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CHARACTERIZATION AND CLASSIFICATION OF SOILS ALONG TOPOSEQUENCE IN TEACHING AND RESEARCH FARM OF FEDERAL UNIVERSITY DUTSE, JIGAWA STATE.

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ABSTRACT
This study characterized and classified soils along a toposequence in the Teaching and Research Farm of the Federal University Dutse, Jigawa State, Nigeria, with emphasis on morphological, physical, and chemical properties and their implications for soil classification and land use. Four representative pedons were described along upper, mid, and lower slope positions using standard field and laboratory procedures. Morphological observations revealed ochric epipedons in all pedons, while argillic (Bt/Btg) horizons occurred in Pedons 1, 2, and 4, indicating active clay illuviation. Redoximorphic features, including mottling and gleyed matrix colours, were prominent in lower slope positions, reflecting periodic waterlogging and drainage limitations. Physical properties showed marked textural differentiation along the toposequence, ranging from sandy loam in upland soils to sandy clay and loam downslope, with bulk density generally increasing with depth and reaching values >1.6 Mg m^{-3} in lower slope soils, implying reduced porosity and aeration. Chemical analyses indicated near-neutral to strongly alkaline pH, low electrical conductivity except in a sodic subsoil horizon (ESP ≈17%), and generally low organic carbon, total nitrogen, and available phosphorus, despite consistently high base saturation. Based on USDA Soil Taxonomy, the soils were classified as Aquic Haplustalf (Pedon 1), Typic Haplustalf (Pedon 2), Typic Ustipsamment (Pedon 3), and sodic Haplustalf (Pedon 4). Corresponding WRB classes were Gleyic Luvisol, Haplic Luvisol, Haplic Arenosol, and Gleyic Luvisol (sodic phase). The results shows strong topographic control on soil development, fertility status, and management potential, with upland soils being coarse-textured and weakly developed, and downslope soils showing higher clay content, density, and sodicity-related constraints.

Keywords: Toposequence, Soil classification, Clay illuviation, Drainage conditions, Soil fertility, Sodicity.

INTRODUCTION
Pedological characterization and classification of soils is fundamental for evaluating land potential, identifying constraints, and ensuring sustainable agricultural productivity (Alemu et al., 2018). Soil characterization involves systematic evaluation of both physical and chemical attributes that are not easily observable during field examination but are crucial for understanding the capacity of soils to function (Sanchez et al., 2003). Soil classification, on the other hand, provides a framework for naming and grouping soils, thereby facilitating appropriate land use decisions, yield estimation, technology transfer, and effective communication among soil scientists, policymakers, planners, researchers, and extension workers (Assen and Yilma, 2010). Thus, adequate information on soil resources equips land users with vital knowledge for proper utilization, sustainable land management, and improved agricultural productivity (Nwaloka et al., 2019). Sustainable agriculture depends largely on detailed knowledge of soil properties and their spatial variability across landscapes. Since soils differ in fertility and productivity potential, characterization and classification at local and regional scales are necessary for effective land use planning (Sereke, 2002; Essoka and Essoka, 2014). Providing classification to soils found in a given area not only gives them identity but also offers baseline information on their properties and management requirements (Akamigbo and Asadu, 1983). Despite this importance, there remains inadequate information on the physicochemical attributes of soils in many regions of Nigeria, as well as on how topography influences these properties (Atofarati et al., 2012; Chukwu et al., 2013).

Topography has been identified as one of the dominant factors influencing soil formation, variability, and profile development (Chikere-Njoku, 2015; Lawal et al., 2013; Esu, 2010). Through redistribution of matter and energy, topography affects runoff, drainage, erosion susceptibility, soil temperature, soil depth, and nutrient status (Esu et al., 2008; Mulugeta and Sheleme, 2010). Variations in soil properties across a landscape are strongly linked to slope position: soils on higher elevations are typically shallow, coarse-textured, and well-drained, whereas soils on lower slopes and valley bottoms often accumulate finer particles, organic matter, and moisture, but may be poorly drained (Egbuchua, 2014; Jimoh et al., 2020). Topographic influence also extends to slope hydrology—where water velocity controls deposition patterns, with sand settling first while clay particles are transported further downslope, leading to variations in soil texture between uplands and lowlands (Lawal et al., 2014).
A toposequence is defined as a succession of sites from crest to the valley bottom which replace catena in soil topography relationship studies (Okusami et al., 1985). Previous research shows that different soil units occur along a toposequence and often require distinct management practices (Ogunkunle and Onasanya, 1992; Olatunji et al., 2007). In many cases, slope gradient exerts a stronger

influence than parent material on soil properties within a toposequence (Omokaro, 2023). Characterizing soils on a landscape basis therefore provides valuable insights for assessing soil productivity, developing conservation strategies, and reducing uniform management practices that may cause uneven input distribution in agricultural fields (Oku et al., 2010). It also supports precision agriculture by supplying baseline information for land use models and site-specific soil management (Bassanta et al., 2013; Fedaku et al., 2018). Classifying soils, in turn, facilitates technology transfer, extension services, and appropriate management decisions for distinct soil units (Assen and Yilma, 2010; Rabia et al., 2013). African soils in particular are strongly influenced by topography, with slope position affecting not only soil morphology and physicochemical properties but also crop productivity (Akamigbo, 1999; Egbuchua, 2014). Landscape studies across Nigeria have confirmed that topography plays a major role in soil distribution, as differences in slope positions translate into significant variations in soil characteristics and agricultural potential (Jimoh et al., 2020; Oriako et al., 2022). Therefore, this study seeks to characterize and classify soils along a toposequence in the Teaching and Research Farm of Federal University Dutse using the United State Department of Agriculture (Soil Survey Staff, 2022) Soil Taxonomy and correlated with World Reference Base (IUSS WRB, 2022) for soil resources. In Dutse, where agriculture is a key livelihood activity, this study is crucial for guiding crop selection, input management, and soil conservation practices.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Federal University Dutse Teaching and Research Farm, located between latitude 11°42′25.23″N to 11°43′12.94″N and longitude 9°22′20.80″E to 9°23′28.11″E, Dutse, Jigawa state, Nigeria (Figure 1). The study area covers an estimated area of 160 ha and lies within the Sudan savannah of the seven agro-ecological zones in Nigeria. It has a tropical climate characterized by two main seasons; the rain season brought by the humid south-westerly breezes from far away Atlantic coast of West Africa from May to September, and the "Harmatan" season of dry, dusty north easterly winds of the Sahara Desert from November to April (JARDA, 2022). The area recorded average rainfall of between 600mm to 1000mm (Ahmed *et al.,* 2019). The hottest months are March and April while coolest are December and January with August being the wettest month (Adejuwon, 2004). The mean temperature of coolest month is about 21˚C while the temperature in the hottest months is about 31˚C (Mustapha *et al.,* 2018).

Total forest cover in the area is very much below national average, due to both natural and human factors. The actual vegetation found in the area are short grasses, 1-2 m high, some shrubs, neem other semi-arid trees. The geology of Dutse, Jigawa State is characterized by basement complex rocks, particularly granites, schists, and gneisses, which form the rocky topography of the city, earning it the nickname "city of stone". The area is also underlain by the Chad Formation, a sedimentary formation comprising clays and sands found in other parts of Jigawa State, though the Basement Complex rocks dominate around Dutse. This rocky foundation includes the Dutse Complex, a Triassic-age ring complex consisting of granite.

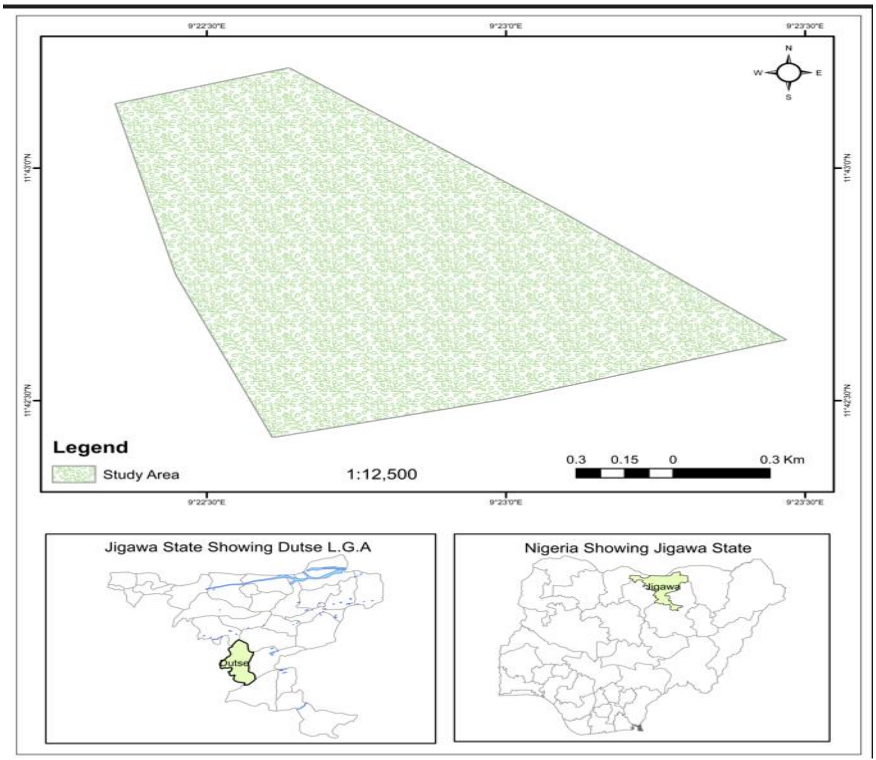

Figure 1: Map of Nigeria showing Jigawa state and the study area

Field Studies
A reconnaissance visits were undertaken to identify the various soil units in the study area. During the pre-field visit, the boundary and coordinates of the study area were recorded using locus map version 4.19. The pre-field site visit was done in order to become familiar with the area, investigate the major soils and their pattern of occurrences as well as probable sites for digging profile pits. After digitization and geo-referencing of the satellite imageries obtained using the coordinates, a base map was produced at a scale of 1:12,500 for the purpose of fieldwork (Figure 1). The base map developed from GIS was uploaded to an android (Avenza maps) for detailed fieldwork. The hard copy of the base map printed at a scale of 1:12,500 along with the soft copy in the android phone were used for easy movement within the study area. The coordinates and altitudes of each profile pit in the study area were recorded using global positioning system (GPS) device. Four profiles designated as FUD1, FUD2, FUD3 and FUD4 were dug at the study site representing the lower slope, valley bottom, upper slope and crest, respectively. The pedons were described in situ following the procedures in the guidelines for soil profile description and horizon designations of the Soil Survey Staff (2014).

Soil sampling and preparation
Soil samples were taken from each genetic horizon identified within a profile pit. Undisturbed soil samples were taken from each genetic horizon with the aid of a core sampler for bulk density. Bulk soil samples were collected from various genetic horizons identified within the profile pits. The samples were air-dried, crushed and sieved through 2mm sieve size, labeled and taken to the laboratory for analysis of physical and chemical properties.

Soil Analyses
Soil physical analysis
The particle size distribution was determined using Bouyoucos hydrometer method as described by Gee and Bauder, (1986). Soil bulk density (ρb) was determined using the core method as described by Blake and Hartge (1986). The bulk density of the soil was calculated thus;

$$\rho_b = \frac{Ms}{Vt}$$

Where:
ρ_b = bulk density (g cm^{-3})
M_s = Mass of soil solids (g)
$V_t = \pi r^2 h$
V_t = total volume (solids and pore) (cm^3)
π = 3.142, r = radius of core = diameter of the core/2, h = height of core

Total porosity was calculated mathematically (Danielson and Sutherland, 1986) from the particle density (ρ_p) and bulk density (ρb) of the soils using the formula; $f (\%) = (1 - \rho_b / \rho_p) \times 100$

Soil chemical analyses
Soil pH was determined at a 1:2.5 soil/water ratio according to the procedure described by Agbenin (1995). Electrical conductivity was measured in a 1:2.5 fresh soil-water suspension with a glass electrode meter according to the procedure described by Jackson (1962). Organic carbon was determined using the Walkley-Black procedures (Walkley, 1947). Available Phosphorus was determined calorimetrically by using Bray- 1 extraction method (Olsen and Sommers, 1982). Total Nitrogen was determined using the Kjeldahl procedure as described by Bremner (1996). The exchangeable bases (Ca, K, Mg, and Na) were determined using the ammonium acetate extract from cation exchangeable capacity (CEC) determination. Flame photometer was used to determine the potassium and sodium content. While Calcium and magnesium were determined using EDTA, the CEC was determined by neutral ammonium acetate method buffered at pH7 (Thomas, 1982). The soil was leached with 1M KCl solution. Total exchange acidity ($H^+ + Al^{3+}$) was determined by titration of the extract with a standard NaOH solution as described by Uyovbisere *et al.* (2013). The exchangeable sodium percentage was calculated as the proportion of CEC (NH_4OAc) occupied by sodium cations as described by Agbenin (1995).

$$ESP = \frac{\text{Exchangeable sodium}}{CEC(NH_4OAc)} \times 100$$

The base saturation percentage was calculated for both CEC (NH_4OAc) using the formula below as described by Agbenin (1995).

$$\% B.S = \frac{\text{Total exchangeable bases}}{\text{CEC or ECEC}} \times 100$$

Statistical analysis
The data obtained from laboratory analyses were analyzed using descriptive statistic.

Soil morphological properties
The result in Table 1 shows the soil morphological properties along a toposequence in the study area. The surface horizons (Ap) generally exhibited dark brown to brown colours such as 7.5YR 4/2 and 10YR 4/3, which are associated with relatively high organic matter accumulation. The darker value and chroma in A horizons implying organic carbon enrichment through root and litter inputs (Schoeneberger et al., 2012). In contrast, subsurface horizons showed lighter and more yellowish-brown hues (10YR 5/6, 7.5YR 5/6) and, in some pedons, greenish or grey colours (5G 4/2) with distinct mottling. These gley colours and mottles are diagnostic of redoximorphic features, reflecting fluctuating groundwater tables and periodic reducing conditions (Hewitt et al., 2021; Heck et al., 2022). The Btg and BCg horizons of Pedon 4 showed prominent mottles and gleyed matrix colours, signifying impeded drainage at lower landscape positions.

The presence of Bt and Btg horizons in pedon 1, 2 and 4 implies the process of clay illuviation (argilluviation), where clay particles are translocated from the surface to subsurface horizons (Buol et al., 2011). This is reinforced by the blocky structures observed in the Bt horizons, reflecting aggregation of clay-rich material under wetting and drying cycles (De Wispelaere et al., 2015). The “g” suffix in Btg and BCg horizons signals strong influence of groundwater, with prolonged saturation leading to iron reduction and subsequent mottling (Schoeneberger et al., 2012). In Pedon 1, the Bt and Btg horizons (21–123 cm) exhibit a finer texture than the Ap horizon, moderate to strong subangular blocky structure, and firm to very firm consistence when moist. The occurrence of smooth ped faces and clay skins (argillans) lining ped surfaces and pores provides direct morphological evidence of downward clay translocation. Clay coatings are considered one of the most reliable field indicators of argillic horizons and reflect sustained pedogenic clay illuviation over time (Schaetzl and Thompson, 2015; Vepraskas and Craft, 2016). Similarly, the Btg horizon of Pedon 2 (9–34 cm) shows a clear increase in clay content relative to the Apg horizon, accompanied by moderate subangular blocky structure and firm consistence. Although periodic saturation has resulted in redoximorphic features, such conditions do not preclude argillic horizon formation. Several studies have shown that argillic horizons commonly coexist with gley features in seasonally waterlogged soils, where clay illuviation occurs during drier periods (Krasilnikov et al., 2018; Schaetzl and Thompson, 2015). In Pedon 4, the Btg horizons (10–83 cm) display weak to moderate horizon differentiation with finer textures and smooth ped surfaces, implying clay translocation. While prolonged wetness has locally reduced structural expression, the combined evidence of increased clay content, clay coatings, and distinct horizon boundaries supports the identification of an argillic horizon. The wetness-induced mottling and low chroma colors primarily reflect hydromorphic conditions rather than the absence of clay illuviation (Vepraskas and Craft, 2016; IUSS Working Group WRB, 2022).

The abundant fine roots in the Ap horizons indicate biologically active, well-aerated top soils, suitable for cultivation (Schoeneberger et al., 2012). However, the scarcity of roots in deeper horizons, especially in gleyed Bt, Btg and BC layers, implies root restriction due to poor aeration and higher bulk density. Similarly, the variation in pore spaces from “many” in surface horizons to “few” in subsurface horizons, confirms root impedement and water movement at depth (Lynch et al., 2022; Wendel et al., 2022). The horizon boundary also revealed pedogenetic transitions. Clear smooth boundaries (cs) between Ap and Bt horizons indicate abrupt changes in texture and colour due to clay illuviation, whereas gradual wavy or smooth boundaries (gw, gs) between lower horizons reflect more diffuse transitions caused by long-term soil-forming processes or groundwater influence. The better-drained upslope pedon (Pedon 3) showed less developed Bt horizons without redoximorphic features, while lower slope pedons (Pedon 4) exhibited Btg and BCg horizons with strong gleying. This confirms the influence of topography on soil development, consistent with the concept of a toposequence where drainage and redox conditions vary with landscape position (Buol et al., 2011; FAO, 2014).

Soil physical properties

Particle size distribution and texture

The soils show clear variation in sand, silt, and clay content across horizons and pedons (Table 2). Pedon 1 contained relatively high clay contents in the subsoil (up to 400 g/kg), resulting in sandy clay (SC) and sandy clay loam (SCL) textures. This confirms the illuviation of clay observed in the morphological description (Bt and Btg horizons). Pedon 2 had moderately fine textures (sandy clay loam to loam), whereas Pedon 3 was coarser, dominated by sandy loam (SL), especially in surface horizons with as little as 40 g/kg clay. Pedon 4 showed intermediate conditions, ranging from sandy loam to loam with more silt accumulation in horizon Bcg1 and Bcg2.
These textural patterns confirms the influence of topography and pedogenic processes. Coarser materials dominate on upper slope positions (Pedon 3), where erosion removes finer particles, while finer fractions accumulate in mid- and lower-slope pedons (1 and 2), where deposition and illuviation occur (Buol et al., 2011; Brady and Weil, 2017). The result corroborates with the findings of Lal (1987) and Akamigbo and Asadu (1983). The high proportion of sand in the soils indicates that the parent materials are largely derived from granite (Wilson, 2010). This condition is further influenced by geological and pedogenic processes such as particle sorting through biological activity, downward movement of clay by eluviation and illuviation, as well as surface erosion by runoff or a combination of these factors (Malgwi et al., 2000; Ya’u and Maniyunda, 2018; Ya’u and Maniyunda, 2019; Jimoh, 2021).

Bulk density and porosity

Bulk density (BD) values ranged between 1.23 and 1.80 Mg m^{-3}, with porosity values of 32%–54% (Table 2). Low BD values (<1.4 Mg m^{-3}) in surface Ap horizons of Pedons 2 and 4 indicate good soil structure, high organic matter, and biological activity that improve porosity. In contrast, high BD values (>1.6 Mg m^{-3}) in subsurface horizons of Pedon 1 and parts of Pedon 2 are associated with higher clay contents and compaction, which reduce aeration and water movement. According to Hillel (2004), bulk densities above 1.6 Mg m^{-3} restrict root elongation, while Lal (1991) emphasizes that such conditions can cause poor seedling emergence in tropical soils. High porosity (>50%) in surface layers is beneficial for root respiration, microbial activity, and water infiltration, while lower porosity in Bt horizons (<35%) can create perched water tables and anaerobic conditions, consistent with the mottling observed morphologically in Table 1. Similar relationships between clay-enriched horizons, high BD, and reduced aeration have been reported by Khan et al. (2000) and Roychand (2017).

Silt/clay ratio and weathering status

The silt/clay ratio provides a useful index of soil development. The ratios in Table 2 ranged from as low as 0.25 in Pedon 1 subsoils to over 7.0 in the surface of Pedon 3. Silt clay ratio varied irregularly with increases in soil depth except in pedon 1 where it decreases with depth. The findings are consistent with the observations of Maniyunda (2012) and Jimoh (2021), who reported silt-to-clay ratios above the critical threshold of 0.15 established by Van Wambeke (1962). According to FAO (1990), ratios below 0.20 typically signify strong weathering. In this study, the mean silt-to-clay ratios in both surface and subsurface horizons exceeded the 0.15 benchmark, indicating that the soils are not highly weathered, a conclusion supported by earlier reports (Van Wambeke, 1962; Nwokocha et al., 2003; Yakubu and Ojanuga, 2009). Thus, Pedons 1 and 2, with low ratios, are relatively more developed, whereas Pedon 3 reflects younger, coarser parent material with minimal pedogenesis. This contrast mirrors observations in tropical catenas where lower slope soils exhibit stronger pedogenic features than upland sandy soils (FAO, 2014; Obi and Asiegbu, 1980).

Soil chemical properties

Soil pH and electrical conductivity (EC)

The result for soil chemical properties is presented in Table 3. The soil pH (H_2O) values ranged from slightly acidic (5.7) in horizon BCg of Pedon 2 to strongly alkaline (9.8) in the Btg horizon of Pedon 4. However, most soils in the study area were near neutral to slightly alkaline (6.5–7.6), which is production.

generally favorable for nutrient availability and microbial activity (Brady and Weil, 2017). The extremely high pH in Pedon 4 (9.81) might be due to sodicity or prolonged water stagnation leading to alkaline conditions (Lal, 1987). The soil pH (H_2O) values observed in this study differed from those reported by Fasina et al. (2007), Maniyunda (2012), Ya'u and Maniyunda (2019), Jimoh (2021), and Auwalu et al. (2022) for soils from other regions of Nigeria. Soil pH can vary due to factors such as soil composition, rainfall, vegetation and management practices (Belay *et al.,* 2023). The slightly acid to a neutral state of soils were in conformity with the reports of Raji and Mohammed (2000); Jimoh (2021), who reported strongly to slightly acidic nature of the Nigerian savannah soils.

Electrical conductivity (EC) values were generally low (<0.2 dS/m in most horizons), indicating non-saline soils (Hazelton and Murphy, 2025). However, the anomalously high EC of 2.83 dS/m in Pedon 4 (Btg1 horizon) implies localized salt accumulation, possibly linked to impeded drainage and evaporative concentration (Richards, 1954). These values corroborate with the findings of Auwalu *et al.* (2022). The values also agree with the value of <1 dSm^{-1} for normal soil as reported by Deshmukh (2012). According to Horneck *et al.* (2011) soils with EC values of less than 1dSm^{-1} are suitable for crop

Table 1: Soil morphological properties

Pedon	Depth (cm)	Munsell colour Moist	Dry	Texture	Structure	Consistence Wet	Moist	Dry	Boundary	Other features
Pedon 1	Latitude 11˚42.542'N		Longitude 9˚22.590'E			Elevation 438m				
Ap	0-21	7.5YR4/2	10YR4/3	SCL	3Sfsbk	s	fi	h	cs	Medium and distinct mottles, common macro-pores, common fine roots.
Bt	21– 57	10YR4/6	10YR4/2	SC	2fsbk	s	vfi	h	gw	Many fine pores, few fine roots
Btg1	57 – 88	10YR4/3	10YR5/4	SC	2mmfsbk	s	fr	h	cs	few fine pores and mottles, few fine roots
Btg2	88 – 123	7.5YR 5/4	7.5YR5/6	SC	2mmfsbk	s	fr	h	gw	Common fine distinct mottles, few fine pores and few fine roots
BCg	123-175	10YR 4/6	10YR 8/4	SCL	1fsbk	ss	fr	sh	-	Common medium prominent mottle.
Pedon 2		Latitude 11 42.655'N			Longitude 9 23.392'E		Elevation 435.5m			
Apg	0-9	7.5YR4/2	7.5YR5/2	L	2fsbk	ss	fr	s	ds	Few fine faint mottles, many fine pores, many fine roots and few animal activities
Btg	9– 34	10YR5/4	7.5YR5/4	SCL	2fsbk	s	fi	s	cs	Few fine faint mottles, many medium pores many fine roots, few animal activities.
BCg	34 – 59	10YR5/4	7.5YR5/4	SCL	1fsbk	s	fi	s	gw	Common fine faint mottles, few fine pores and many fine roots, cracks.
Cg1	59 – 100	10YR5/6	-	SCL	Om	ss	l	-	ds	Many medium distinct mottles, few very fine roots
Cg2	100 – 150	7.5YR5/4	-	SCL	om	ss	l	-	-	Few very fine roots

Symbols were derived from soil survey manual (Soil Survey Division Staff, 2022).

LULC – Land use land cover, Texture: SL-Sandy loam, LS - Loamy Sand. Structure: 1fsbk: Weak fine sub-angular blocky, 1msbk-weak medium sub-angular, 2Mmabk: moderate medium angular blocky, 2msbk: moderate medium sub-angular blocky, 2fsbk: moderate fine sub-angular blocky, 2fsbk: moderate fine sub-angular blocky, 3Sfsbk: strong fine sub-angular blocky structure, Om: structureless, massive, Os: structureless, single grained, Soil consistence: wet: S-sticky, ns- non-sticky, ss- slightly sticky; sp- slightly plastic; ms-moderately sticky Moist: vfr – very friable, fr – friable, fi-firm; vfi- very firm Dry: h – hard, Sh- slightly hard, s – soft, LO: - loose. Boundary: dw – diffuse, wavy, ds – diffuse, smooth, gw - gradual wavy, gs – Gradual smooth, cs – Clear smooth, gi- Gradual irregular, cw- Clear wavy

Table 1 Contd: Soil morphological properties

Pedon	Depth (cm)	Munsell colour		Texture	Structure	Consistence			Boundary	Other features
		Moist	Dry			Wet	Moist	Dry		
Pedon 3	Latitude 11 42.933'N	Longitude 9 22.612'E	Elevation 443.99m							
A	0 - 17	10YR5/6	10YR6/6	SL	1fabk	ns	l	s	cs	common fine roots and pores
AB	17 – 58	10YR5/6	10YR6/6	SL	1fabk	ns	l	s	Ci	few fine pores and roots, big roots
BC	58 – 104	7.5YR5/8	10YR7/6	SL	1fabk	ns	l	s	cs	very few fine pores and few very fine roots
C1	104 – 152	10YR 4/6	-	SL	Om	ns	l	-	gw	few fine pores and roots, few animal activities.
C2	152 – 205	10YR 6/8	-	SL	Om	ns	l	-	-	few fine roots.
Pedon 4	Latitude 11 43.150'N	Longitude 9 22.493'E	Elevation 451.03m							
Ap	0-10	10YR6/2	-	SL	Om	ss	fr	-	cs	Few fine faint mottles, many fine pores, many fine roots and few animal activities
Btg1	10– 47	10YR5/3	-	SL	Om	s	l	-	gw	Common fine faint mottles, few fine pores, many fine and medium roots.
Btg2	47 – 83	10YR5/3	-	SL	Om	s	fr	-	gw	Many medium distinct mottles, few fine pores, many fine and coarse roots.
BCg1	83 – 107	5G4/2	-	L	Om	vs	l	-	gs	Many coarse prominent mottles, few fine pores, many fine and coarse roots
BCg2	107 – 130	5G5/2	-	SL	om	ss	fr	-	-	Common fine mottles, medium and coarse roots.

Symbols were derived from soil survey manual (Soil Survey Division Staff, 2022).
LULC – Land use land cover, Texture: SL-Sandy loam, LS - Loamy Sand. Structure: 1fsbk: Weak fine subangular blocky, 1msbk-weak medium subangular, 1fabk: Weak fine sangular blocky, 2Mmabk: moderate medium angular blocky, 2msbk: moderate medium subangular blocky, 2fsbk: moderate fine subangular blocky, 2fsbk: moderate fine subangular blocky, Om: structureless, massive, Os: structureless, single grained, Soil consistence: wet: S-sticky, ns- non-sticky, ss- slightly sticky; sp- slightly plastic; ms- moderately sticky Moist: vfr – very friable, fr – friable, fi-firm; vfi- very firm Dry: H – hard, Sh- slightly hard, S – soft, lo: - loose. Boundary: dw – diffuse, wavy, ds – diffuse, smooth, gw - gradual wavy, gs – Gradual smooth, cs – Clear smooth, gi- Gradual irregular, cw- Clear wavy

Organic carbon (OC) and total nitrogen (TN)

Organic carbon contents varied considerably, from very low values (1.2 g/kg in C horizons of Pedons 3) to higher levels (>10 g/kg in Ap and Btg2 horizons of Pedon 2). The mean OC values were rated low for soils in pedon 1, 3, 4 and medium for soils in pedon 2 (Hazelton and Murphy, 2025). The pattern of OC distribution did not follow a strictly decreasing trend, but instead fluctuated between surface and subsurface horizons (Table 3). Such irregular variation can be attributed to several pedogenic and environmental factors. Organic compounds, especially soluble organic acids, might have leached from the surface horizons and translocated into the subsoil, where they accumulate temporarily in illuvial horizons (Bt or Btg). This explains why some subsurface horizons may show unexpectedly higher OC than the overlying horizons (Stevenson, 1994; Sollins et al., 1996). Similarly, in horizons with higher clay content, organic matter might become more stabilized through organo-mineral complexes, protecting it from microbial decomposition. Thus, subsurface horizons with more clay (such as Bt horizons) may retain relatively high OC despite limited organic inputs (Six, Conant, Paul, and Paustian, 2002; Krull, Baldock, and Skjemstad, 2003). In the same vein, poorly drained lower slope soils exhibited gleying and redoximorphic features. Waterlogging under anaerobic conditions can slow microbial activity and organic matter decomposition, leading to irregular OC accumulation in subsoils (Lal, 1987; Obalum et al., 2017). Surface horizons may sometimes show reduced OC due to cultivation, biomass removal, or erosion, while root deposition and bioturbation could enrich subsurface horizons with carbon (Fageria et al., 2005). This is especially likely in Ap horizons where tillage accelerates organic matter mineralization compared with the more protected subsoils.

Total nitrogen values were generally low (<1.5 g/kg), resulting in high C:N ratios in some horizons, which might slow organic matter mineralization (Stevenson, 1994). The TN content of the soils ranged from 0.35 to 1.40 g/kg, which is below the 2.0 g/kg threshold for adequate fertility (Landon, 1991), confirming nitrogen deficiency across the toposequence. Pedon 1 recorded the highest mean (1.12 g/kg), likely due to greater organic matter deposition at lower slopes (Sanchez, 2019), while Pedon 2 averaged 0.84 g/kg, with some enrichment in Bt horizons attributed to clay–organic stabilization (Six et al., 2002). Upland Pedon 3 had lower values (mean 0.56 g/kg), reflecting sandy texture, weak profile development, and leaching losses (Shareef et al., 2019). Pedon 4 was the most deficient (mean 0.42 g/kg), which might be linked to sodicity and poor drainage that suppress microbial activity and nitrogen cycling (Li et al., 2021). The distribution of TN with depth was irregular, with some subsurface horizons having similar or slightly higher values than surface soils. This might be due to the eluviation and illuviation of organic matter, root turnover, and stabilization of nitrogen in clay-rich horizons (Johnson, 1995).

Total Exchangeable Bases (TEB) and Exchangeable Acidity (Al+H)

The Total Exchangeable Bases (TEB) across the pedons ranged between 4.0 and 6.6 cmol(+)/kg, with calcium (Ca^{2+}) being the dominant cation, followed by magnesium (Mg^{2+}), while potassium (K^+) and sodium (Na^+) occurred in very low amounts. This dominance of Ca^{2+} and Mg^{2+} reflects the geochemical stability of divalent cations and the granitic nature of the parent material, which tends to release Ca and Mg through weathering (Zhang et al., 2023). The dominance of Ca on the exchange sites corroborates with other works in Nigerian savannah soil (Raji, 1995; Maniyunda, 2012; Ya'u and Maniyunda 2019; Jimoh, 2021). The consistently low K^+ contents (<0.30 cmol(+)/kg) reflect nutrient depletion, while the generally low levels of exchangeable bases, particularly Na and K, can be attributed to intensive cultivation and continuous crop removal without adequate nutrient replacement, leading to gradual chemical deterioration of the soils (Odunze, 2006; Tarawali et al., 2015). The TEB varied inconsistently with depth, however at certain horizons, there was an increase in value of TEB with an increase in soil depth, especially in B horizon which may be due to the saturation of the horizons with base enriched ground water Esu (1982); Ya'u and Maniyunda (2019).

The exchangeable acidity (Al+H) values were very low (<1.0 cmol(+)/kg) across all pedons, indicating that the exchange complex is strongly dominated by bases. Such conditions are typical of soils in semi-arid to sub-humid tropics, where leaching is not intense enough to cause severe acidification (Zhang et al., 2023). The absence of high Al^{3+} toxicity is a major advantage for crop production because aluminum saturation in acidic soils often impedes root elongation, reduces fine root density, and limits rooting depth, thereby restricting access to water and nutrients (Kochian et al., 2015; Rengel, 2011). In strongly acidic environments, soluble Al^{3+} interferes with phosphorus availability and can precipitate essential nutrients such as Ca^{2+} and Mg^{2+}, further aggravating nutrient stress (Ryan and Delhaize, 2010).

Available phosphorus (AvP)

The available phosphorus ranged from 0.7 to 24 mg/kg, with mean values of 5.79, 6.59, 3.12, and 2.93 mg/kg for Pedons 1–4, respectively. Since values below 10 mg/kg are considered deficient (Landon, 1991), most horizons were P-limited. Pedon 2 recorded the highest mean, largely due to a subsurface horizon (Bt1) with 24 mg/kg, possibly from organic matter decomposition or past fertilizer inputs. Pedon 1 also showed moderate enrichment in subsurface horizons, while Pedons 3 and 4 had consistently low values, reflecting sandy texture, low organic matter, and sodicity effects. Similarly, there was an irregular distribution of AP with depth, with occasional subsurface enrichment, typical of tropical soils where phosphorus is fixed by Fe and Al oxides (Tiessen et al., 1994; Sanchez, 2019).

Cation Exchange Capacity (CEC)

The CEC values ranged from 4.22 to 7.33 cmol(+)/kg, categorizing these soils as low to moderately fertile. Low CEC values are common in tropical soils dominated by low-activity clays (kaolinite, sesquioxides) that provide limited surface charge and nutrient retention (Antonangelo et al., 2024). In such soils, nutrient availability relies heavily on organic matter inputs, as humus contributes more exchange sites than clay minerals (Sarkar et al., 2018). The variations in CEC among horizons and pedons might be attributed to differences in clay content and organic matter, with higher clay-rich Bt horizons showing slightly higher CEC compared to sandy Ap horizons. Low CEC implies that these soils are nutrient-leaky systems, where applied fertilizers (especially K and N) can be easily lost through leaching if not managed carefully. This limitation necessitates integrated fertility management practices such as manure application, cover cropping, or biochar addition to improve nutrient retention and soil buffering capacity (Lehmann et al., 2015; Antonangelo et al., 2024).

Base Saturation Percentage (BSP) and Exchangeable Sodium Percentage (ESP)

The BSP values were consistently high (86–95%) across the pedons, showing that most of the exchange complex is saturated with Ca^{2+} and Mg^{2+} rather than acidic cations. High BSP is often linked to younger, less weathered soils or soils developed under moderate leaching environments (Zhang et al., 2023). High BSP generally favors agricultural use because it reflects strong buffering against acidification and ensures the availability of Ca and Mg, which are essential for crop growth. However, high BSP in combination with low CEC indicates that, while bases dominate the exchange complex, the absolute storage capacity is small, making the soils prone to rapid nutrient depletion under continuous cultivation (Ćirić et. al., 2023; Zhang et al., 2023). The ESP values were mostly low (<3%), but in Pedon 4 (Btg1), values rose to 17.2%, exceeding the sodicity threshold of 15% (FAO, 2000). Elevated ESP in lower slope positions results from poor drainage and salt accumulation, conditions that reduce leaching of Na^{+} and encourage its build-up on exchange sites (Choudhary and Kharche, 2018). Sodicity is associated with dispersion of clay particles, poor aggregation, surface crusting, and reduced hydraulic conductivity, all of which negatively affect root penetration and water movement (FAO, 2000; Rai et al., 2021). The occurrence of sodicity in Pedon 4 emphasize the role of topography and hydrology in soil chemical differentiation. While upland and mid-slope soils are chemically suitable for most crops with appropriate fertilization, sodic soils in depression areas require reclamation practices such as gypsum application, organic matter incorporation, and improved drainage to displace exchangeable Na^{+} with Ca^{2+} and restore soil structure (Barnard, 2006; Osman, 2018; Rai et al., 2021).

Sodic soils are characterized by excessive exchangeable Na^{+} on the soil exchange complex, which leads to clay dispersion, structural degradation, reduced permeability, and poor aeration (Rengasamy and Marchuk, 2016; Qadir et al., 2018). The high pH (9.81) and EC (2.83 dS m^{-1}) observed in the Btg1 horizon further support the diagnosis of sodicity and natric horizon development, consistent with international classification criteria (IUSS Working Group WRB, 2022). Beyond classification, the presence of sodicity in Pedon 4 has important land-use and management implications. Reclamation of sodic soils typically requires both chemical and physical interventions aimed at replacing exchangeable Na^{+} with divalent cations, particularly Ca^{2+}. The application of gypsum ($CaSO_4 \cdot 2H_2O$) is widely recommended as an effective amendment for sodic soils, as it supplies soluble calcium that promotes Na^{+} displacement from exchange sites and subsequent leaching (Qadir et al., 2018; Wong et al., 2020). Where natural drainage is limited, as evidenced by gley features in Pedon 4, gypsum application should be combined with improved surface or subsurface drainage to facilitate sodium removal and prevent re-accumulation (Rengasamy and Marchuk, 2016). In addition, the incorporation of organic amendments such as farmyard manure or crop residues might enhance aggregate stability and biological activity, thereby accelerating structural recovery in sodic subsoils (Chaganti and Crohn, 2015; Wong et al., 2020).

Soil classification according to the USDA Soil Taxonomy (Soil Survey Staff, 2022).

The four (4) pedons possessed orchric epipedons, and argillic horizons in pedon 1, 2 and 4. The pedons possessed high bas saturation (>80 %) throughout the entire profile depth. While pedon 3 is *Psamments* (Soil Survey Staff, 2022). At the *order level,* all the soils were classified as *Alfisols* except pedon 3, which was grouped into the order *Entisols*. They were placed into *suborder* Ustalfs, Ustipsamment (pedon 1, 2, 4 and 3 respectively) by virtue of their ustic soils moisture regime as the soils control sections were dry for more than 90 cumulative days but less than 180 cumulative days or 90 consecutive days during the year. At the *Great Group* level, pedon 1, 2 and 4 were classified as *Haplustalfs* because it does not fit in to any other great groups. While pedon 3 was classified as *Ustipsamments* (Other Psamments that have an ustic soil moisture regime). At the *subgroup* level, pedon 1 was classified as *Aquic Haplustalf*s because of the mottling/gleying indicating aquic conditions. While pedon 2 was classified as *Typic Haplustalfs* because it does not fit in to any of the subgroups. Similarly, pedon 4 was classified as *Typic Haplustalfs (sodic)*, the Btg1 has high ESP (17.2%), very high pH (9.81), and elevated EC (2.83 dS/m), implying sodicity without columnar/prismatic structure throughout the sodic horizon. However, pedon 3 was classified as *Typic Ustipsamments* because they are other Psamments that do not fit in to any subgroup.

Table 2: Soil physical properties

Pedon	Horizons	Depth (cm)	Sand	Silt	Clay	Silt/Clay	Texture	Bulk Density (Mg m^{-3})	Porosity (%)
			(g kg^{-1})						
Pedon 1	Latitude 11°42.542'N		Longitude 9°22.590'E			Elevation 438m			
	Ap	0-21	500	200	300	0.667	SCL	1.7	35.85
	Bt	21– 57	460	140	400	0.350	SC	1.7	35.85
	Btg1	57 – 88	480	140	380	0.368	SC	1.8	32.08
	Btg2	88 – 123	460	140	400	0.350	SC	1.8	32.08
	BCg	123-175	600	80	320	0.250	SCL	1.7	35.85
		Mean	**500**	**140**	**360**	**0.40**		**1.74**	**34.34**
Pedon 2	Latitude 11 42.655'N		Longitude 9 23.392'E			Elevation 435.5m			
	Apg	0-9	520	280	200	1.400	L	1.23	53.58
	Btg	9– 34	460	240	300	0.800	SCL	1.41	46.79
	BCg	34 – 59	560	200	240	0.833	SCL	1.57	40.75
	Cg1	59 – 100	600	180	220	0.818	SCL	1.6	39.62
	Cg2	100 – 150	660	140	200	0.700	SCL	1.61	39.25
		Mean	**560**	**208**	**232**	**0.91**		**1.48**	**44**
Pedon 3	Latitude 11 42.933'N Longitude 9 22.612'E Elevation 443.99m								
	A	0 - 17	680	280	40	7.000	SL	1.55	41.51
	AB	17 – 58	660	260	80	3.250	SL	1.47	44.53
	BC	58 – 104	700	140	160	0.875	SL	1.6	39.62
	C1	104 – 152	700	160	140	1.143	SL	1.5	43.40
	C2	152 – 205	660	300	40	7.500	SL	1.5	43.40
		Mean	**680**	**228**	**92**	**3.95**		**1.52**	**42.49**
Pedon 4	Latitude 11 43.150'N		Longitude 9 22.493'E			Elevation	451.03m		
	Ap	0-10	600	260	140	1.857	SL	1.62	38.87
	Btg1	10– 47	700	200	100	2.000	SL	1.65	37.74
	Btg2	47 – 83	740	160	100	1.600	SL	1.59	40.00
	BCg1	83 – 107	520	400	80	5.000	L	1.48	44.15
	BCg2	107 – 130	640	380	60	6.333	SL	1.74	34.34
		Mean	**640**	**280**	**96**	**3.36**		**1.62**	**39.02**

Table 3: Soil chemical properties

Pedon	Horizons	Depth	pH	EC (ds/m)	O.C (g/kg)	TN	AvP (mg/kg)	Na (cmol(+)/kg)	K	Ca	Mg	Al+H	TEB	CEC	BSP (CEC)	ESP (%)
Pedon 1		Latitude 11˚42.542'N		Longitude 9˚22.590'E				Elevation 438m								
	Ap	0-21	6.5	0.06	5.8	1.05	9	0.05	0.23	3.3	2.2	0.83	5.77	6.6	87.42	0.70
	Bt	21– 57	6.8	0.05	4.6	1.05	2	0.15	0.27	4.26	2.9	0.83	7.5	8.33	90.04	1.81
	Btg1	57 – 88	6.8	0.09	1.6	1.05	4.7	0.20	0.36	3.6	2.3	0.5	6.26	6.76	92.60	2.96
	Btg2	88 – 123	7.4	0.17	10	1.4	5	0.23	0.3	4.67	2.63	0.66	7.83	8.6	91.05	2.67
	BCg	123-175	7.6	0.13	2.8	1.05	8.3	0.24	0.17	4.8	0.5	0.66	5.71	6.37	89.64	3.77
		Mean	**7.02**	**0.10**	**4.96**	**1.12**	**5.79**	**0.17**	**0.27**	**4.13**	**2.11**	**0.70**	**6.61**	**7.33**	**90.15**	**2.38**
Pedon 2		Latitude 11 42.655'N		Longitude 9 23.392'E				Elevation 435.5m								
	Apg	0-9	7.02	0.02	12	1.05	2.7	0.05	0.19	2.8	1.44	1	4.476	5.4	82.89	0.85
	Btg	9– 34	6.95	0.01	3.8	1.4	24	0.05	0.19	4.35	2.25	0.83	6.83	7.66	89.16	0.60
	BCg	34 – 59	5.9	0	19	0.35	2	0.05	0.17	5.3	0.5	0.66	6.016	6.84	87.95	0.67
	Cg1	59 – 100	5.7	0	10	0.7	2.3	0.03	0.13	4.62	1	0.66	5.782	6.44	89.78	0.50
	Cg2	100 – 150	6.7	0.05	10	0.7	2	0.05	0.1	1.95	1.55	0.5	3.652	4.152	87.96	1.25
		Mean	**6.45**	**0.02**	**10.96**	**0.84**	**6.59**	**0.04**	**0.16**	**3.80**	**1.35**	**0.73**	**5.35**	**6.10**	**87.55**	**0.77**
Pedon 3		Latitude 11 42.933'N		Longitude 9 22.612'E				Elevation 443.99m								
	A	0 - 17	6.84	0.02	4.6	1.05	5	0.01	0.16	4.6	1.5	0.5	6.273	6.773	92.62	0.19
	AB	17 – 58	6.96	0.01	3	0.35	1.3	0.02	0.19	4.2	2.3	0.33	6.7	7.03	95.31	0.27
	BC	58 – 104	6.85	0.01	7.9	0.35	0.7	0.03	0.096	1.2	0.2	0.5	1.528	2.02	75.64	1.58
	C1	104 – 152	6.78	0.01	1.2	0.7	3.7	0.02	0.076	1.7	0.4	0.66	2.195	2.855	76.88	0.67
	C2	152 – 205	6.81	0.01	1.2	0.35	5	0.21	0.098	2.6	0.7	0.5	5.498	5.998	91.66	3.50
		Mean	**6.85**	**0.01**	**3.58**	**0.56**	**3.12**	**0.06**	**0.12**	**2.86**	**1.02**	**0.50**	**4.44**	**4.94**	**86.42**	**1.24**
Pedon 4		Latitude 11 43.150'N		Longitude 9 22.493'E				Elevation 451.03m								
	Ap	0-10	6.65	0.07	2	0.35	3.3	0.10	0.042	2.31	1.3	0.33	3.752	4.082	91.92	2.45
	Btg1	10– 47	9.81	2.83	5.2	0.35	1.3	0.80	0.18	2.96	0.6	0.16	4.55	4.71	96.60	17.20
	Btg2	47 – 83	7.67	0.07	5	0.35	1	0.05	0.06	2.3	1.1	0.33	3.506	3.386	103.54	1.36
	BCg1	83 – 107	7.31	0.06	5	0.7	7	0.03	0.20	3.7	0.3	0.33	4.232	4.562	92.77	0.70
	BCg2	107 – 130	7.03	0.04	4.8	0.35	2	0.03	0.16	3.5	0.35	0.33	4.036	4.336	93.08	0.60
		Mean	**7.69**	**0.61**	**4.40**	**0.42**	**2.93**	**0.20**	**0.13**	**2.95**	**0.73**	**0.30**	**4.02**	**4.22**	**95.58**	**4.46**

Classification Base on FAO/UNESCO Soil Legend (World Reference Base) (IUSS Working Group WRB, 2022)

The four pedons all possessed *ochric horizons* at the surface. Argic horizons were identified in Pedons 1, 2, and 4, confirming clay illuviation. Pedon 3 lacked an argic horizon and was dominated by sandy textures, thus excluding it from *Luvisols*. All pedons had high base saturation (>80%) throughout the profile, which places them in *Luvisols* rather than Acrisols. Pedon 3, with weak profile development and sandy textures, was classified as *Arenosol*. At the *Reference Soil Group (RSG)* level, Pedons 1, 2, and 4 were classified as *Luvisols* due to their argic horizons and high base saturation, while Pedon 3 was classified as *Arenosol*, reflecting its sandy nature and lack of subsurface horizon development. At the *qualifier* level, Pedon 1 was classified as a *Gleyic Luvisol,* based on the presence of mottling and gleyic properties indicating prolonged wetness. Pedon 2 was classified as a *Haplic Luvisol,* because it represents the typical expression of Luvisols without additional features. Pedon 4 was classified as a *Gleyic Luvisol* **(***sodic phase*), due to high ESP (17.2%), alkaline pH (9.81), and elevated EC (2.83 dS/m), implying sodicity, but without columnar/prismatic structure required to qualify it to be *Solonetz*. Pedon 3 was classified as a *Haplic Arenosol,* since it is sandy, weakly developed, and lacks further diagnostic horizons or features. The summary of the pedons classified in the study area is presented in Table 4.

Table 4: Summary of soil classification in the study area

Pedon	USDA Soil Taxonomy	WRB Equivalent	Key Diagnostic Features
1	Aquic Haplustalf	Gleyic Luvisol	Argillic horizon, mottling, high BSP
2	Typic Haplustalf	Haplic Luvisol	Argillic horizon, BSP >80%, no strong gleying
3	Typic Ustipsamment	Arenosol	Sandy loam, weak horizonation, no Bt
4	Haplustalf (gleyic, sodic)	Gleyic Luvisol	Argillic horizon, sodicity in Btg1, gleying

WRB – World Reference Based Soil Resource

Implications for soil fertility and land use management

The soils across the toposequence are constrained by generally low organic matter, nitrogen, and available phosphorus, showing the need for fertility management. For upland sandy soils (Pedon 3), practices such as integrated nutrient management, organic matter additions, mulching, and split fertilizer applications are crucial to minimize leaching losses and maintain soil moisture. In the mid-slope and lower slope soils (Pedons 1 and 2), which are clay-rich and nutrient-retentive, management should focus on improving drainage (e.g., ridging, raised beds, or contour drains) and minimizing compaction through conservation tillage. However, pedon 4 requires special attention because of its sodicity and very poor drainage. Reclamation measures such as gypsum application, organic amendments, and improved drainage systems are necessary to restore productivity. Despite these challenges, the intermediate balance of texture and porosity in Pedon 4 also shows potential suitability for crop production if properly managed.

Conclusion

The soils along the toposequence of the Teaching and Research Farm, Federal University Dutse, exhibit pronounced morphological, physical, and chemical variability largely controlled by landscape position and drainage conditions. Morphological evidence, including argillic horizons with clay illuviation and redoximorphic features, was prominent in mid- and lower slope positions, whereas upland soils remained sandy, weakly developed, and well drained. Consequently, the upland soils, classified as Arenosols/Ustipsamments, are coarse-textured, low in organic matter and cation exchange capacity, and highly susceptible to nutrient leaching and drought stress. In contrast, mid- and lower slope soils show stronger pedogenic development, higher clay content, bulk density, and water-holding capacity, qualifying them as Luvisols/Haplustalfs, but with reduced permeability and aeration. Periodic waterlogging and poor drainage at the lower slope position, particularly in Pedon 4, have resulted in gleyic properties and localized sodicity and alkalinity, which pose constraints to root growth, soil physical condition, and nutrient availability. Despite consistently high base saturation across all pedons, the generally low levels of organic carbon, nitrogen, and available phosphorus indicate low inherent fertility and potential limitations to sustainable crop production. These findings advocated for soil management strategies tailored to different positions along the toposequence. Such approaches should include enhancing soil organic matter to improve soil structure and nutrient retention, applying balanced fertilization to address localized nutrient constraints, improving drainage in poorly drained zones, and implementing sodicity reclamation measures such as gypsum application, improved leaching, and appropriate irrigation management where elevated sodium levels adversely affect soil physical properties and crop performance.

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