CHARACTERIZATION AND CLASSIFICATION OF SOILS ALONG A TOPOSEQUENCE AT OBIO AKPA IN ORUK ANAM AREA OF AKWA IBOM STATE, NIGERIA

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ABSTRACT
This study was conducted to characterize and classify soils along a toposequence at Obio Akpa in Oruk Anam Area of Akwa Ibom State, Nigeria. Five soil profiles sited at the summit, upper slope, middle slope, lower slope and valley bottom positions of the toposequence were described, while twenty disturbed and twenty undisturbed soil samples were obtained and routinely analyzed to determine some physical and chemical properties of the soils. Results showed that the surface horizons were light grey at the summit and middle slope and pinkish white at the valley bottom; whereas the subsoil horizons were generally pink and reddish brown at the summit and valley bottom respectively. Surface horizons were loamy sand except at the valley bottom, where it was sandy loam; whereas subsoil horizons were generally sandy clay loam. Bulk density ranged from 1.36 g/cm^3 in the surface horizon of valley bottom soil to 1.58 g/cm^3 in the Bt2 horizon of summit soil. pH varied in the order: valley bottom (5.3) > lower slope (5.0) > middle slope/summit (4.9) > upper slope (4.8). Organic carbon ranged from 0.12% at the upper slope to 2.45% at the valley bottom. Exchangeable Ca and K concentrations increased down the slope ranging from 1.11 to 2.46 cmol/kg and 0.41to 0.75 cmol/kg respectively. Mean ECEC and base saturation increased down the slope ranging from 5.12 to 5.77 cmolkg^{-1} and 66.88to 71.38% respectively. All the soils were classified as Ultisols under the USDA Taxonomy, except the valley bottom soil which was classified as an Inceptisol. Effective erosion control, regular applications of manure, liming and conservation tillage are strategies recommended to help improve the quality and productivity of the soils.

Keywords: Toposequence, topographic positions, soil profiles, morphological characteristics, USDA Taxonomy.

INTRODUCTION

Soil is a major component of every landscape and its formation, development and properties are all influenced by the integrated effect of parent material, climate, topography, biota and time (Brady & Weil, 2012). A lateral sequence of related soils on a slope which differ, one from another, primarily because of topography as a soil-forming factor is called toposequence (GSST, 1987). Due to the undulating nature of their landscapes, toposequences have often been exposed to different physical and chemical processes of degradation including erosion, crusting, waterlogging, nutrient-leaching (Ijah *et al*., 2024) and organic matter loss (Edem *et al.,* 2012) following anthropogenic impacts resulting in changes in the morphological, physical and mineralogical properties of their soils at various topographic positions (Brady & Weil, 2012). Hence regular characterization of soils of toposequences, especially those utilized for agriculture, becomes very crucial, as it is not only important for their productivity/fertility evaluation, but is also important for their classification (FAO, 2006), particularly under the USDA Soil Taxonomy or the World

Reference Base for Soil Resources (WRB), which are the two common natural soil classification systems upon which all soil classification works are based (Esu, 2010; FAO, 2006).

Many characterization and classification studies on soils along toposequences have been conducted across the globe and even those conducted across Nigeria (Adegbite *et al*., 2019; Nsor, 2020; Ajoagu *et al*., 2024) have equally revealed that the soils at the various topographic positions usually differ in morphological, physical, chemical and mineralogical properties. Nsor (2020), for instance, reported medium to coarse texture, low pH, low to medium levels of exchangeable bases, argillic subsoil horizons with < 35% base saturation and udic moisture regime for the summit and upper slope soils of a toposequence at Obuohia-Iberein southeastern Nigeria. The soils, according to the researcher, were therefore classified as Ultisols at the Order level, Udults at the Suborder level (because of the udic moisture regime) and Paleudults and PsammenticPaleudults at the Great Group and Subgroup levels respectively (because of their medium to coarse texture). Further report by the researcher has it that the soils at the toe slope and valley bottom of the toposequence had umbric eppipedons, cambic endopedons (Bg), aquic moisture regime, high organic carbon contents (> 0.2%) and medium to high levels of exchangeable bases and therefore were classified as Inceptisols at the Order level, Aquepts at the Sub-order level (because of the aquic moisture regime) and Humaquepts and Cumulic Humaquepts at the Great Group and Sub-group levels respectively.

Information on soils along toposequences in OrukAnam Area of Akwa Ibom State is scarce and this study became necessary because most of these toposequences have been extensively utilized for crop production, as it is believed that the information from this study might facilitate better use and management of the soils for improved crop productivity. The objectives of this study were, therefore, to determine the morphological characteristics of soils of a toposequence at Obio Akpa in Oruk Anam Area of Akwa Ibom State, Nigeria, determine some physical and chemical properties of the soils and classify the soils based on the USDA Soil Taxonomy.

MATERIALS AND METHODS

Study Area

This study was conducted at Obio Akpa in Oruk Anam Area of Akwa Ibom State. Obio Akpa is located on latitude 4°57'30''N and longitude 7°44'40''E. It has the humid tropical climate with the wet season that spans between April and October and and the dry season that spans between November and March. The mean annual rainfall recorded for the ranges between 2000 and 2500 mm. The daily air temperature ranges between 23 °C and 32 °C, while the relative humidity ranges between 70 and 80%. Soils in the area are mostly formed from coastal plain sand and fluvial deposits and the vegetation is generally secondary forests which have been cleared from time to time for farming purposes (NGSA, 2009; Uduak *et al*., 2020).

Field Characterization of the Soils

A total of five soil profiles sited at five topographic positions (summit, upper slope, middle slope, lower slope and valley bottom) of the toposequence were described and characterized for the morphological properties of the soils. Each soil profile was obtained using a soil pit measuring 2 m x 1.5 m x 2 m (Esu, 2010) or less. Soil horizon boundary, colour, mottling, texture, structure, consistence, pores, roots, biological features and horizon boundary were the morphological properties of the soils observed. Horizon boundary was observed and described in terms of depth and distinctness by tape mea-

Table 1: Coordinates, elevation, slope gradient and slope gradient class of the studied sites/slope on the Toposequence

Study Site/ Slope position	Coordinates	Elevation (m)	Slope gradient (%)	Slope gradient Class
Summit	4°57'40.4242"N 7°44'45.6554"E	63.829	2	Level
Upper Slope	4°57'40.4881"N 7°44'45.6854"E	61.110	4	Gently sloping
Middle Slope	4°57'40.4242"N 7°44'45.6554"E	57.482	6	Sloping
Lower Slope	4°57'40.5956"N 7°44'45.6660"E	54.035	9	Strongly sloping
Valley Bottom	4°57'44.1180"N 7°44'34.2906"E	46.035	0	Flat

surement in centimeter, soil matrix colour was determined in the moist condition using the Munsell Soil Colour Charts, mottling of the soil matrix was determined in terms of size and abundance, texture was determined by the feel method and structure was described in terms of type of aggregates. Consistence was described in the moist soil condition by attempting to crush a mass of moist or slightly moist soil material, pores were described in terms of size and abundance using a x10 hand lens and roots/other biological features like ant channels and worm casts were described in terms of size and abundance (FAO, 2006; Soil Survey Staff, 2015).

Soil Sample Collection and Sampling Techniques

A total of forty soil samples were obtained from five soil profiles after horizon designation and description. They consisted of twenty samples collected with core cylinders of known size and weight and twenty samples collected with a hand trowel. Each soil profile was sited at each of the five topographic positions studied (summit, upper slope, middle slope, lower slope and valley bottom). The coordinates and elevation as well as the slope gradient and slope gradient class of the studied sites are shown Table 1. The undisturbed soil samples were obtained with core samplers of known volume and weight, while the disturbed samples were obtained with a hand trowel. All the soil samples were marked, packaged and moved carefully to the laboratory for processing and analysis.

Processing of Soil Samples for Laboratory Analysis

All soil samples obtained with a hand trowel were carefully processed prior to laboratory analysis. They were air-dried for two weeks, ground and passed through a 2-mm-mesh sieve. The portions of the 2-mm soil samples meant for the determination of organic carbon and total nitrogen were further passed through a 0.5- mm-mesh sieve, as outlined by Udo *et al*. (2009). Core soil samples were not processed, rather they were subjected to analysis as soon as they were brought to the laboratory to determine bulk density, total porosity and moisture content, as outlined by Bowen (2023).

Laboratory Characterization of the Soils

All processed soil samples were analyzed in the laboratory by the routine or standard methods to determine the physicochemical properties of the soils. Particle size distribution was determined by the hydrometer method with Calgon (sodium hexametaphosphate) as the dispersant (Bowen, 2023). Textural classes were determined using the USDA Soil Textural Triangle (Udo *et al*., 2009). Bulk density was determined by the core method (Grossman &Reinsch, 2002). Total porosity was determined using the expression: TP = 1 – bulk density/particle density x 100, where TP represents total porosity and particle

density was assumed to be 2.65 (Bowen, 2023). Moisture content was determined gravimetrically (Udo *et al*., 2009). Electrical conductivity was measured with an electrical conductivity meter at the soil to water ratio of 1: 5 (Bowen, 2023). Soil pH was determined in water with a glass electrode meter at the soil to water ratio of 1: 2.5 (Bowen, 2023). Organic carbon was determined by the Walkley and Black wet oxidation method (Nelson & Sommers, 1996). Total nitrogen was determined by the macro-kjeldahl digestion method (Udo *et al*., 2009). Available phosphorus was determined by the Bray 1 method (Udo *et al*., 2009).
Exchangeable bases (Ca, Mg, K and Na) were determined by the neutral ammonium acetate extraction method and the concentrations of Ca and Mg in the extract were measured with the atomic absorption spectrophotometer, while the concentrations of K and Na were measured with a flame photometer (Udo *et al*., 2009). Exchangeable acidity was determined by the 1M KCl extraction method ((Udo *et al*., 2009). Effective cation exchange capacity (ECEC) was determined by summing up total exchangeable bases and exchangeable acidity and base saturation was determined using the expression: TEB/ECEC x 100, where TEB represents total exchangeable bases (Udo *et al*., 2009).

Statistical Analysis

Arithmetic mean and range were used to statistically analyzed soil physical and chemical data and all calculations were done using the SAS (2001) software.

RESULTS AND DISCUSSION

Morphological Characteristics of Soils Along the Toposequence

The morphological characteristics of soils along the toposequence are shown in Table 2. The soils were deep at all the locations studied ranging from 121 cm in effective depth at the valley bottom to 200 cm at the summit, indicating that the soils were mature with full profile development irrespective of their sloping terrain. However, the soil at the valley bottom did not appear to be as deep, though its effective depth was more than the critical limit of 45 cm considered adequate for crop production (FAO, 1986). This could be an indication of the youthfulness and minimal profile development of the soil.

The colour of the moist surface (Ap) horizon soils at the summit and middle slope was light grey (7.5YR 7/1), that of the Ap horizons of the soils at the upper and lower slopes was grey (7.5YR 6/1), whereas the colour of the moist surface (Ap) horizon of the valley bottom soil was pinkish white. The colours of the immediate subsoil horizons at the summit, upper slope, middle slope, lower slope and valley bottom were pinkish grey, pale brown, pinkish grey, light brown and light brownish grey respectively; whereas the colours of the other moist subsoil horizons were generally pink at the summit, reddish yellow at the upper slope, brownish yellow at the middle slope, pinkish grey at the lower slope and reddish brown/dark reddish brown at the valley bottom. All the colours exhibited by the different horizons of the soils could be a reflection of the mineral and organic composition as well as the redox conditions of the soils (FAO, 2006; Esu, 2010). Some of these colours agree with those reported by Nsor (2020) and other past researchers.

Horizon	Horizon thickness (cm)	Colour (moist)	Mottles	Texture	Structure	Consistence (most)	Roots	Drainage	Pores	Biological Features	Horizon Boundary	
						Pedon 1 (Summit)						
Ap	0-23	7.5YR 7/1	None	LS	Crumb	Very Friable	MM	Well-drained	CM	Many (Ants)	Cw	NPS
AB	23-35	7.5 YR 7/2	None	SL	SBK	Friable	FM	Well-drained	CM	Common (Ants)	Gw	NPS
Bt1	35-56	7.5 YR 7/4	None	SCL	SBK	Firm	FF	Well-drained	CM	Few (Ants)	Gw	NPS
Bt2	56-132	10 YR 6/8	None	SCL	SBK	Firm	FVF	Well-drained	CM	None	Gd	D
						Pedon 2 (Upper Slope)						
Ap	0-14	10 YR 6/1	None	LS	Crumb	Very Friable	MM	Well-drained	CM	Many (Ants)	Cw	NPS
Bt1	14-59	10 YR 6/3	None	SCL	SBK	Friable	FM	Well-drained	CM	Common (Ants)	Gw	NPS
Bt2	59-129	7.5 YR 6/6	None	SCL	SBK	Firm	FF	Well-drained	CM	Few (Ants)	Gw	NPS
Btc	129-161	7.5 YR 6/8	None	SC	SBK	Firm	FVF	Well-drained	CM	None	Gd	D
						Pedon 3 (Middle Slope)						
Ap	0-13	7.5 YR 7/1	None	LS	Crumb	Very Friable	MM	Well-drained	CM	Common (Ants)	Cw	NPS
Bt1	13-79	7.5 YR 7/2	None	SCL	SBK	Friable	FM	Well-drained	CM	Few (Ants)	Gw	NPS
Bt2	79-123	7.5 YR 7/4	None	SCL	SBK	Firm	FF	Well-drained	CM	None	Gw	NPS
Bc	123-167	10 YR 6/8	None	SC	SBK	Firm	FVF	Well-drained	CM	None	Gd	D
						Pedon 4(Lower Slope)						
Ap	0.14	7.5 YR 6/1	None	LS	Crumb	Very Friable	MM	Well-drained	CM	Few (Charcoal)	Cw	NPS
Bt1	14-38	10 YR 6/2	None	SCL	SBK	Friable	FM	Well-drained	CM	Few (Charcoal)	Gw	NPS
Btg.	38-114	7.5 YR 6/2	None	SCL	SBK	Firm	FF	Well-drained	MF	None	Gw	NPS
BC	114 -169	7.5 YR 6/8	None	SC	SBK	Firm	FVF	Well-drained	MVF	None	Gd	D
						Pedon 5 (Valley Bottom)						
Ap	0.11	5.0 YR 8/2	FF	SL	Granular	Friable	CM	Poorly drained	CM	Few	Cw	NPS
Btg1	11-40	5.0 YR 6/2	CM	SCL	Prismatic	Friable	FM	Poorly drained	CM	Earthworms	Gw	NPS
Btg2	40-72	5.0 YR 6/4	CM	SC	Prismatic	Firm	FF	Poorly drained	MF	None	Gw	D
BC	72 -121	5.0 YR 2/6	CM	C	Prismatic	Firm	FVF	Poorly drained	MVF	Mone	Gd	D

FF = ;Few and faint, CM = Common and medium, LS = Loamy sand, SC = Sandy clay, SCL = Sandy clay loam, C = Clay, SBK = Subangular blocky, MM = Medium and many, FM = Fine and many, FF = Fine and

Mottles were observed only in the different horizons of the valley bottom soil and were few in number (2-5%) and fine (2 - 6 mm in size) at the Ap horizon, common (5 – 15%) at Bt1 horizon and medium (6 – 20%), many (15 – 40%) and coarse (> 20 mm) at the BC horizon which could form as products redox reactions. The Ap horizons were all loamy sand except the valley bottom where it was sandy loam The texture of the immediate subsurface horizon of the summit soil was sandy loam, whereas that of the immediate subsurface horizons of the other soils was generally sandy clay loam.

The structural grade of all the surface (Ap) horizons of the soils was described as moderate, except at the valley bottom where it was strong. The structural type for all the surface (Ap) horizons of the soils was crumbly, except at the valley bottom where it was granular. The structural type for the endopedons of the soils was subangular blocky at all the topographic positions. However, that of the endopedons of the valley bottom soil was prismatic. The moist consistence of the Ap horizons of the soils was very friable, whereas that of the subsoil horizons of the soils was generally firm because the soil materials could only crush under moderate pressure between thumb and forefinger.

The crumb structural type observed in the surface (Ap) horizons of the summit, upper slope, middle slope and lower slope soils as well as the granular structural type of the Ap horizon of the valley bottom soil was an indication that the soils were all pedal (not structureless) and that the structure of the surface horizons of the soils might be created by tillage and related forms of disturbance, except that of the valley bottom soil which could be largely due to the grassy vegetation at the valley bottom. The very friable moist consistence of the Ap soils at the summit, upper slope, middle slope and lower slope topographic positions might be due to the high sand, low clay and low moisture contents of the soils at the time of description; whereas the firm moist consistence of their subsurface soils could be largely due to the relatively high clay and low moisture contents of the soils. Soil moisture and clay contents are among factors influencing soil consistence and as soil moisture content decreases, soils lose their stickiness and plasticity and become friable and soft and become firm and coherent when dry (Brady & Weil, 2012).

There were many medium-size plant roots in the soils, particularly in the Ap horizons of the soils, and the number and size of the roots decreased with soil depth and slope. There were some ant channels in the first two horizons of the summit, upper slope and middle slope soils and some worm casts in the first two horizons of the bottom valley soil. The presence of different sizes of roots in the various horizons of the soils was an indication that the soils were supporting plant growth and development and the deceasing number and size of roots with soil depth showed that the surface horizon is inadvertently the main soil layer that influences plant growth.

The presence of ants and earthworms was an indication of biological activity, which brings about numerous transformations in soils (FAO, 2006). Earthworms, for example, feed on soil organic matter and soil nutrients and excrete worm casts which other organisms feed on; their channels help increase aeration, water infiltration and permeability (Brady & Weil, 2012). The presence of charcoal in some of the soil horizons, particularly those of the summit and upper slope soils, was an evidence of human disturbance of the soils and could be linked mostly to the slash-and-burn method of crop production practised by locals in the area as well as indiscriminate bush burning by herders.

Physical and Chemical Properties of Soils of the Toposequence

The physical properties of the soils along the toposequence are presented in Table 3. Sand dominated all the horizons of the soils irrespective of the topographic position and decreased with soil depth at each topographic position. Sand contents ranged from 48.20% in the BC horizon of the upper slope soil to 86.20% in the Ap horizon of the summit soil. The mean sand contents of the soils varied in the order: upper slope (66.05%) > middle slope (65.60%) > summit (64.60%) > lower slope (64.40%) > valley bottom (56.10%).

Table 3: Selected Physical Properties of the studied soils

Horizon	Horizon thickness(cm)	Sand %	Silt %	Clay %	TC	BD g/cm	TP %	MC %
			Pedon 1 (Summit)					
Ap	0-23	86.20	4.60	9.20	LS	1.47	44.58	38.01
AB	23-35	67.20	8.20	24.20	SL	1.48	44.15	38.33
Bt1	35-56	56.60	7.40	36.00	SCL	1.54	41.89	39.42
Bt2	56-132	48.40	10.60	41.00	SC	1.58	40.38	40.23
Mean		64.60	7.70	27.60		1.52	42.74	39.00
			Pedon 2 (Upper Slope)					
Ap	0-14	83.40	5.00	11.60	LS	1.46	44.91	39.12
Bt1	14-59	68.20	9.60	22.20	SCL	1.48	44.15	38.62
Bt2	59-129	59.40	8.20	40.60	SC	1.50	43.40	39.64
BC	129-1616	48.20	11.40	40.40	SC	1.55	41.51	41.25
Mean		66.05	8.55	28.20		1.50	43.49	39.66
			Pedon 3 (Middle slope)					
Ap	0-3	84.20	6.40	9.40	LS	1.44	45.66	40.06
Bt1	13-79	89.40	5.60	25.00	SCL	1.46	44.09	39.25
Bt2	79-123	58.60	9.20	32.20	SCL	1.48	44.15	41.65
BC	123-167	50.20	10.40	39.40	SC	1.52	42.64	41.82
Mean		65.60	7.90	26.50		1.48	44.14	40.70
			Pedon 4 (Lower slope)					
Ap	0-14	81.20	6.20	12.60	LS	1.44	46.79	41.26
Btg1	14-38	70.60	6.20	23.20	SCL	1.44	45.66	42.11
Btg2	38-114	58.20	10.40	31.20	SCL	1.45	45.28	43.81
BC	114-169	52.60	10.20	37.20	SC	1.48	44.15	43.92
Mean		64.40	8.25	26.05		1.45	45.34	45.78
			Pedon 5 (Valley Bottom)					
Ap	0-11	70.60	10.00	19.40	SL	1.37	48.30	43.36
Btg1	11-40	61.20	9.40	29.40	SCL	1.38	47.92	44.18
Btg2	40-72	50.20	12.20	37.60	SC	1.41	46.79	46.25
C	72-121	42.40	10.60	47.60	C	1.45	45.28	46.33
Mean		56.10	10.55	33.35		1.40	47.07	45.03

TC = Textural class, LS = Loamy sand, SCL = Sandy clay loam, SL = Sandy loam, SC = Sandy clay, BD = Bulk density, TP = Total porosity, MC = Moisture content.

Clay followed sand in dominance and decreased with soil depth at each topographic position. Clay contents of the soils ranged from 9.20% in the surface (Ap) horizon of the summit soil to 41.00% in the Bt2 horizon of the same summit soil. The mean clay contents of the soils varied in the order: valley bottom (33.35%) > upper slope (28.20%) > summit (27.60%) > middle slope (26.50%) > lower slope (26.05%). The mean silt contents of the soils varied in the order: valley bottom (10.55%) > upper slope (8.55%) > lower slope (8.25%) > middle slope (7.79%) > summit (7.70%), though silt distribution in the soils did not follow any pattern at each topographic position. The results largely agree with those reported by Nsor (2020). The texture of the Ap horizons of the soils was coarse (loamy sand), except the texture of the Ap horizon of the valley bottom soil which was moderately coarse (sandy loam). The subsoil texture varied from moderately fine (sandy clay loam) to fine (sandy clay) at all topographic positions studied. The dominance of sand in all the horizons of the soils could be due to the sandy nature of the parent materials, whereas the relatively high contents of clay in the subsurface horizons of the soils could be due to regular clay movements from the overlying layers by rainfall and subsequent deposition of the eluviated clay in the subsurface horizons.

Bulk density varied from 1.36 gcm^{-1} in the Ap horizon of the valley bottom soil to 1.58 g/cm in the Bt2 horizon of the summit soil and decreased down the slope (from summit to valley bottom) and with soil depth at any of the topographic positions studied. The bulk densities of all the soils were within the normal range (1.0 – 1.6 g/cm) for crop growth (Acquaah, 2005) which suggest no compaction issues. According to Acquaah (2005), soil bulk densities greater than 1.60 g/cm are not favourable to crop plants because such high values are an indication of soil compaction, which may impede porosity, aeration, water infiltration, permeability, root growth and nutrient uptake (Brady & Weil, 2012).

Total porosity increased down the slope (from summit to valley bottom), but decreased with soil depth at any of the topographic positions studied. The mean total porosity values varied in the order: summit (42.74%) < upper slope (43.49%) < middle slope (44.14%) < lower slope (45.34%) < valley bottom (47.07%). The decrease in total porosity with soil depth reflected the negative influence of high bulk density and high clay contents on soil total porosity which could negatively affect aeration and hydraulic properties of the soils.

The moisture contents of the Ap horizons of the soils varied from 38.01% at the summit to 43.36% at the valley bottom; whereas the moisture contents of the subsurface horizons of the soils varied from 38.33% at the summit to 44.18% at the valley bottom. Moisture contents increased with slope (from summit to valley bottom) and with soil depth at any of the topographic positions studied. The mean moisture contents varied in the order: summit (39.00%) < upper slope (39.66%) < middle slope (40.70%) < lower slope (45.78%) < valley bottom (45.03%). Most of the results agree with those of past researchers (Ekong & Uduak, 2015; Nsor & Akamigbo, 2015; Adegbite *et al*., 2019; Nsor, 2020; Uduak *et al*., 2022; Ajioagu *et al*., 2024).

The chemical properties of the soils along the toposequence are shown in Table 4. The mean electrical conductivity values recorded for the soils varied from 0.107 dS/m at the summit to 0.132 dS/m at the valley bottom and the electrical conductivities of the soils were all very low, suggesting that the all the horizons of the soils had no salinity problems. According to Brady & Weil (2012), salinity becomes an issue to be worried about in a soil when the electrical conductivity values of the saturation extract exceed 2.0 dS/m at 25 °C.

The pH (in water) of the summit, upper slope, middle slope and lower slope soils ranged from 4.7 to 4.9 indicating very strong acidity; whereas that of the valley bottom soil ranged from 5.2 to 5.4 indicating strong active acidity. Such levels of active soil acidity can have a reducing effect on the availability of P (Ijah *et al.,*2021) and S as well as an increasing effect on the availability of Al, Mn and Fe (Havlin *et al*., 2009). The organic carbon contents of the Ap horizons of the soils varied from 1.86% at the upper slope to 2.45% at the valley bottom; whereas the organic carbon contents of the subsurface horizons of the soils varied from 0.12% at the upper slope to 2.00% at the valley bottom. Organic carbon contents

Table 4: Selected Chemical Properties of the Studied Soils

Horizon	Horizon thickness Cm	EC dS/m	pH	OC %	TN %	Av.P mg/kg	Exch. Ca cmol/kg	Exch. Mg cmol/kg	Exch. K cmol/kg	Exch. Na $cmolkg^{-1}$	EA $cmolkg^{-1}$	ECEC cmol/kg	BS %
Pedon 1 (Summit)													
Ap	0-23	0.101	4.9	1.96	0.13	18.26	2.11	1.43	0.60	0.02	1.86	6.02	69.10
AB	23-35	0.102	4.9	1.53	0.12	16.11	1.98	1.22	0.51	0.01	1.80	5.52	67.39
Bt1	35-56	0.112	4.8	0.91	0.10	17.20	1.41	1.10	0.53	0.01	1.91	4.96	61.49
Bt2	56-132	0.113	4.8	0.52	0.09	14.31	1.42	0.91	0.41	0.02	1.21	3.97	69.52
Mean		0.107	4.9	1.23	0.11	16.47	1.73	1.17	0.51	0.02	1.70	5.12	66.88
Pedon 2 (Upper Slope)													
Ap	0-14	0.110	4.9	1.86	0.14	17.10	2.14	1.44	0.61	0.02	1.86	6.07	69.36
Bt1	14-59	0.121	4.9	1.60	0.13	18.25	1.98	1.35	0.52	0.02	1.78	5.65	68.50
Bt2	59-129	0.122	4.8	0.85	0.12	15.11	1.52	1.22	0.53	0.01	1.75	5.03	65.21
BC	129-1616	0.121	4.8	0.42	0.10	12.12	1.46	0.94	0.43	0.02	1.30	4.15	68.67
Mean		0.119	4.8	1.18	0.12	15.65	1.78	1.24	0.52	0.02	1.67	5.23	67.94
Pedon 3 (Middle Slope)													
Ap	0-3	0.122	5.0	2.01	0.14	19.20	2.27	1.50	0.63	0.01	1.75	6.16	71.59
Bt1	13-79	0.123	4.9	1.96	0.13	18.24	2.10	1.41	0.55	0.02	1.70	5.78	70.59
Bt2	79-123	0.124	4.8	0.95	0.13	15.20	1.86	1.32	0.44	0.02	1.56	5.20	70.00
BC	123-167	0.122	4.8	0.43	0.12	14.30	1.21	0.91	0.44	0.02	1.50	4.08	63.24
Mean		0.123	4.9	1.34	0.13	16.69	1.86	1.29	0.52	0.02	1.63	5.31	68.36
Pedon 4 (Lower Slope)													
Ap	0-14	0.121	5.2	2.14	0.15	20.22	2.30	1.52	0.67	0.02	1.62	6.13	73.57
Btg1	14-38	0.123	5.0	2.00	0.13	19.14	2.11	1.43	0.60	0.02	1.60	5.76	72.22
Btg2	38-114	0.124	4.8	1.94	0.11	15.53	1.98	1.33	0.52	0.02	1.51	5.36	71.83
BC	114-169	0.124	4.8	0.51	0.10	13.61	1.11	0.98	0.50	0.01	1.43	4.03	64.52
Mean		0.123	5.0	1.65	0.12	17.12	1.88	1.32	0.57	0.02	1.54	5.33	70.54
Pedon 5 (Valley Bottom)													
Ap	0-11	0.131	5.3	2.45	0.20	22.12	2.46	1.58	0.73	0.04	1.57	6.38	75.39
Btg1	11-40	0.132	5.4	2.40	0.16	22.03	2.03	1.32	0.66	0.05	1.51	5.57	72.89
Btg2	40-72	0.130	5.4	1.78	0.12	15.41	1.95	1.41	0.66	0.05	1.53	5.60	65.36
BC	72-121	0.133	5.2	0.62	0.12	13.36	1.99	1.43	0.51	0.03	1.55	5.51	71.87
Mean		0.132	5.3	1.81	0.15	18.23	2.11	1.44	0.64	0.04	1.54	5.77	71.38

EC = Electrical conductivity, OC = Organic carbon, TN = Total nitrogen, AP = Available phosphorus, Exch. = Exchangeable, EA = Exchangeable acidity,ECEC = Effective cation exchange capacity, BS = Base saturation.

increased from the summit to valley bottom and with soil depth at any of the topographic positions studied. Similar findings were reported by Ekong and Uduak, 2015). Total nitrogen contents of the soils varied from 0.09% at the summit to 0.20% at the valley bottom. Total nitrogen contents increased with slope (from summit to valley with slope (from summit to valley bottom) and with soil depth at any of the topographic positions studied. The mean available phosphorus contents varied in the order: upper slope (15.65 mg/kg) < summit (16.47 mg/kg) < middle slope (16.69 mg/kg) < lower slope (17.12 mg/kg) < valley bottom (18.23 mg/kg).

The exchangeable Ca, Mg, K and Na ranged from 1.11 cmol/kg to 2.46 cmol/kg, 0.91 cmol/kg to 1.58 cmol/kg, 0.41 cmol/kg to 0.75 cmol/kg and 0.01 cmol/kg to 0.05cmol/kg respectively. Each of the exchangeable bases increased with slope, but decreased with soil depth at each topographic position. The relatively high contents of organic carbon, total nitrogen, available phosphorus, exchangeable bases (Ca, Mg and K) in the valley bottom soil indicated lateral movements of the elements along the slope by rainwater and subsequent deposition at the valley bottom (Uduak *et al*., 2022; Iyanam *et al*., 2024).

The exchangeable acidity levels in the soils ranged from 1.21 cmol/kg at the summit to 1.86 cmol/kg at the summit/upper slope. Exchangeable acidity decreased with slope (from summit to valley bottom) and with soil depth at virtually all the topographic positions studied. The mean exchangeable acidity levels in the soils varied in the order: summit (1.70 cmol/kg) < upper slope (1.67 cmol/kg) < middle slope (1.63 cmol/kg) < lower slope = valley bottom (1.54 cmol/kg). The effective cation exchange capacity ranged from 3.97 cmol/kg at the summit to 6.38 cmol/kg at the valley bottom and increased with slope right from the summit to the valley bottom. The ECEC of the soils was low, though it was higher in the valley bottom soil which could be due to the relatively high contents of organic matter and clay which constitute the main colloids controlling ion exchange in soils. High soil ECEC is important for nutrient retention and pH buffering (Brady & Weil, 2012; Ekong & Uduak, 2015; Uduak *et al*., 2017; Akpan *et al*., 2023).

Base saturation ranged from 61.49% at the summit to 75.39% at the valley bottom and mean base saturation values varied in the order: summit (66.88%) < upper slope (67.94%) < middle slope (68.36%) < lower slope (70.54%) < valley bottom (71.38%).

Classification of Soils of the Toposequence (USDA Soil Taxonomy)

The classification categories of soils of the toposequence, based on the USDA Soil Classification System, are presented in Table 5. The soils at the summit, upper slope, middle slope and lower slope were classified as Ultisols, Udults, Paleudults and Typic Paleudults at the Order, Suborder, Great Group and Subgroup levels respectively. They were classified as Ultisols at the Order level because of their high active acidity (< pH 5.0), low base status (< 50%) and clay-enriched or argillic subsoil horizons with strong reddish/yellowish colour as well as low native fertility (Soil Survey Staff, 2015; Iyanam *et al*., 2024).

The soils were classified as Udults at the Suborder level because of their udic moisture regime following seasonally well-distributed precipitation; Paleudults at the Great Group level because of their argillic (clay accumulation) horizon and clay contents that did not decrease significantly within the depth of 150 cm; and Typic Paleudults at the Subgroup

Table 5: Classification of Soils of the Toposequence

Soil/Topograhic Position	Order Level	Suborder Level	Great Group Level	Subgroup Level
Summit	Ultisol	Udult	Kandiudult	TypicKandiudult
Upper Slope	Ultisol	Udult	Kandiudult	TypicKandiudult
Middle Slope	Ultisol	Udult	Kanhapludult	TypicKanhapludult
Lower Slope	Ultisol	Udult	Kanhapludult	TypicKanhapludult
Valley Bottom	Inceptisol	Aquept	Humaquept	CumulicHumaquept

level mostly because they were deep (> 50 cm) and well-drained and had ochric epipedons and argillic horizons that were loamy in texture (sandy clay loam), as reported by Soil Survey Staff (2015). The classification of the summit, upper slope, middle slope and lower slope soils as Ultisols at the Order level, Udults at the Suborder level, Paleudults at the Great Group level and Typic Paleudults at the Subgroup level might be so done because the soils satisfied the requirements of the USDA Soil Classification System. According to Soil Survey Staff (2015, 2022), Ultisols are mature and highly leached soils with high active acidity, low base status and low native fertility. These soils are therefore not suited to continuous agriculture in their natural state without the use of lime and fertilizers. While effective use of lime reduces soil acidity, effective use of fertilizers enhances soil fertility and crop productivity.

CONCLUSION

The morphological, physical and chemical properties of the soils along the toposequence varied from one topographic position to another. Sand dominated all the horizons of the soils irrespective of the topographic position and decreased with soil depth at each topographic position. Clay followed sand in dominance and decreased with soil depth at each topographic position. The mean clay contents of the soils varied in the order: valley bottom > upper slope > summit > middle slope > lower slope. Bulk density increased with soil depth at each topographic position, but decreased down the slope (from summit to valley bottom). Total porosity increased down the slope (from summit to valley bottom), but decreased with soil depth at any of the topographic positions studied. The organic carbon contents decreased with soil depth, but increased down the slope. The soils at the summit, upper slope, middle slope and lower slope were sandy at the surface layers and sandy clay loam subsoil layers. were classified as Ultisols, Udults, Paleudults and Typic Paleudults at the Order, Suborder, Great Group and Subgroup levels; whereas the valley bottom soil was classified as Inceptisol, Aquept, Humaquept and Cumulic Humaquept at the Order, Suborder, Great Group and Subgroup levels respectively. Based on the above findings and conclusions, effective erosion control, regular applications of manure, liming and conservation tillage are strategies recommended to help improve the quality and productivity of the soils.

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