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Original Research Article

Evaluation of soil properties variability along a toposequence in Wasinmi, Southwest Nigeria

Oluwatoyosi Oyetola **Oyebiyi**[1], Usman Olaleke **Fagbohun**[2], Oluwatosin Abimbola **Egbinola**[2], Julius Olayinka **Ojetade**[2], Sikiru Adekoya **Muda**[2], Opeyemi Ayomide **Adewumi**[2]

[1]*Institute for Sustainable Development, First Technical University, Ibadan, Nigeria*
[2]*Obafemi Awolowo University, Ile-Ife, Osun, Nigeria*

Correspondence to:
O.O. Oyebiyi, Institute for Sustainable Development, First Technical University, Ibadan, Nigeria.
E-mail: oluwatoyosi.oyebiyi@tech-u.edu.ng

Abstract

Topography significantly influences soil development and characteristics within an uneven agricultural field. Therefore, a comprehensive understanding of soil attributes and processes through detailed pedological knowledge is crucial for effective soil management. This research was carried out in Wasinmi, southwestern Nigeria, to delineate and categorise the soils across different slopes for agricultural insights. Three soil profiles were excavated across the topographical sequence, specifically designated as upper, middle, and lower slope positions. The prevailing soil texture was sandy loam with a discernible trend of lighter soil colour as the slope descended and soil depth increased. The pH of the soil ranged from moderately acidic to slightly acidic. The saturated hydraulic conductivity and soil organic matter content were lowest on the lower slope. Available phosphorus distribution varied inconsistently with higher concentrations of heavy minerals observed at the upper slope. The study underscored the influential role of topography in soil property variations and the need for tailored management practices. The classification of the soils revealed Typic Plintustults in the upper and middle slope positions, while the soils in the lower slope were identified as Typic Kandiaquults. This study demonstrated that topography significantly influenced soil properties, thereby emphasising the need for informed practices to better support the long-term sustainability of land use and agricultural outputs in topographically diverse landscapes.

Keywords: soil characterisation; soil classification; soil properties; toposequence; tropical soils

INTRODUCTION

Soil is a collection of natural bodies on the earth's surface, in places modified or even made by man, containing living matter and supporting or capable of supporting plants outside. Its upper limit is air or shallow water, and it grades to deep water or barren areas of rock or ice at its borders. The lower limit of biological activity is the lower limit of soil, which often correlates with the common rooting depth of native perennial plants (Soil Survey Staff, 1975). Soils play a vital role in the quality of our environment. For example, soil impacts the quality of our food, serves as the foundation of our structures, and interacts with the hydrosphere and atmosphere. Soil can be a source, a sink, or an interacting medium for many nutrients, as well as contaminants that impact humans, plants, wildlife, and other organisms (Aqeel et al., 2014; Rodríguez-Eugenio et al., 2018).

Soils are an integral part of landscapes and the knowledge of the distribution of different soils helps preserve a high standard of environmental quality. For example, site-specific management cannot be developed without detailed knowledge of soils. Critical sites e.g. shallow hill slope soils prone to erosion and leaching of nutrients can be identified through detailed/useful study of the soils. The soil properties along the toposquence in Wasinmi, Southwest Nigeria, exhibit significant variability, with distinct patterns observed at different positions along the landscape gradient. An understanding of soil properties and processes is therefore critical to the evaluation of criteria to be adopted for the soil's management. Detailed pedological knowledge is useful for land evaluation purposes, i.e. the classification of fertile productive soils and less valuable soils. The main objective of this investigation was to characterise the soils in the area along a toposequence, evaluate their properties, and provide basic information about the soils for sustainable agricultural development. Based on the topographic gradients and their influence on soil development processes, we hypothesise that soil properties will exhibit significant variability along the toposequence in Wasinmi, Southwest Nigeria.

MATERIALS AND METHODS

Site Description

The study was carried out in Wasinmi, a location situated in Osun State, southwestern Nigeria, within the wet tropical savanna region. Wasinmi is well-known for its significant agricultural production, particularly for crops like tomatoes, maize, and other arable crops. It is located approximately 12 km to the north of Ikire. The geographical coordinates of Wasinmi span from latitudes 7°25′59″N to 7°26′14″N and longitudes 4°16′0″E to 4°16′35″E.

The region experiences sufficient rainfall for most months of the year, with the highest rainfall intensities occurring between June and August. The dry season typically lasts for about three months, from December to February. The mean annual rainfall in the area falls within the range of 1500–1800 mm, while the mean annual temperature is around 27 °C. The soil composition in Wasinmi is based on the Pre-Cambrian basement complex, characterised by crystalline metamorphic rock. The topography of the region is generally gently undulating, with slopes ranging from 2% to 8%. There are occasional steep rock outcrops with slopes greater than 30%, forming inselbergs. The typical topographical sequence in the area includes hill crests, upper slopes, middle slopes, lower slopes, and valley bottoms, following a pattern described as hillside geomorphology. The vegetation in the study area is classified as secondary, with scattered oil palm trees present. Tenant farmers occupy and work in the study area, indicating an agricultural focus and human settlement.

Field survey and sampling

The study employed physiographic approaches to examine the soil characteristics within different segments of a hill slope, including the upper, middle, and lower slopes. This approach aimed to understand the variations in soil properties across the toposequence. Based on the homogeneity or heterogeneity of soils and the gradient of the slope, three distinct pedon sites were identified for detailed investigation.

The investigation of soil morphological characteristics was carried out in the field, following the procedures outlined in the FAO guidelines for soil description (FAO, 2006). The pedons, which are vertical cross-sections of soil from the surface to the parent material, were described according to specific pedological horizons for horizon depth with the aid of a measuring tape, colour of the soil in its moist state was assessed and recorded using the Munsell colour chart, texture using hand feel method, the structure, consistency, horizon boundaries, presence of roots, mottles, nodules, and concretions were also observed and described.

Soil sample preparation and analysis

The soil samples were carefully labelled, placed in transparent polythene bags, and transported to the laboratory for analysis. After air drying, the samples were crushed with a mortar and pestle and sieved through a 2 mm diameter sieve. The <2 mm air-dried soil fraction was used for the determination of particle size distribution by the modified hydrometer method of Bouyoucos (1962) as reported by Gee and Bauder (2002) after dispersing the soil with sodium hydroxide (NaOH).

Sand fractionation was carried out by allowing the sample suspensions from the particle size distribution to settle overnight. The suspensions were thoroughly shaken upside down by covering the top of the measuring cylinder. The suspensions were poured gently through a 0.063 mm sieve; the fractions were thoroughly washed with water to remove the silt and clay. The sand fractions were collected in a Petri dish and oven-dried at 105 °C. The oven-dried sand samples were weighed and sieved into very coarse sand (1–2 mm), coarse sand (0.5–1 mm), medium sand (0.25–0.5 mm), fine sand (0.1–0.25) and very fine sand (0.05–0.1 mm) fractions. Heavy and light minerals were separated in a fume cabinet following the procedure outlined by Brewer (1976) and Cady et al. (1986). The procedure involves using bromoform as the heavy liquid for the separation. Bromoform has a specific gravity (sg) of 2.89, minerals with sg > 2.89 are heavy minerals while minerals with sg < 2.89 are light minerals as studied by Morton (1991), Mange and Wright (2007), Nwajide (2013) and Adekola et al. (2018).

A saturated hydraulic conductivity assessment was carried out using a Guelph permeameter at three different slope positions i.e. lower, middle, and upper slope. The Guelph permeameter operates on the Mariotte siphon principle for simultaneously determining the saturated hydraulic conductivity in the field at the depth of 25 cm for two water heads (i.e. 5 cm and 6 cm). Soil pH was determined in distilled water and 1.0 M KCl (1:1 soil: solution ratio) using a combined glass electrode digital pH meter (Thomas, 1996). The pH determination was carried out in duplicate. Soil organic carbon was determined by the Walkley-Black method using chromic acid digestion (Nelson and Sommers, 1996). Total nitrogen was analysed using a modified micro Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was determined using the Bray-1 method, as described by Bray and Kurtz (1945). Exchangeable cations were extracted with neutral ammonium acetate solution (Thomas, 1982) and analysed with an atomic absorption spectrometer. Exchangeable acidity was determined by the KCl extraction method and the extractant was titrated against 0.05N NaOH and HCl solutions to measure total acidity (Al^{3+} and H^{+}) concentrations, respectively (Bertsch and Bloom, 1996). Effective cation exchangeable capacity (ECEC) was calculated as the summation of the exchangeable bases and KCl extractable Al (Soil Survey Staff, 2014). The percentage base saturation (BS) was the summation of total exchangeable bases expressed as a percentage of ECEC.

Statistical analysis

The data obtained from the results of the laboratory analysis were subjected to Pearson's correlation analysis to determine the relationships between the soil properties and the influence of topography on its distribution across the slope.

RESULTS AND DISCUSSION

Morphological description of the soils

Soil depth

The soil depths in the study area were shallow, measuring less than 80 cm in all pedons. The presence of a plinthite layer on the upper and middle slope posed challenges for excavation, resulting in the shallow pits. Soil depth plays a crucial role in water and nutrient retention and influencing root growth. Consequently, the shallow soil depth observed in the study area will restrict its ability to retain nutrients and moisture over extended periods, making it unfavorable for robust root development.

Soil colour

The upper slope had a colour varying from dark reddish brown (5YR 3/2) on the surface horizon to yellowish red (5YR 4/6) in the subsurface horizon. The colour of the soil in the middle slope varied from brown (7.5YR 4/2) in the surface horizon to strong brown (7.5YR 5/6) in the subsurface horizon (Table 1). In the lower slope position, colour of the surface horizons was very dark grey (10YR 3/1) grading to yellowish brown (10YR 5/4) in the subsurface horizons. More litter availability at the upper slope emanating from the relatively denser vegetation and material deposit may have encouraged higher organic matter contents at the surface horizons which impacted a dark colour to the soil. Generally, the colour indicated that virtually all pedons show a sign of eluviation in which sesquioxides and/or clay minerals have been leached out except at the lower slope where the aquic condition was encountered.

The redder colour of the soils at the upper slope may be due to the release of iron as a result of intense weathering (Dutta et al., 1999). As we moved down the slope, drainage conditions deteriorated. The bright subsurface soil colour at the upper and middle slopes is perhaps indicative of the good internal drainage of the soil (Amusan, 1991). The greyish-brown colour suggests that the lower slope is poorly drained and has less inherent productivity resulting from seasonal fluctuations in the water table. The results agree with the findings of Sharma et al. (1996) which reported that soils linked with high topography were redder in colour, becoming grey down the slope. Also, the observed soil colour further suggests that OM is a major contributor to the variations recorded in soil colour in the study area.

Soil structure and consistency

The upper slope was characterised by a moderate, medium, and subangular blocky structure at the surface horizon (Table 1). The middle slope had weak, medium and subangular blocky structure. The lower slope position had weak, fine to medium and granular structure. The subsurface horizons had moderate, medium, and subangular blocky structures in the upper, middle, and lower slope positions. The structure generally became stronger with increasing depth as a result of increased in clay content.

Table 1. Morphological description of the soils

LSP	Horizon	Depth (cm)	Colour (moist)	Texture^a	Structure^b	Consistence^c	Boundary^d
Upper Slope	Ap	0–25	5YR 3/2	grscl	2msbk	mfrwstpl	gs
	B	25–54	5YR 4/6	grsl	2msbk	mvfmwstpl	–
Middle Slope	Ap	0–16	7.5YR 4/2	ngrcl	1msbk	mvfrwnstnpl	gs
	BA	16–36	7.5YR 5/3	sgrc	2msbk	mvfrwsstspl	gs
	B	36–72	7.5YR 5/6	grc	2msbk	mfrwstpl	–
Lower Slope	Ap	0–22	10YR 3/1	grc	1fmgr	mvfrwnstnpl	cw
	AB	22–34	10YR 4/2	grc	2msbk	mvfrwsstspl	cw
	B	34–58	10YR 5/4	grc	2msbk	mvfrwsstspl	—

LSP = landscape position; ^{a}Texture: gr = gravelly, sgr = slightly gravelly, ngr = non gravelly, c = clay, cl = clay loam, scl, sandy clay loam, sl = sandy loam; ^{b}Structure: 1 = weak, 2 = moderate, f = fine, m = medium, fm = fine to medium, gr = granular, sbk = subangular blocky; ^{c}Consistence: m = moist, w = wet, vfr = very friable, fr = friable, fm = firm, sst = slightly sticky, st = sticky, spl = slightly plastic, pl = plastic; ^{d}Boundary: c = clear, g = gradual, w = wavy, s = smooth

Table 2. Physical properties of the soils studied

LSP	Horizon	Depth (cm)	VCS	CS	MS	FS	VFS	Total Sand	Silt	Clay	Textural class	Silt/ Clay
			(%)									
Upper Slope	Ap	0–25	14.4	14.7	12.1	15.1	4.1	60.4	13.0	26.6	Sandy clay loam	0.49
	B	25–54	23.0	20.5	16.9	13.2	2.8	76.4	12.0	10.6	Sandy loam	1.13
Middle Slope	Ap	0–16	9.4	24.9	20.8	20.3	4.0	79.4	11.0	9.6	Sandy loam	1.15
	BA	16–36	10.5	22.5	19.4	23.2	4.8	80.0	9.8	10.2	Sandy loam	0.96
	B	36–72	12.7	20.6	18.9	19.8	4.4	76.4	11.0	12.6	Sandy loam	0.87
Lower Slope	Ap	0–22	5.6	17.4	19.8	26.2	5.4	74.4	13.5	12.1	Sandy loam	1.12
	AB	22–34	5.0	13.5	19.7	31.5	6.7	76.4	14.0	9.6	Sandy loam	1.46
	B	34–58	4.1	13.5	18.9	30.3	6.1	72.9	17.5	9.6	Sandy loam	1.82

LSP = landscape position, VCS = very coarse sand, CS = coarse sand, MS = medium sand, FS = fine sand, VFS = very fine sand

Table 3. Saturated Hydraulic conductivity of the soil

	K_{fs}	Remark (Clapp and Hornberger, 1978)
Lower slope	-4.856×10^{-4}	Low
Middle lope	4.205×10^{-3}	High
Upper slope	9.312×10^{-3}	High

K_{fs} = Saturated hydraulic conductivity

Table 4. Chemical properties of the soil

LSP	Horizon	Depth	pH	pH	ΔpH	OC	SOM	Avail. P	Ca	Mg	K	Na	TEB	Exc. Al	ECEC	PBS (%)
		(cm)	(H_2O)	(KCl)		(%)		(ppm)	cmol/kg							
Upper Slope	Ap	0–25	6.2	5.9	0.3	1.77	3.05	47.0	0.890	0.410	0.081	0.028	1.409	0.30	1.709	82.45
	B	25–54	6.5	6.0	0.5	0.65	1.11	50.8	0.590	0.150	0.053	0.013	0.806	0.23	1.036	77.80
Middle Slope	Ap	0–16	6.5	5.8	0.7	0.94	1.61	44.0	0.660	0.150	0.069	0.010	0.889	0.30	1.189	74.77
	BA	16–36	6.8	6.1	0.7	0.64	1.10	43.7	0.630	0.090	0.060	0.009	0.789	0.35	1.139	69.27
	B	36–72	6.6	6.1	0.5	0.55	0.94	54.4	0.090	0.015	0.005	0.015	0.125	0.30	0.425	29.41
Lower Slope	Ap	0–22	5.8	5.1	0.7	0.74	1.27	55.5	0.120	0.019	0.009	0.016	0.164	0.40	0.564	29.08
	AB	22–34	5.9	5.3	0.6	0.47	0.81	49.0	0.070	0.017	0.005	0.013	0.105	0.25	0.355	29.58
	B	34–58	6.4	5.6	0.8	0.51	0.87	49.4	0.070	0.016	0.005	0.013	0.104	0.25	0.354	29.38

OC = organic carbon, SOM = soil organic matter, Avail. P = available phosphorus, TEB = total exchangeable bases, Exc. Al = exchangeable Al, ECEC = effective cation exchange capacity, PBS = percent base saturation

Table 5. Correlation coefficient among selected soil physical and chemical properties

	Sand	Silt	Clay	Silt/Clay	pH(water)	pH(KCl)	SOC	Avail. P	Ca	Mg	K	Na	TEB	Exch. Al
Silt	–0.371													
Clay	–0.923**	–0.011												
Silt/Clay	0.423	0.671	–0.732*											
pH(Water)	0.348	–0.503	–0.176	–0.158										
pH(KCl)	0.040	–0.582	0.181	–0.476	0.904**									
OC	–0.805*	–0.115	0.916***	–0.710*	–0.113	0.180								
Avail. P	–0.070	0.274	–0.048	0.075	–0.452	–0.381	–0.301							
Ca	–0.322	–0.498	0.536	–0.648	0.375	0.552	0.745*	–0.665						
Mg	–0.729*	–0.190	0.851**	–0.689	0.065	0.372	0.945***	–0.429	0.871**					
K	–0.263	–0.511	0.480	–0.610	0.389	0.538	0.719*	–0.707*	0.995***	0.840**				
Na	–0.966***	0.202	0.956***	–0.583	–0.385	–0.025	0.817*	0.188	0.313	0.721*	0.250			
TEB	–0.447	–0.426	0.642	–0.680	0.296	0.516	0.823*	–0.615	0.990***	0.932***	0.978***	0.439		
Exch. Al	0.048	–0.338	0.118	–0.388	–0.170	–0.238	0.162	0.142	0.023	–0.067	0.031	0.057	–0.004	
ECEC	–0.453	–0.456	0.668	–0.726*	0.264	0.472	0.852**	–0.606	0.979***	0.920***	0.970***	0.456	0.989***	0.138

*significant at $p < 0.05$ level, ** significant at $p \leq 0.01$ level, and *** significant at $p \leq 0.001$ level

Variation between pedons and horizons was observed in the consistency of soil in the study area. Surface horizon varied from very friable to friable when moist, and non-sticky/plastic to sticky/plastic when wet. The subsurface horizons ranged from very friable to firm when moist, and slightly sticky/plastic to sticky/plastic when wet (Table 1). The consistency of soil has been reported to change with soil depth due to variations in the amount of clay and organic matter (Wakene and Heluf, 2003). Firm and plastic characteristics of consistency are common in the subsurface horizon because of high clay content and low soil organic matter. This supports the result of soil consistency in the study area.

Soil horizon boundary

There were gradual smooth horizon boundaries at the upper and middle slope positions and clear wavy in the lower slope position. A gradual smooth horizon boundary in soil profiles is often associated with the process of illuviation (Buol et al., 2011). The presence of a clear wavy horizon boundary in the lower slope position could have resulted from the alternating wetting and drying cycles influenced by fluctuations in the water table observed in the slope area. Hartemink et al. (2019) identified landscape position and drainage as part of the major factors responsible for within-horizon variations.

Soil physical properties

Soil texture

Particle size distribution data showed that the textural classes of the surface soils of the upper slope were sandy clay loam, and sandy loam in the middle and lower slope positions. The subsurface horizons in all the landscape positions were sandy loam. Total sand content ranged from 60.4–76.4%, 76.4–80.0%, and 72.9–76.4% in the upper, middle and lower slope positions, respectively. The lower slope had relatively higher silt content (13.5–17.5%) followed by the upper slope (12–13%) and middle slope (9.8–11.0%). The proportion of clay was relatively higher at the upper slope (10.6–26.6%), followed by the middle slope (9.6–12.6%), and lower slope (9.6–12.1%) of the soil profiles (Table 2). The lower slope had a larger proportion of fine sand (72.9–76.4%), followed by the middle slope (19.8–23.2%), and upper slope (13.2–15.1%). The upper slope has the highest fraction of very coarse sand (14.4–23.0%), followed by the middle slope (9.4–12.7%), and the lower slope (4.1–5.6%). The particle size distribution also varied with depth in all soil profiles. The sand was negatively and significantly correlated with OC ($r = –0.805^*$) while the clay was positively correlated with OC ($r = 0.916^{***}$) (Table 5).

The higher fraction of very coarse sand at the upper slope could be attributed to the higher intensity of weathering occurring at the landscape position. The

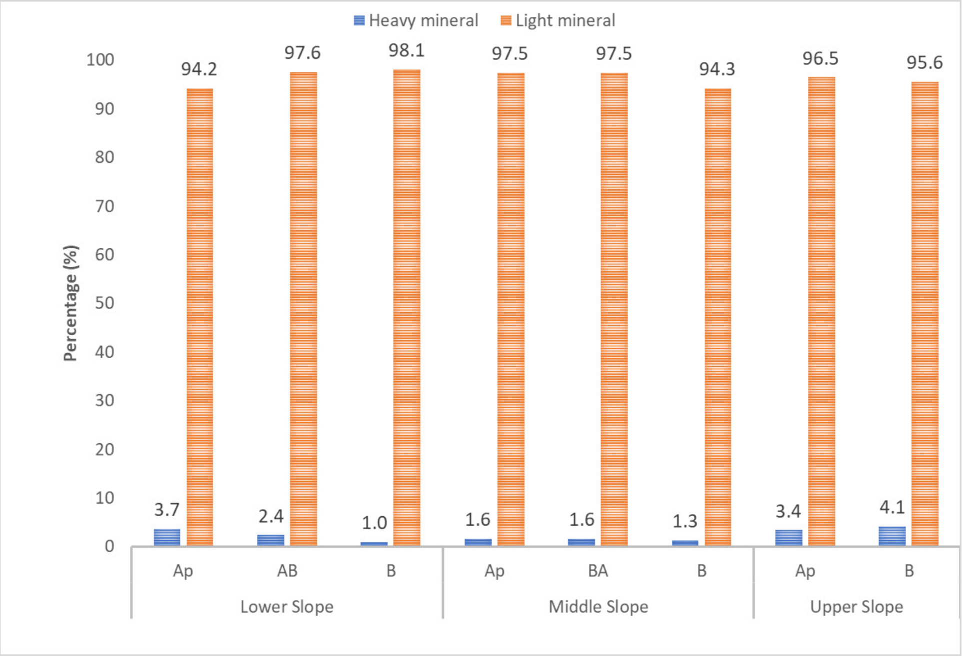

Figure 1. Separation of sand fraction using heavy liquid

presence of nodules and concretions which further restrict the penetration of roots on this land area may also be responsible for the coarse texture. The higher proportion of fine sand in the lower slope could result from sorting transported materials and the deposition of finer particles. Soils transported from the upper slope to the lower slope along with moving water are predominantly fragile matter not more than 100 µm in diameter which includes fine sand, silt, and clay (Schoonover and Crim, 2015), hence, the increase in fine sand fraction in lower slope. The weathered soils are transported to the mid and lower slope thus resulting in the higher fraction of very coarse and coarse sand observed in the upper slope. The lower silt/clay ratio at the surface soil of the upper slope also implies a pronounced relative intensity of weathering in the surface horizons (Ojo-Atere and Ogunwale, 1982).

The highest saturated hydraulic conductivity was recorded in the upper slope (9.312×10^{-3}), followed by the middle slope (4.205×10^{-3}) and the lower slope (-4.856×10^{-4}) (Table 3). According to Clapp and Hornberger (1978), the saturated hydraulic conductivity values obtained for the lower slope were low, while those of the middle and upper slope were high. The nearness of the surface soil to the groundwater table in the lower slope position impacted the low saturated hydraulic conductivity recorded in the landscape position. This suggests that the soils in the lower slope may be flooded for most of the year.

Figure 1 shows the proportion of heavy and light minerals in the soils. The light minerals dominated the studied area with values ranging from 94.2–98.1% while heavy minerals ranged from 1.0–4.1%. The light minerals comprise more than 90% of the total parent rock mineralogy with the upper slope having a higher proportion. This indicates that the parent rock of the soils has been highly weathered and contains a considerable amount of quartz and feldspar, thus indicating the resistance of the soil to weathering. Heavy minerals are most concentrated on the upper slope and decrease down the slope. Conversely, light minerals are least concentrated on the upper slope and become more prevalent as the slope descends.

Chemical properties of the soils

Soil pH

According to the ratings by Jones (2002), the soil pH values were moderately acidic in the upper and middle slopes while it ranged from slightly acidic to moderately acidic in the lower slope position. Specifically, the pH values of the surface horizons of soils were 6.2, 6.5, and 5.8 in the upper, middle, and lower slopes, respectively. In the subsurface horizons, recorded pH values were 6.5 on the upper slope, 6.6–6.8 on the middle slope, and 5.9–6.4 on the lower slope (Table 4). The variations of soil reaction in the study area were highly related to variations in topographic situation. The mean pH value in the upper slope was relatively lower than the middle slope. As a result of the relatively higher slope gradient, soil reaction in the upper slope was influenced by the leaching of basic cations subsequently deposited at relatively lower slope gradients in the middle slope. Thus, soils in the upper slope were more acidic than those in the middle slope position. Lower pH values recorded in the lower slope position may be related to the excessive leaching due to the alternate wetting and drying cycles occasioned by the fluctuating water table at the landscape position.

The pH of the soils showed a slightly increasing pattern with increasing profile depth (Table 4). A similar result was reported by Filippi et al. (2019), Zhou et al. (2019), and Abure (2022). Herrera (2005) argued that the release of fewer hydrogen ions at the subsurface soil due to the low amount of OM may have contributed to the higher pH at the subsurface horizons. All landscape positions and soil depths had soil pH values that were between 0.3 and 0.8 units higher than those of the corresponding KCl solution measurements (Table 4). The low soil pH recorded in the KCl solution indicates the release of significant amounts of exchangeable H (H^+) and aluminium ions (Al^{3+}) into the soil solution. This has also been attributed to the presence of Al^{3+} and H^+ in the clay lattice or colloidal surfaces suggesting high potential acidity (Kome et al., 2019). Generally, the soils are within the optimal pH range of 5.5–7.0 for overall satisfactory availability of plant nutrients (Brady and Weil, 2010).

Soil organic carbon

The organic matter contents in the surface horizon ranged from 1.27% in the lower slope to 3.05% in the upper slope (Table 4). In the subsurface layers, it ranged from 0.81% in the lower slope to 1.11% in the upper slope. The SOM content followed the order; upper slope > middle slope > lower slope. Soil organic matter was also observed to decrease with increasing soil depth. This agrees with the findings of other works (Smyth and Montgomery, 1962; Ogunkunle, 1993; Akinbola et al., 2006) whereby higher OM content was recorded in the surface horizons.

The high OM content at the surface soil in the upper slope results from accumulated leaf litter that subsequently decays and mineralizes to yield OM (Olayinka, 2009). Visual field observation indicated that greater canopy cover was found within the upper slope; this possibly explains the higher OM content in the upper slope compared to the middle and lower slopes. The significant positive correlation observed between SOC and the basic cations (Table 5) aligns with the findings of several other authors (Kadeba and Benjaminson, 1976; Oyedele et al., 1999; Gael et al., 2022), indicating that SOM is a primary contributor to soil fertility in tropical regions (Oyebiyi et al., 2018).

According to the rating of Udo et al. (2009), the amount of soil organic carbon in the surface soils at the upper slope (1.77%) was rated high, while the middle slope (0.94%) and lower slope (0.74%) were rated low. Thus, the middle and lower slope positions require sustainable management practices to improve the OC content especially as it influences nutrient recycling, moisture content, and good soil tilth.

Available phosphorus

Available phosphorus (P) content varied from 49.0–55.5 ppm, 43.7–54.4 ppm, and 47.0–50.8 ppm in the lower, middle, and upper slopes, respectively. The distribution of P content in the surface horizon shows no regular pattern of variation down the toposequence. In the subsurface horizon, the lower slope had the lowest mean available P content, and the upper slope had the relatively highest mean available P content. This indicates that the availability of phosphorus tends to increase slightly from the lower slope to the upper slope in the subsurface horizon.

Exchangeable cations

The level of exchangeable bases decreased regularly with soil depth. The contents of exchangeable basic cations were low throughout the profiles studied varying from 0.11 cmol/kg in the subsurface horizon of the lower slope to 1.52 cmol/kg in the surface horizon of the upper slope. According to Smyth and Montgomery (1962), the soils of central western Nigeria's upland areas have limited exchangeable capacity due to the primarily kaolinitic character of their clay components. The surface horizon accumulated more bases than the subsurface soils. Sehgel et al. (1972) ascribed the relative quantity of exchangeable cations in surface soil to the fact that it was constantly refilled by mobile elements freed by organic residue decomposition, regardless of exposure to leaching and run-off. Soil organic carbon content was positively and significantly correlated with exchangeable Ca (r = 0.745*), Mg (r = 0.945***), K (r = 0.719*), Na (r = 0.817*) and the ECEC (r = 0.852**). The value of exchangeable Al decreased with increasing soil depth in the study area. Exchangeable Al ranged from 0.15 in the upper slope to 0.40 in the lower slope position. Exchangeable Al values were classified as generally low (<1.0 cmol/kg), and this suggests that the soils have little or no acidity problems.

The variations of exchangeable cations and ECEC in the study area were highly related to variations in topographic situation. The effective cation exchange capacity (ECEC) calculated based on the sum of cations varied from the lowest 0.57 cmol/kg in the lower slope to the highest 1.77 cmol/kg in the upper slope of surface horizons and 0.36 cmol/kg in the lower slope to 1.15 cmol/kg in the middle slope of subsurface soils. Similar variation was observed in the subsurface layers. The value of exchangeable acidity decreased with increasing soil depth in the study area. This indicates that the ability of the soils to retain nutrients at their natural pH levels is low. The cation exchange capacity of the soils was generally rated low (<6 cmol/kg) according to Malgwi (2007). A low CEC value indicates that the soil has little or no capacity to hold cations for subsequent plant uptake (Hazelton and Murphy, 2007). The percent base saturation of the soils ranged from 84.58–85.65%, 29.07–74.45%, and 29.30–29.72% in the upper, middle, and lower slope positions, respectively. Soils with a base saturation greater than 50% are classified as fertile, while those with less than 50% base saturation are considered infertile (FAO, 1999).

Soil classification

The soils were classified according to the USDA Soil Taxonomy (Soil Survey Staff, 2014) and correlated with the World Reference Base (WRB) for soil resources system (FAO, 2014). Given the morphological and physical properties of the soil, the profiles have a low base saturation at depth below 50 cm and hence classified at order level as Ultisols. The ustic moisture regime qualified the upper and middle slope as Ustults at the suborder level. Whereas, the lower slope was classified as Aquults due to the presence of aquic moisture conditions which prevail for some time in the year. At the great group level, the upper and middle slopes fitted into Plinthustults because of the occurrence of a continuous plinthite horizon in the subsoil and Typic Plintustults at sub-group level which correlated with Plinthosols under WRB classification system. The lower slope was classified as Kandiaquults due to the very low cation exchange capacity at the subsoil horizons and Typic Kandiaquults at the subgroup level.

CONCLUSIONS

This study demonstrated that topography significantly influenced soil properties, leading to noticeable variations in soil color, texture, and saturated hydraulic conductivity along the toposequence from the upper to the lower slopes. Notably, sand content was higher at the middle and lower slopes, whereas soil acidity increased, and organic matter decreased along the slope. Imperfect drainage conditions were attributed to the presence of an indurated (plinthite) layer in the subsurface soil. The shallow soil depth observed in the study area poses a significant challenge to robust root development, thereby limiting the availability of nutrients and moisture necessary for optimal plant growth.

Understanding these soil variations is critical for effective soil management and improvement, especially given the continuous cultivation and land use in the area. The marked differences in soil properties based on slope position underscore the necessity for tailored soil management practices to optimize soil health and enhance crop productivity. These practices should be designed to preserve soil organic matter and maintain vital plant nutrients. Consequently, indiscriminate soil management approaches, such as random soil sampling without preliminary testing and uninformed fertilizer recommendations, should be avoided to ensure sustainable agricultural productivity. Implementing informed practices will better support the long-term sustainability of land use and agricultural outputs in topographically diverse landscapes.

CONFLICT OF INTEREST

The authors declare no conflicts of interest concerning the research, authorship, and publication of this article.

ETHICAL COMPLIANCE

The authors have followed ethical standards in conducting the research and preparing the manuscript.

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