Chemical Characterization And Fertility Assessment Of Pedons Along A Toposequence In Obubra, Cross River State, Nigeria

Kamalu, O. J. and Anozie, H. I*.

Department of Soil and Crop science, Faculty of Agriculture, University of Port Harcourt, P.M.B. 5323 Port Harcourt
*henifez@yahoo.com (corresponding author)

Abstract: The removal of soil materials from upper slope positions, and transportation through and deposition at the foot slope has been a major factor for variations in soil properties along a toposequence. This study assessed the variation in chemical properties along a 15 km toposequence in Obubra area of Cross River State with the aim of providing information on the best management practices that should be adopted. Three physiographic positions representing the Crest slope (Cs), middle slope (Ms) and toe slope (Ts) were delineated and sampled. A total of fifty soil samples from 3 profiles sampled according to genetic horizons and 9 minipedons sampled at 0 – 20, 20 – 40, 40 – 60 and 60 – 80 cm were collected and analysed for chemical properties along a toposequence. The pH ranged between 5.60 and 6.00 with low coefficient of variability (CV ≤ 20 %); TEB had a range of 1.67 – 4.06 cmol/kg with moderate variability (CV = 20 – 50 %), with highest CV of 32.6 % at Ms and least at Ts 20.3. The mean values for Base Saturation across the slopes were 37 % for Cs, 36 % for Ms and 32 % for Ts. Total Organic Carbon ranged from 0.21 % to 3.151 % with very high coefficient of variability in Cs (104.6 %), Ms (103.8 %) and Ts (53.6 %). Total Nitrogen ranged from 0.026 % – 0.158 % with highest coefficient of variability, 115.9 % in Cs and lowest in the Ms (25.2 %). The study revealed that detrimental effects of soil erosion and leaching were relatively greater at upper slopes than middle and lower slopes. There is need to employ integrated soil fertility management in the crest and middle slopes in order to ensure favourable soil physicochemical properties. Application of organic amendments including manures and crop residues may also be beneficial in increasing the fertility of the Crest and Middle-sloped areas.
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Introduction

Soil is a vital natural resource and must be well managed for sustainable agricultural production (Benton, 2003). Managing soil resources for food security and sustainable environment is quite apt and deserves great attention considering the increasing pressure on our soils due largely to population increase and intensive agricultural production (Ogeh and Ukodo, 2012). In the past, farmers relied mainly on shifting cultivation through which the land was allowed to fallow for well over five to eight years to allow organic matter and plant nutrient build up before another cropping on same land (Udo *et al*., 2010). The reduction in fallow period associated with population pressure has resulted in decrease in soil fertility and selection of marginal soils for agriculture and increase in soil erosion (Rumpel *et al.,* 2006). Decline in soil fertility is becoming one of the major challenges to achieving sustainable agriculture in the sub Saharan Africa (Muchena, 2008). This is heightened by changes in land use and alteration of the ecosystem by developmental projects (Roy *et al*., 2003; Rumpel *et al*., 2006).

Major changes in soil type can occur over very small difference in distance due to topography. Elevation, slope and aspect are the main elements of topography that can influence soil development (Plaster, 2013). Stability of the landform directly influences the environmental features such as soil properties and genesis. Understanding soil properties and their variation is important for their sustainable utilization and proper management (Usman and Kundiri, 2016). It is important to know that different soils occur at different positions on the landscape (Nuga *et al*., 2006). The slope position causes properties differentiation along hill slopes and among soil horizons, and has improved the assessment of the interaction of pedogenic and geomorphic processes (Gessler *et al*., 2000). The declining land resources in the study area and the challenges of food security call for researches into marginal soils. Regrettably, there is dearth of information about the chemical properties and fertility status of the soils of the study area. Cognizant of this fact, the objective of this study was to investigate the impact of topographic position on soil chemical properties and soil fertility with a view to providing information to the farmers on sustainable agricultural production.

Materials And Methods

Study Area

The study area is located in Obubra area of Cross River State. Obubra lies on latitude 06.08 ^{0}N and longitude 08.33 ^{0}E, with an average elevation of 109 m. It has a land mass of about 1,115 km^2 and is bounded on the East by Ikom, North by Yala, and in the South by Yakurr Local Government Areas of Cross River State, while in the West by Afikpo Local Government Area of Ebonyi State, Nigeria (Adinya, *et al.,* 2007) (Figure 1). The topography is fairly flat with a good drainage system. The soil is predominantly Sandy Loam. The area has an annual rainfall distribution, which ranges from 2,500 to 3,000 mm with a temperature of 25 ^{o}C – 27 ^{o}C (Adinya *et al.*, 2007).

Obubra is situated in the rainforest belt, which is suitable for the growth of crops such as Oil Palm (*Elaeis guineensis*), Oranges (*Citrus spp*), Plantain (*Musa paradisiaca*), Banana (*Musa spp*), Guava (*Pisum guajava*), Rice (*Oryza sativum*), Yam (*Dioscorea spp*), Cassava (*Manihot spp*), Potato (*Ipomea batatas*), Cocoyam, Maize (*Zea mays*) and Vegetables. Apart from farming, the people are also engaged in agro-based activities such a cassava processing, while a good number are involved in civil service, marketing of agricultural products (trading) and other forms of non-farming activities or businesses (Adinya *et al.*, 2007).

Table 1: Landscape and Geographical Characteristics of Pedons and Minipeds (MP) Under Different Mapping Units.

Mapping Units	Latitude	Longitude	Elevation (ft)	Landscape Position	Land use	Erosion Status
MP_1-A	008^{0}17.040'	05^{0}59.862'	14	NL	RH, CL	Slight
MP_2 O-A	008^{0}19.730'	06^{0}01.619'	139	SiS	CL, FRH	Nil
MP_3 O-M_6	008^{0}19.091'	06^{0}01.221'	98	GS	ED, CL	Nil
MP_4 O-M_6	008^{0}19.403'	06^{o}01.410'	272	S	UCL	Slight
MP_5 O-A	008^{0}19.245'	06^{0}01.362'	271	GS	CL, CPP	Nil
MP_6 O-A	008^{0}19.224'	06^{0}01.259'	255	NL	UCL	Minor rift
MP_7-A	008^{0}19.174'	06^{0}01.117'	261	NL	CL	Nil
MP_8 O-A	008^{0}19.116'	06^{0}01.048'	173	S	CL, RH	Moderate
MP_9 O-A	008^{0}19.047'	06^{0}00.988'	205	NL	CL, FF	Slight
PP_1 A-O (Crest)	008^{0}17.584'	06^{0}00.064'	255	NL	CL, RH	Moderate
PP_2 O-OW (Middle)	008^{0}20.078	06^{0}01.831'	195	GS	CL, CPP	Moderate
PP_3 O-OW (Bottom)	008^{0}19.826'	06^{0}01.720'	166	GS	CL	Gully, about 50m away.

RH: Residential Houses, CL: Cultivated Land, RH: Farm and Residential Houses, ED: Education, UCL: Uncultivated Land, CPP: Cassava Processing Plant, FF: Fish Farming, NL: Nearly Level, SIS: Simple Slope, GS: Gently Sloping, S; Sloping.

Methods of Data Collection

The toposequence spans about 15 km from Obubra community to Apiapum community of Cross River State. At the beginning, a general visual field survey of the area was carried out to have a general view of the study area. Global Positioning System readings were used to identify the geographical locations and the coordinate system where data could be taken, and clinometers were used to identify slopes of the sampling sites. Soil samples were collected from crest slope (Cr), middle slope (Ms) and toe slope (Ts). Soil samples were collected from nine (9) minipeds at a dimension of 80 cm x 60 cm x 80 cm. Samples were collected at the following depth ranges: 0 – 20 cm, 20 – 40 cm, 40 – 60 cm and 60 – 80 cm from each minipedon. Samples were also collected from three profile profiles (2 m x 1.5 m x 2 m) according to genetic horizons. A total of fifty (50) samples were collected from the twelve pedons. The soils were subject to various soil fertility assessments.

Soil Laboratory Analysis

The collected samples were air-dried, homogenized and sieved to pass a 2 mm mesh sieve for physical and chemical analyses. Particle-size distribution was determined using the pipette methods or hydrometer method (Gee and Bauder, 1986). Soil pH was determined in water and 1M KCl in a soil to solution ratio of 1:2.5 soil water solution (McLean, 1982) using glass electrodes after reciprocal shaking for 1 hour. The exchangeable acidity was extracted with 1M KCl and it can be determined by the titration method using 0.01M NaOH (Sumner and Stewart, 1992). Organic matter and total organic carbon were determined using 'loss-on-ignition' method (Banning, 2008) Total nitrogen was determined using Kjeldahl method (Okalebo *et al.*, 1993) and total organic Carbon in soil was determined by the wet digestion (Nelson and Sommers, 1982). Olsen method was used to determine available Phosphorous content of the soil (Olsen *et. al*, 1954). Exchangeable cations (K, Ca, Mg and Na) were extracted with 1M NH_4OAc buffered at pH 7. The concentrations of K, Ca, Mg and Na in the solutions were measured by AAS (Shimadzu AA-

6800). Cation Exchange Capacity (CEC) was determined by 0.05M K_2SO_4 using the soil used for the basic exchangeable cation determination or by the neutral ammonium acetate (CH_3COONH_4) saturation method (Rhoades, 1982). The exchangeable bases in the ammonium acetate filtrates collected above were measured by atomic absorption spectrophotometer (Rhoades, 1982). The effective cation exchange capacity (ECEC) was determined by the summation of total exchangeable bases (Ca, Mg, K and Na) and acidity whereas; percentage base saturation (% BS) = $\frac{TEB}{ECEC}$ X 100.

Data Analysis

The soil samples were analysed using the descriptive method. The range, mean, standard deviation (S.D) and coefficient of variation (C.V) were determined:

$$C.V = \frac{S.D}{Mean} \times 100$$

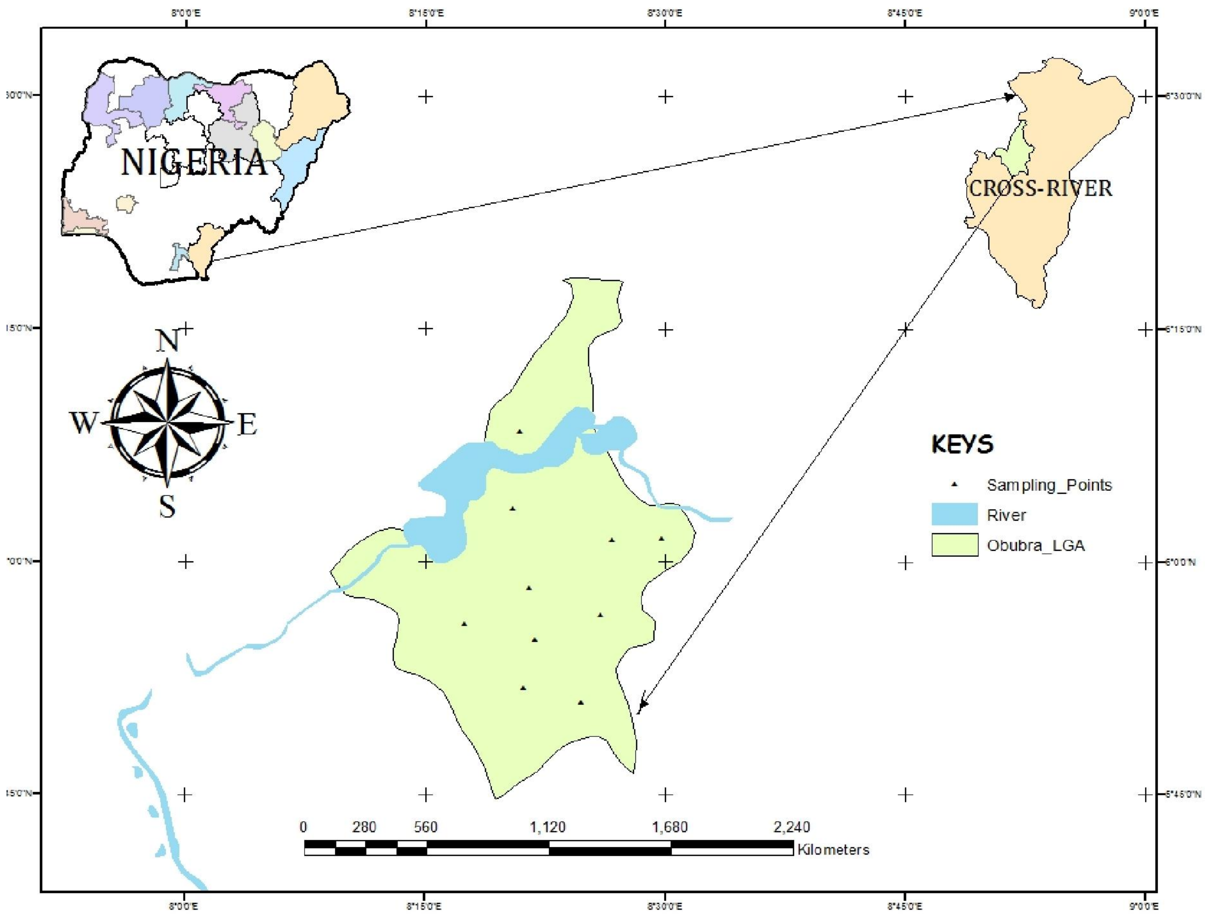

Figure 1: Map of Obubra Area Showing Sampling Stations

Results And Discussion

Soil Reaction (pH)

Soil pH is important chemical parameter of soil that affects nutrient availability (Brady & Weil, 2004). Soil pH (H_2O) generally reveal ranged from moderately to slightly acidic with range, 5.0 – 6.8 for all the profiles (Soil survey manual, 2014). The pH values of the soil at the upper horizons in all the pedons were similar (5.7 – 6.0) and this is in conformity with the finding of Babalola *et al.,* (2007) who did similar work on soil properties and slope position in a humid forest and observed same trend of pH. Pedon MP_3 recorded the lowest pH value range (5.0 – 6.2) while MP_7 showed the highest pH value (5.1 – 66.8). Moreover, the soil in higher slope had low pH values, perhaps suggesting the washing out of solutes (Na^+) from these parts which is evident from previous works (Abayneh Esayas, 2001). Whereas, the lowest pH value at lower slope can be due to intensive and continuous cultivation that cause depletion of basic cations in crop harvest and depletion of basic cations drainage to streams in runoff generated from accelerated erosions. Secondly, application of inorganic fertilizer might be the reduction of pH at lower slope position (Hussein, 2002). The increase in soil pH down the soil depth could be attributed to the downward movement of Ca and Mg and accumulation therein the subsurface soil layer. Previous researches also reported a sharp increase in soil pH with increasing soil depth (Khan *et al*., 2004) due to higher accumulation of Ca^2+ in the sub-surface soil (Kaihura *et al.,* 1999).

Available Phosphorus (Avail P)

Phosphorus is the master key to agriculture. The growth of both cultivated and uncultivated plants is limited by availability of P in the soils (Forth and Ellis, 1997). The results of available P in the study area are presented in Table 2. The values of Av. P at Cs (18.34 mg/kg – 36.67 mg/kg), Ms (25.01 mg/kg – 35.01 mg/kg) and Ts (21.67 mg/kg –38.34 mg/kg) were high across all the horizons compared to the critical limit of P (Adeoye and Agboola, 1985). Similarly Avail P across the 9 minipeds ranged from 8.8 – 39.10 mg/kg with MP_7 having the highest (39.1 mg/kg) at the upper horizon while MP_6 recorded the lowest (8.8 mg/kg) at Bt_2 horizon. The trend of avail P was similar to the values reported by Amhaknian and Achimugu (2011) who worked on characteristics of soils on a toposequence in Kogi State, Nigeria. The highest value of P observed in Ts could be attributed to translocation and deposition of sediments from the summit to the Ls (Bray and Weil, 2002).

Total Nitrogen (TN)

Nitrogen as essential nutrient had important role in plants growth which showed its distribution in different slope position. The content of N across the landscape positions decreases with increase in depth for the Cs, Ms and Ts. TN was highest at the Ap horizon on the Crest (0.147 %) and lowest on the Ts at the Bt_2 horizon (0.011 %), this trend is as a result of the geomorphological unit of the toposequence. This agrees with the findings of TN content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub humid tropics due to leaching and low OM content (Tisdale *et al.,*1995).

Organic Carbon (OC)

Organic matter is an important source of plant essential nutrients after their decomposition by microorganisms (Johnson, 2007). Evaluation of organic component in this research work revealed the descending order of organic carbon from Cs, Ms and Ts respectively. The value of SOC decreased across the landscape with increase in depth and was high at the Cs (2.94%, Ap horizon) and lowest on the Bt_2 horizon (0.21 %) at the Ts. As stated in Table 2, the lowest OC (0.21 %) was recorded in continuous and intensive lower slope cultivated fields, whereas the highest OC (2.94 %) in recently cultivated higher slope as compared to other slopes might be due to addition of soil organic matter (SOM) foliage. The lowest OC in the lower slope cultivated land, on the other hand, could be due to reduced inputs of organic matter, reduced physical protection of OC as a result of tillage and increased oxidation of SOM. In this study continuous and intensive cultivation reduced the organic matter content of the soil to a larger extent and increasing SOM decomposition rates similar results reported by Yeshaneh (2015)

Carbon/Nitrogen (C/N) ratio

However, the C/N ratio on the toposequence ranged from 19.71 % – 20.09 %. These values were below C/N ratio 25 being the separating index for mineralization and mobilization of N as established by Paul and Clark (1989). The trend of Total N, Organic Carbon, and C/N ratio are similar to the value reported by Ogeh and Ukodo, (2012) who worked on profile distribution of physical and chemical properties of soils on a toposequence in Benin, Edo State of Nigeria.

Total Exchangeable Acidity (TEA)

Total exchangeable acidity ranged from 0.32 – 2.60 cmol/kg for all the three pedons across the various geomorphological positions (Table 2). This range is low when compared to the critical level of 2.1 – 4.0 cmol/kg proposed by Holland *et al*., (1989). This is probably due to preponderance of H^+ and Al^{3+} through the application of Acidic fertilizers thus lowering the soil pH. Ackley (2012), who worked on physico-chemical properties degradation rate and vulnerability potential of the soils in South-Eastern Nigeria reported the same findings.

Basic Exchangeable Cations

The data revealed that the total exchangeable bases varied greatly across the various horizons in all the profiles and the minipeds. The Ca content was 0.44 cmol/kg at the lower slope compared with 0.88 cmol/kg at higher slope, and progressively decreased with increased year of cultivation period. The Ca content (0.88 cmol/kg) at 0 – 12 cm depth in comparison with the Ca content (0.68 cmol/kg) at 35 - 70 cm depth showed that decreased from surface to subsurface layers. The results in Mg and K content showed the same trends compared with those of Ca (Table 2). The Mg and K content were 0.54 cmol/kg and 0.46 cmol/kg at lower slope as compared with 0.88 cmol/kg and 0.86 cmol/kg at higher slope, respectively. Data regarding exchangeable bases increased with increased slope percentage. The lowest value obtained at the lower slope could be also be related to influence of intensity of cultivation and abundant crop harvest with little or no use of input as reported by Singh *et al*., (1995). Similarly, higher cations at subsurface soil layer might be due to leaching and accumulation factor.

Variability in Soil Chemical Properties

The spatial variability of soil occurs due to pedogenetic factors and their use and management

(Rodenburg *et al.,* 2003), and is expressed in physical and chemical properties (Cerri *et al*., 2004), mineralogy (Sovik and Aagaard, 2003), moisture content and field capacity (Reichardt *et al*., 2001), in the organic matter content and mineralization of carbon (Amador *et al*., 2000). It was observed that Avail P for the profiles were moderately variable and was highest at the Cs (CV = 25.2 %) but slightly different between the Ms (CV = 23.6 %) and the Ls (CV = 23.2 %) as shown in Table 3. Also, Avail P ranged from low variability (12.6 %) to high variability (63.1 %) across the 9 minipeds. It was observed that Pedon MP_7 had the lowest variability (12.6 %) while the highest variability (63.1 %) was observed in Pedon MP_2.

The variability of Soil pH was low at various topographic levels as follows: Cs (2.8 %), Ms (3.5 %) and Ts (3.88 %). Similarly, soil pH across the 9 minipeds showed a low CV which ranged from 3.7 % (miniped 8) to 11.7 % (miniped 7). The value of TEB across the profiles ranged from low to moderate variability. The CV of TEB was moderate at all topographic locations as follows Cs, 23.4 %; Ts, 20.3 % and Ms, 32.0 %. TEB range from low CV in MP_3 (8.0 %) to moderate CV in MP_8 (31.8%) across the minipeds.

It was observed that TEA showed high variability at Cs (CV = 58.2%), moderate variability at Ts (33.3%) and very low variability at Ms (6.90 %) along the toposequence. Across the 9 minipeds, TEA ranged from moderate to high variability. Mapping units, MP_1 to MP_3 were high in variability (CV ≥ 50) while MP_4 to MP_9 were all moderately variable (CV = 20 – 50 %). CN ratio ranged from moderately variable to highly variable across the miniped and pedons respectively. It was observed that the CV of CN ratio decreases down the toposequence as follow: Us, 95.1%, Ms, 90.4% while Ls had 8.1%.

The observed variability in soil properties agrees with Upchurch *et al*., (1998) that soil dynamic properties such as OC ON, Avail. P, TEB, TEA are highly variable while properties which are measured and closely calibrated to a standard such as soil pH are less variable. The observed high variability of soil properties on the slope showed that the soil under investigation is a typical highly weathered soil of the tropical region in the southern Nigeria (Eshett, 1996, Onweremadu *et al*., 2007).

Conclusion

The degree of detachment, transportation and deposition of soil materials are key determinants in variations of soil properties along a slope gradient. Understanding soil properties and their variation is important for their sustainable utilization and proper management. The study confirmed that detrimental effects of soil leaching are higher at upper slopes as compared to mid and lower slopes thereby changing the mineral nutrient concentration in the root zone thus affecting soil productivity. The cation exchange capacity (CEC) is low in these soils due to their inherent low base status. Typically, these soils have an ochric or umbric epipedon over a cambic horizon. Present use may be restricted by the shallowness of the solum (e.g. on steep slopes) or by poor drainage (e.g. in depression areas). Considering the low to moderate status of soil organic matter, the incorporation of manure or compost and crop residue retention, green manuring etc are suggested for the improvement of soils of the area.

Table 2: Chemical properties of Soil

Soil Identity	**Depth (cm)**	**Horizon**	**pH (H_2O)**	**Avail P**	**OC %**	**TN**	**C:N**	**Ca cmol/kg**	**Mg**	**K**	**Na**	**TEB**	**TEA**	**ECEC**	**BS (%)**
MP_1-A	0-20	Ap	5.5	39.05	3.151	0.158	19.94	0.69	1.00	1.01	0.56	3.26	3.3	6.56	50
	20-40	BA	6.1	20.61	2.111	0.106	19.92	0.90	0.55	1.12	0.76	3.33	2.6	5.93	56
	40-60	Bt1	5.6	18.06	2.011	0.101	19.91	1.50	1.66	0.70	0.06	3.92	9.2	13.12	30
	60-80	Bt2	5.4	30.71	1.021	0.051	20.02	0.99	0.54	1.30	1.00	3.83	5.1	8.93	43
MP_2O-A	0-20	Ap	6.7	9.08	1.976	0.099	19.96	0.85	0.89	1.00	0.48	3.22	3.2	6.42	50
	20-40	BA	6.0	12.45	1.561	0.078	20.01	1.80	0.22	0.88	0.33	3.23	4.5	7.73	42
	40-60	Bt1	5.1	25.01	1.306	0.065	20.09	0.67	0.23	0.60	0.90	2.40	5.9	8.3	30
	60-80	Bt2	5.9	38.60	0.516	0.026	19.85	0.61	1.50	1.11	0.56	3.78	4.6	8.38	45
MP_3O-M6	0-20	Ap	5.0	14.80	2.851	0.143	19.94	1.00	0.27	0.99	0.56	2.82	4.7	7.52	38
	20-40	BA	6.2	35.65	2.112	0.106	19.92	1.20	0.80	0.55	0.34	2.89	4.1	6.99	41
	40-60	Bt1	5.0	28.24	1.156	0.058	19.93	0.54	0.78	1.00	1.05	3.37	1.6	4.97	68
	60-80	Bt2	5.5	16.16	1.011	0.051	19.82	0.45	0.99	1.01	0.61	3.06	10.0	13.06	23
MP_4O-M6	0-20	Ap	6.8	29.06	1.171	0.059	19.85	0.97	0.53	0.98	0.73	3.21	6.3	9.51	34
	20-40	BA	6.5	30.01	1.001	0.050	20.02	0.87	1.12	0.12	0.90	3.01	4.6	7.61	40
	40-60	Bt1	6.1	28.80	0.911	0.046	19.80	1.15	1.00	0.25	0.45	2.85	8.2	11.05	26
	60-80	Bt2	5.9	18.45	0.600	0.030	20.00	0.10	0.05	0.89	1.01	2.05	5.7	7.75	27
MP_5O-A	0-20	Ap	6.0	36.69	0.815	0.041	19.88	0.82	0.16	0.87	0.66	2.51	1.0	3.51	72
	20-40	BA	6.0	25.20	0.611	0.031	19.71	0.88	0.85	0.76	0.23	2.71	5.8	8.51	32
	40-60	Bt1	6.5	19.18	0.312	0.016	19.50	1.11	1.70	1.12	0.67	4.60	3.1	7.7	60
	60-80	Bt2	5.9	30.00	0.104	0.005	20.80	0.97	0.77	1.12	0.56	3.42	1.0	4.42	77

Soil Identity	Depth (cm)	Horizon	pH (H_2O)	Avail P	OC %	TN	C:N	Ca cmol/kg	Mg	K	Na	TEB	TEA	ECEC	BS (%)
MP_6O-A	0-20	Ap	5.7	38.67	0.991	0.050	19.82	0.84	0.87	1.07	0.67	3.45	5.1	8.55	40
	20-40	BA	5.6	21.00	0.510	0.026	19.62	0.90	1.66	1.90	0.87	5.33	2.8	8.13	66
	40-60	Bt1	5.4	15.15	0.121	0.006	20.17	2.00	0.89	2.22	0.54	5.65	1.1	6.75	84
	60-80	Bt2	6.4	8.80	0.100	0.005	20.00	1.90	1.66	2.41	1.56	7.53	1.0	8.53	88
MP_7-A	0-20	Ap	6.0	39.10	3.000	0.150	20.00	0.98	1.10	1.14	0.71	3.93	2.7	6.63	59
	20-40	BA	6.8	37.50	1.001	0.050	20.02	1.80	2.22	1.98	1.45	7.45	7.7	15.15	49
	40-60	Bt1	5.9	33.40	0.197	0.010	19.70	1.70	1.89	1.55	1.00	6.14	1.0	7.14	86
	60-80	Bt2	5.1	29.80	0.121	0.006	20.17	2.15	2.00	1.58	0.88	6.61	1.1	7.71	86
MP_8O-A	0-20	Ap	6.1	20.50	0.861	0.043	20.02	1.07	0.74	1.00	0.70	3.51	1.1	4.61	76
	20-40	BA	5.9	14.89	0.618	0.031	19.94	1.45	1.90	1.55	1.05	5.95	2.9	8.85	67
	40-60	Bt1	5.6	16.10	0.401	0.020	20.05	0.98	0.88	1.23	0.90	3.99	3.8	7.79	51
	60-80	Bt2	6.0	36.67	0.311	0.016	19.44	2.50	1.80	1.89	0.75	6.94	2.8	9.74	71
MP_9O-A	0-20	Ap	5.9	25.21	0.411	0.021	19.57	1.12	0.98	0.89	0.54	3.53	3.4	6.93	51
	20-40	BA	5.6	25.21	0.312	0.016	19.50	0.55	0.45	0.81	1.00	2.81	1.7	4.51	62
	40-60	Bt1	6.1	28.80	0.105	0.005	21.00	1.99	2.00	0.10	0.50	4.95	1.0	5.95	83
	60-80	Bt2	6.7	15.90	0.100	0.005	20.00	0.50	1.11	0.45	0.82	2.88	1.0	3.88	74
PP_1A-O (Crest)	0-12	Ap	6.0	36.67	2.94	0.147	20.00	0.88	0.88	0.86	0.56	3.18	17.1	20.28	16
	12-35	BA	5.7	18.34	1.60	0.080	20.00	0.74	0.77	0.65	0.60	2.16	11.5	13.66	16
	35-70	Bt1	5.6	36.67	0.35	0.018	19.44	0.68	0.74	0.55	0.56	2.53	3.4	5.93	43
	70-100	Bt2	5.9	36.67	0.38	0.019	20.00	1.15	0.18	0.70	0.72	2.75	1.0	3.75	73
	100-113	Bt3	5.9	30.01	0.29	0.015	19.33	0.54	0.36	0.44	0.33	1.67	2.9	4.57	37
PP_2O-OW (Mid-slope)	0-10	Ap	6.2	35.01	1.97	0.099	19.90	0.95	1.33	1.06	0.72	4.06	13.2	17.26	24
	10-60	Bt1	5.9	25.01	0.30	0.015	20.00	0.73	0.70	0.55	0.56	2.54	2.9	5.44	47
PP_3O-OW (Toeslope)	0-21	Ap	6.0	28.34	1.17	0.059	19.83	0.79	0.58	0.98	0.51	2.86	10.7	13.56	21
	21-44	BA	5.5	30.01	0.92	0.046	20.00	0.64	0.58	0.53	0.66	2.41	5.0	7.41	33
	44-70	Bt1	5.9	21.67	0.74	0.037	20.00	0.48	0.86	0.76	0.38	2.48	6.8	9.28	27
	70-111	Bt2	5.9	38.34	0.21	0.011	19.09	0.44	0.54	0.46	0.27	1.71	2.1	3.81	45

Mid-slope = Middle slope.

Table 3: Variability in the Toposequence

	PEDON 1 (CREST SLOPE, Cs)				PEDON 2 (MIDDLESLOPE, Ms)				PEDON 3 (TOE SLOPE, Ts)			
Soil properties	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**
% Sand	80.6-90.2	86.8	3.718	4.3	88.4-90.4	89.4	3.718	4.2	80.4-86.4	84.9	1.414	1.67
% Silt	3.4-9.4	6.640	3.26	49.1	7.4-9.4	8.4	1.414	16.8	1.4-17.4	7.4	6.928	93.6
% Clay	2.2-8.6	6.56	2.766	42.2	2.2-2.2	2.2	0.12	5.45	2.2-10.2	7.7	3.786	49.2
TOC (%)	0.29-2.94	1.112	1.159	104.20	0.3-1.97	1.135	1.181	104.1	0.21-1.17	0.76	0.407	53.6
SOM (%)	0.49-5.06	1.910	1.997	104.50	0.52-3.39	1.955	2.029	103.8	0.36-2.01	1.305	0.199	15.25
TN (mg/kg)	0.10-0.71	0.232	0.269	115.94	0.11-0.15	0.127	0.032	25.2	0.11-0.19	0.126	0.04	31.7
pH (H_2O)	5.60-6.00	5.82	0.164	2.81	5.90-6.20	6.05	0.212	3.5	5.5-6.0	5.825	0.222	3.81
Av. P (mg/kg)	18.3-36.7	31.67	7.991	25.23	25-35	30.01	7.071	23.6	21.7-38.3	29.59	6.856	23.16
TEA (Cmol/kg)	0.32-1.36	0.68	0.396	58.23	0.40-0.44	0.42	0.029	6.90	1.6-2.6	2.1	0.699	33.3
TEB (Cmol/kg)	1.67-3.18	2.46	0.575	23.37	2.54-4.06	3.30	1.075	32.6	1.71-2.86	2.365	0.479	20.3
C/N ratio	1.0-17.1	7.20	6.850	95.13	2.9-13.2	8.05	7.28	90.4	2.1-10.7	6.2	3.6	58.1

S.D = Standard Deviation; C.V = Coefficient of variation; TOC= Total Organic carbon; SOM= Soil Organic Matter; TN= Total Nitrogen; Av. P= Available Phosphorus;
TEA= Total Exchangeable Acidity; TEB= Total Exchangeable Bases; C/N= Carbon/Nitrogen.

Table 4: Variation in Soil Physicochemical Properties for the minipeds

	Miniped 1				**Miniped 2**				**Miniped 3**			
Soil properties	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**
TOC (%)	1.021-3.15	2.074	0.871	42	0.516-1.98	1.340	0.615	45.9	1.01-2.85	1.783	0.864	48.5
SOM (%)	1.76-3.65	3.128	0.915	29.3	0.89-3.41	2.31	1.01	45.9	1.74-4.92	3.073	14.93	48.6
TON (mg/kg)	0.2-0.9	0.543	0.391	72	0.111-0.85	0.383	0.326	85.1	0.10-0.1	0.484	0.268	55.4
pH (H_2O)	5.4-6.1	5.65	0.311	5.5	5.1-6.7	5.925	0.65	11.0	5.0-6.2	5.425	0.568	10.5
Av. P.	18.06-39.1	29.608	8.655	29.2	9.08-38.6	21.29	13.425	63.1	4.8-3.65	23.71	9.991	42.1
TEA (Cmol/kg)	0.1-1.21	0.7	0.554	79.1	0.44-1.31	0.81	0.408	50.4	0.28-1.41	0.988	0.494	50
TEB (Cmol/kg)	3.26-3.92	3.585	0.338	9.4	2.4-3.78	3.158	0.569	18.0	2.82-3.37	3.03	0.245	8.1
C:N	2.6-9.2	5.05	2.96	58.6	3.2-5.9	4.55	1.1	24.2	1.6-10.0	5.1	3.5	68.6

Table 4 Contd.

	Miniped 4				Miniped 5				Miniped 6			
Soil properties	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**
TOC (%)	0.6-1.171	2.271	2.489	109.6	0.104-0.815	0.461	0.31	67.3	0.1-0.991	0.431	0.419	97.2
TON (mg/kg)	0.106-0.185	0.154	0.005	3.25	0.1-0.911	0.779	0.49	62.90	0.103-0.196	0.148	0.047	31.8
pH (H_2O)	5.9-6.8	6.325	0.403	6.4	5.9-6.5	6.10	0.271	4.4	5.4-6.4	5.775	0.435	7.5
SOM (%)	1.03-2.02	1.588	0.416	26.2	0.18-1.41	0.795	0.544	68.4	0.17-1.71	0.743	0.723	97.3
Av. P (mg/kg)	18.45-30.01	26.58	5.449	20.5	19.81-36.69	27.925	7.174	25.7	8.80-36.10	34.95	4.189	12
TEA (Cmol/kg)	0.52-1.01	0.963	0.417	43.3	0.44-1.21	0.801	0.345	43.10	0.51-1.04	0.88	0.248	28.2
TEB (Cmol/kg)	2.05-3.21	2.780	0.508	18.3	2.51-4.60	3.310	0.944	28.5	3.45-7.53	5.490	1.71	21.31
C:N	4.66-8.2	6.2	1.51	24.4	1.0-5.8	2.7	2.28	84.44	1.0-5.1	2.5	1.92	76.8

Table 4 contd.

	Miniped 7				Miniped 8				Miniped 9			
Soil properties	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**	**Range**	**Mean**	**S.D**	**C.V (%)**
TOC (%)	0.121-3.0	1.080	1.341	124.2	0.311-0.861	0.548	0.245	44.7	0.10-0.411	0.232	0.155	67.0
SOM (%)	0.21-5.17	1.863	2.310	123.9	0.54-1.48	0.945	0.421	44.6	0.17-0.17	0.40	0.269	67.3
TON (mg/kg)	0.021	0.359	0.494	137.6	0.105-0.811	0.31	0.338	109.0	0.107-0.186	0.156	0.050	32.1
pH (H2O)	5.1-6.8	5.95	0.695	11.7	5.6-6.1	5.9	0.216	3.86	5.6-6.7	5.823	0.670	11.5
Av. P (mg/kg)	29.8-39.1	34.95	4.198	12.0	14.89-36.67	22.04	10.047	45.6	15.9-28.8	23.7555	5.511	23.2
TEA (Cmol/kg)	0.65-1.25	0.988	0.261	26.4	0.39-0.86	0.608	0.238	39.1	0.61-102	0.805	0.182	22.66
TEB (Cmol/kg)	3.93-7.45	6.032	1.503	24.9	3.51-6.94	5.098	1.619	31.8	2.81-4.95	3.543	0.993	28.0
C:N	1.0-47.7	13.1	23.1	176.3	1.1-3.8	2.7	1.13	41.9	1.0-3.4	1.8	1.13	62.8

Table 5: Variability Classes in Soil Chemical Properties

Coefficient of variability (%)	**Variability class**
≤ 20%	Low variability
20 – 50%	Moderate variability
≥ 50%	High variability

Source: Aweto, 1982

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