lowered pH (Gillman and Sumpter, 1986) and such exponential increases in aluminium saturation are of remarkable agronomic importance in terms of acid soil infertility. But studies (Alva *et al.*, 1986) found that aluminium toxicity is not correlated with total aluminium and this is due to complexation of soluble Al-forms by organic molecules (Gillman *et al.*, 1989). The presence of humic fractions of organic matter in soils causes the disappearance of phytotoxic forms of aluminium (Yamaguchi *et al.*, 2004). While organic matter reduced the toxicity of Al and other metals in the rhizosphere, organic acids in these forested soils can induce acidification and acid leaching (Akamigbo, 1999), resulting in unavailability of exchangeable cations particularly Ca and Mg in the root zone (Osemwota *et al.*, 2003). Similar findings in were reported in European forest soils (Thimonier *et al.*, 2001) and North American forest soils (Raben *et al.*, 2000).

In these soils, a good number of chemical properties showed high variations (CV $\geq$ 50%) in the subsurface horizons while in surface soils little (CV <20%) to moderate (CV = 21-49%) variations were exhibited by soil exchangeable cations (Table 5). These classifications and rankings were

Table 4: Subsurface distribution of selected soil properties (N = 36)

Soil property	Mean	CV (%)	Ranking	Maximum	Minimum
Interfluve					
pH	4.54	58	HV	4.50	4.40
Ca	2.00	38	MV	2.20	1.80
Mg	1.30	77	HV	1.40	1.18
K	1.00	37	MV	1.10	0.91
Na	0.05	28	MV	0.06	0.03
EA	5.55	43	MV	5.70	5.40
CEC	9.90	44	MV	10.73	9.12
BS (%)	43.93	45	MV	45.66	42.45
Alsat (%)	40.11	13	LV	41.00	39.01
Colluvial footslope					
pH	4.80	62	HV	5.00	4.60
Ca	2.05	52	HV	2.25	1.85
Mg	1.40	92	HV	1.50	1.28
K	0.90	45	LV	1.10	0.70
Na	0.06	60	HV	0.08	0.05
EA	4.90	38	MV	5.00	4.70
CEC	9.31	29	MV	9.50	9.25
BS (%)	47.36	51	HV	48.52	46.08
Alsat (%)	38.65	17	LV	40.10	36.06
Channel bed					
pH	5.80	38	MV	5.90	5.70
Ca	3.20	42	MV	3.30	3.10
Mg	1.80	62	HV	1.90	1.70
K	1.20	40	MV	1.30	1.10
Na	0.09	65	HV	0.10	0.07
EA	3.63	70	HV	3.70	3.54
CEC	9.92	47	MV	10.00	9.80
BS (%)	63.48	42	MV	66.10	60.86
Alsat (%)	29.80	16	LV	30.00	29.60

Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, EA = Exchangeable Acidity, CEC = Cation Exchange Capacity, BS = Base Saturation, Alsat = Aluminium saturation, LV = Little Variation, MV = Moderate Variation, HV = High Variation

Table 5: Two sample t-test of horizons differences among the soil groups (N = 18)

	Horizons	
Variables	Surface	Subsurface
pH	**	***
Ca	*	**
Mg	**	**
K	**	**
Na	NS	NS
EA	*	**
CEC	**	*
BS	**	*
Alsat	***	**

Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, EA = Exchangeable acidity, CEC = Cation Exchange Capacity, BS = Base Saturation, Alsat = Aluminium saturation, ***: Significant at the rate of p = 0.001, **: Significant at the rate of p = 0.01, *: Significant at the rate of p = 0.05, NS = Not Significant

consistent with the report of Aweto (1982) in slope soils of southwest Nigeria. However, greater variability in subsurface horizons could be ascribed to lateral drainage. Nonetheless, differences in surface chemical properties may arise due to variation in nature of organic materials and vegetation types. Onweremadu *et al*. (2006) reported differences in soil properties in response to variability in vegetal types. Moderate to high variations in exchangeable cations were observed in a similar work by Goderya (1998) which he attributed to differences in management practices. However, variability in CEC was more than values reported by Butt and Park (1999) and this is attributable to climatic and edaphic differences in addition to varying land use history.

Table 6: Comparative analysis of selected soil parameters among soil groups given as means (± SD) (N = 18)

Variables	Surface	t-test	Sub-surface t-test
Organic carbon	69.2±18.1	**	7.21±2.11
Bulk density	1.5±0.23	NS	1.10±0.31
Transmission pores	0.2±0.02	NS	0.20±0.06
Residual pores	0.8±0.04	NS	0.40±0.02
Hydraulic conductivity	1.3±0.91	**	7.40±0.86

**: Significant at the rate of p = 0.01, NS = Not Significant, SD = Standard Deviation in parentheses

Table 7: Relationships among some soil properties (N =36)

Factors correlated	R	R^2	Level of significance
OM vs BD	-0.53	0.28	*
OM vs Ks	0.95	0.90	*
OM vs CEC	0.76	0.58	**
OM vs EA	-0.42	0.18	*
KS vs Clay	-0.86	0.74	**
Ks vs Sand	0.93	0.86	**
Ks vs Silt	0.16	0.02	NS
Ks vs BD	-0.78	0.61	**
OM vs Ca	0.91	0.83	**
OM vs Mg	0.58	0.34	*
OM vs K	0.72	0.52	*
OM vs Na	-0.32	0.10	NS
Ks vs Ca	-0.55	0.30	*
Ks vs Mg	-0.79	0.62	*
Ks vs K	-0.66	0.43	*
Ks vs Na	-0.78	0.07	NS

OM = Organic Matter, BD = Bulk Density, Ks = Saturated hydraulic conductivity, CEC = Cation Exchange Capacity, EA = Exchangeable Acidity, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, **: Significant at p = 0.01, *: Significant at p = 0.05, NS = Not Significant

Hydraulic properties of studied soils are shown in Table 6, indicating significant differences ($p>0.01$) in organic matter and hydraulic conductivity. Bulk density, transmission pores and residual pores exhibited non-significant differences. These results suggest that organic matter content and hydraulic conductivity determine movement of exchangeable cations in the soils. Relationships between these attributes and other soil properties are shown in Table 7. In these soils as OM increased, soil water is conducted through the soil system. This is possibly due to increased aggregation and increased macro-porosity of soils. Organic matter creates negative exchange sites that attract exchangeable cations, thereby reducing their availability for transport. However, this ability depends on pH and concentration of ligand (Giesler *et al*., 2005). As Ks increases, exchangeable cations become unavailable in the soil system, especially when soils are sandy since Ks correlated significantly ($p = 0.01$) (Table 7). Although sandy soils are porous, their ability to conduct solutes depend on their pore space geometry (Ezeaku and Anikwe, 2006). Spatial dependence; Table 8 indicates geostatistical data on exchangeable cations on the hilly landscape at surface and subsurface horizons. Nugget values expressed in percentages showed marked differences in the degrees of spatial dependence for variable in all physiographic land units and at both surface and subsurface horizons. Earlier, Cambardella *et al.* (1994) classified nugget values into three categories, namely <25%, 25 to 75% and >75% defining strong, moderate and weak spatial dependence, respectively. In surface horizons, variables in soils of the interfluve indicated strong spatial dependence while soils of colluvial footslope and channel bed exhibited strong to moderate spatial dependence. On the other hand, soil variables in these soil groups indicted strong moderate spatial dependence. However, variables exhibited differences in their spatial dependence. In addition to the above, fits of spherical and exponential models on generated data were good for surface horizons irrespective of physiographic land units while spherical and linear models dominated in the subsurface horizons, suggesting the adoption of spherical models in predicting spatial dependence of soils of the study area. While exchangeable Ca, exchangeable Mg exchangeable acidity

Table 8: Variability within surface and subsurface horizons using geostatistical analysis

		Surface					Subsurface			
Variables	Model	T/U	Range (m)	Nugget (%)	R^2	Model	T/U	Range (m)	Nugget (%)	R^2
Interfluve										
Ca concentration	S	T	3.3	21.6	0.92	E	T	5.5	65.0	0.18
Mg concentration	E	U	4.4	11.9	0.90	S	T	0.9	0.0	0.82
K concentration	S	T	1.4	30.1	0.95	S	T	0.8	13.0	0.61
Na concentration	S	U	1.5	36.2	0.80	S	T	0.5	35.0	0.38
Exchangeable acidity	S	U	1.7	0.1	0.91	S	U	0.9	41.0	0.71
CEC	S	T	1.9	0.2	0.89	E	U	0.5	35.0	0.79
Colluvial footslope										
Ca concentration	L	T	0.4	22.0	0.90	L	3.4	-	-	0.12
Mg concentration	L	U	0.6	10.6	0.89	S	-	-	-	0.15
K concentration	L	U	0.3	25.0	0.93	S	-	-	-	0.17
Na concentration	E	T	1.1	45.0	0.76	E	-	-	-	0.09
Exchangeable acidity	E	U	0.4	-	0.88	S	3.8	38.0	43.0	0.66
CEC	L	T	0.1	-	0.86	S	3.1	31.0	41.0	0.57
Channel bed										
Ca concentration	S	T	0.8	12.1	0.25	L	T	-	-	0.11
Mg concentration	E	U	0.3	9.6	0.11	L	T	-	-	0.12
K concentration	S	T	0.4	21.0	0.61	L	T	0.6	48.0	0.13
Na concentration	S	U	0.2	26.9	0.13	L	U	-	-	0.16
Exchangeable acidity	L	U	0.8	48.0	0.28	E	U	3.3	-	0.58
CEC	L	T	0.2	-	0.08	E	U	2.6	45.0	0.47

S = Spherical, E = Exponential, L = Linear, T = Transformed, U = Untransfomed

and CEC showed strong dependence in surface soils of interfluve and colluvial footslope, exchangeable acidity exhibited moderate spatial dependence on soils of the channel bed, suggesting that physiographic position has very great influence on its spatial behaviour. These results were not the same at subsurface horizons. Exchangeable K and Na indicated moderate spatial dependence in both surface and subsurface horizons, especially at the interfluve.

With the exception of exchangeable Ca and Mg K with strong spatial dependence, other measured exchange attributes showed moderate spatial dependence in the subsurface horizons, irrespective of the geomorphic setting. Exchangeable Ca was the most variable in spatial behaviour while Na was the least variable, suggesting that Ca is most sensitive to pedogenic changes in the studied soils.

Soils indicated pronounced vertical anisotropy in these chemical attributes in the two horizons (Table 8) and this is attributable to the prevalence of biological activities especially cycling of nutrients coupled with the effects of climate and land use practices in the area. Shorter ranges observed in spatial dependence could e a reflection of scales of preferential flow pathways (Ezeaku and Anikwe, 2006). It could be inferred that local-scale variability in vegetation which was not investigated in this study may have contributed greatly to spatial dependence and pedogenetic processes in the sloping terrain.

CONCLUSION

This study revealed variability in the distribution of exchangeable cations with space, with exchangeable cations increasing downslope in both surface and subsurface horizons. Higher values of CV were obtained in subsurface soils for all the chemical properties, particularly at colluvial slope and channel bed physiographic positions. Conventional and geostatistical techniques indicated clear differences in the distribution of exchangeable basic cations. It was also found that spatial dependence of these chemical attributes varied from strong, moderate and weak categories in the study site. We also found that variations were best described using spherical and linear models in the subsurface attributes. In future studies, considerations should be made in areas of scaling, more intensive sampling and involvement of more geostatistical and multi-variate techniques. Investigations of ion exchange chemistry and mounting of similar studies in lowland landscapes will certainly enhance the generation of more reliable data, helpful in precision agriculture.

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