



Research Article

Characterization and Classification of Soils at Federal University Dutse, Jigawa State, Northern Sudan Savanna of Nigeria

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ABSTRACT

Soil characterization and classification are important for understanding soil properties, identifying land limitations and improving soil management. This study characterized the morphological, physical and chemical properties of soils, examined variations among three pedons and classified them using USDA Soil Taxonomy and the World Reference Base for Soil Resources. The study was conducted at the Zoological Garden (FUD-P1), Soil Science Research Farm (FUD-P2) and Faculty of Agriculture Farm (FUD-P3), Federal University Dutse, Jigawa State, Nigeria. Soil profiles were described in the field, and samples were analysed in the laboratory. Analysis of variance assessed differences among pedons. Soil colours varied across pedons and horizons. FUD-P1 had very pale brown (10YR 7/4) to strong brown (7.5YR 5/5) topsoil, with brownish yellow (10YR 6/6) and reddish yellow (7.5YR 6/6) subsoil. FUD-P2 had very pale brown (10YR 7/3) to brown (7.5YR 5/4) topsoil and light-grey subsoil (10YR 7/2 and 10YR 7/1). FUD-P3 had very pale brown topsoil (10YR 7/3 and 10YR 7/4), with light brown (7.5YR 6/3) and light yellowish brown (10YR 6/4) subsoil. The soils were loamy sand to sandy loam, with bulk density ranging from 1.19 to 1.68 Mg m⁻³. Soil pH ranged from 6.5 to 9.7, while electrical conductivity ranged from 0.01 to 0.47 dS m⁻¹, indicating generally low salinity. Organic carbon and total nitrogen were generally low. The soils were classified as Typic Haplustepts under USDA Soil Taxonomy and correlated with Cambisols under the World Reference Base for Soil Resources.

Keywords: Cambisols; Federal University Dutse; Horizons; Organic carbon; Soil properties

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INTRODUCTION

Soil characteristics are formed by the combined effects of climate, organisms, relief, parent material and time. These factors influence weathering, the movement and transformation of soil materials, and the accumulation and decomposition of organic matter. Over time, these processes contribute to the development of distinct soil horizons and differences in soil properties across a landscape (Balaselvakumar and Hemavarthinii, 2026). Soil properties are also

important for identifying and classifying soils, evaluating their quality and determining their suitability for agricultural production (Brady and Weil, 2017). Maintaining good soil conditions is important for food security and environmental sustainability, particularly as population growth and intensive agricultural practices place increasing pressure on land resources. As the demand for food rises, farmers must produce more food from the available agricultural land without causing further soil

degradation. Reliable information on soil properties is therefore essential for identifying land limitations, selecting suitable crops and developing appropriate soil management practices. Soil characterization and land suitability assessment can support these decisions by providing information on the potential and limitations of different soils for agricultural production (Gomiero et al., 2016; Rahman et al., 2022). Soil genesis provides a basis for explaining the observed characteristics of the soils at FUD. Changes in soil colour, texture, horizon differentiation and chemical properties can provide evidence of soil development and the movement or transformation of soil constituents within the profile. These characteristics are particularly important when comparing pedons located in different land use areas and landscape positions. Their combined assessment helps establish whether the observed differences are associated with variations in soil development, drainage conditions or other soil forming factors. (Gambo et al., 2025; Haile et al., 2024).

In the semi-arid region of north-western Nigeria, soil development is influenced by rainfall patterns, high temperatures, vegetation cover, evaporation, parent material and landscape position (Olagunji, 2015, Macaulay, 2014; Idris et al., 2011). These factors affect soil moisture, organic matter accumulation, weathering and the movement of soil materials. Consequently, many soils in the region have sandy textures and low organic carbon content, although their properties vary with local conditions. Topographic position also influences drainage, runoff, erosion and the deposition of sediments, leading to differences in soil depth, colour, texture, structure and horizon development across the landscape (Gambo et al., 2025; Ibrahim et al., 2020). These differences across the land are important because they affect the ability of soils to store water, supply nutrients, support root growth and sustain agricultural production. Studies of soil properties have shown that topographic position influences soil characteristics, including texture, drainage and the distribution of nutrients (Ike et al., 2026). Sandy soils are also commonly associated with low organic carbon content, limited nutrient-retention capacity and low water-holding capacity, particularly in arid and semi-arid environments (Yost and Hartemink, 2019).

Dutse, in Jigawa State, north-western Nigeria, lies within the semi-arid savanna zone, where agricultural production depends partly on the properties and distribution of soil resources. Rainfall variability, high temperatures and prolonged dry periods influence

soil moisture, organic matter accumulation and soil development. The geology, parent materials and landscape position also contribute to differences in soil characteristics across the area. Recent studies have provided useful information on the properties and classification of soils around Dutse. Gambo et al. (2025) examined soils along a toposequence at the Nigerian Institute for Oil Palm Research in Jigawa State and reported textural classes ranging from sand to loamy sand, together with variations in soil chemical properties across the profiles. Santuraki et al. (2026) also found that the soils were predominantly sandy loam to loamy sand at the Federal University Dutse. Similarly, Girei et al. (2026) studied soils along a toposequence at the Teaching and Research Farm of the Federal University Dutse. Their findings showed differences in horizon development and drainage conditions across landscape positions. These studies validate the importance of examining soil properties in relation to landscape position on soil development and classification when characterizing and classifying soils in the Dutse area. The soils ranged mainly from sandy loam to loamy sand, while variations in soil properties were observed between and in other landscape positions. Based on these characteristics, most of the soils were classified as Entisols under USDA Soil Taxonomy and as Arenosols and Eutric Cambisols under the World Reference Base for Soil Resources (WRB). These classifications indicate that the soils have limited profile development and are strongly influenced by their sandy nature. Studies from other parts of Nigeria have reported that variations in soil parent material and landform can lead to differences in soil morphology, development and classification (Zata et al., 2010; Santuraki et al., 2025). Although previous studies have improved knowledge of the soils around Dutse, further investigation is needed to understand their development and classification across different landscape positions and land-use areas. Examining soil profiles from representative locations can help identify the extent of horizon development, explain the pedogenic processes involved and establish how soil properties relate to soil-forming factors. This is particularly important in the semi-arid environment of Dutse, where soil erosion, low nutrient reserves and limited water availability may constrain agricultural production. A better understanding of soil genesis and classification can provide a scientific basis for soil surveys, land evaluation, agricultural planning and sustainable soil management. It can also help identify the factors responsible for differences in soil development and

support the assignment of soils to appropriate taxonomic classes. Therefore, this study aims to: characterize the morphological, physical and chemical properties of soil of the study area, evaluate their variation and classify the soil based on USDA Soil Taxonomy and correlate it with World Reference Base for Soil Resources.

MATERIALS AND METHODS

Site Description

The study was conducted at the Federal University Dutse (FUD), located in Dutse, the capital of Jigawa State, north-western Nigeria. The study focused on three representative soil pedons located within the Federal University Dutse premises: the Zoological Garden (FUD-P1), Soil Science Research Farm (FUD-P2) and Faculty of Agriculture Farm (FUD-P3). These sites were selected to examine variations in soil profile characteristics and to assess the influence of environmental conditions on soil development. The geographical coordinates of the individual sampling locations at Federal University Dutse (FUD), Jigawa State, Nigeria, were recorded using a handheld Global Positioning System (GPS) receiver during fieldwork. The study area lies between latitudes 11°41'48"N and 11°43'08"N and longitudes 9°21'49"E and 9°23'27"E, at an approximate elevation of 440 m above sea level. These coordinates and elevation were used to establish the geographical location of the study area and document the positions of the sampled soil pedons (Figure 1).

Climate

The climate of Jigawa State is generally semi-arid, with distinct rainy and dry seasons influenced by the interaction of tropical maritime and tropical continental air masses. The rainy season generally extends from May to September or October, while the dry season occupies the remainder of the year. Annual rainfall varies spatially across the state, with amounts ranging from approximately 600 to 1,000 mm and an average of about 650 mm with a mean annual temperature of 26.9°C. Relative humidity is usually low during the early dry season, mainly from January to March, and increases during the rainy season, reaching its highest levels around August. The Harmatt is characterized by dry, dusty north-easterly winds originating from the Sahara and affecting the area during the dry season.

Physiography

The relief of the study area is characterized by hills, undulating terrain and gentle slopes that descend towards the surrounding plains. Small streams and rivers originating in elevated areas drain the slopes

and flow towards the main river channels, while some drainage channels terminate in the plains without reaching the main rivers (Rilwanu, 2023).

Geology

The geology of Jigawa State forms part of the wider geological framework of northern Nigeria, where sedimentary formations and deposits of varying ages occur alongside other geological units. The nature and distribution of parent materials influence soil formation and contribute to variations in soil texture, mineral composition and other physical and chemical properties (Bawden, 1972; Obaje, 2009). In areas underlain by sedimentary materials, variations in lithology, including sandstone, shale and other sedimentary rocks, may influence the characteristics of soils developed from these materials. Quaternary alluvial deposits also occur along river channels and floodplains in parts of northern Nigeria, where the deposition and redistribution of sediments contribute to soil development in low lying areas (Obaje, 2009).

Farming activities and vegetation

Agriculture is the main economic activity in Dutse, Jigawa State, where many households depend on farming for food and income. Located within the Sudan Savanna ecological zone, the area supports rain-fed agriculture during the wet season, while irrigation farming is practised during the dry season using available surface and groundwater resources. Major crops cultivated in Jigawa State include millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*), maize (*Zea mays*), rice (*Oryza sativa*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), sesame (*Sesamum indicum*) and roselle (*Hibiscus sabdariffa*). Vegetables such as tomatoes (*Solanum lycopersicum*), onions (*Allium cepa*) and pepper (*Capsicum spp.*) are also cultivated, particularly under irrigation during the dry season (Santuraki et al., 2026). Natural vegetation includes species of *Vachellia* (*Acacia spp.*), desert date (*Balanites aegyptiaca*) and baobab (*Adansonia digitata*). Livestock rearing, particularly cattle, sheep, goats and poultry, also contributes to rural livelihoods and agricultural production. Although smallholder farming remains important, government-supported agricultural development programmes promote improved seeds, fertiliser use, mechanisation, irrigation and extension services to enhance agricultural productivity (Ahmed and Abubakar, 2026).

Field work

A semi detailed soil survey was conducted in the area at a scale of 1:50,000. A base map with grid at 100 m intervals which enabled the soil boundary delineation. The hand held GPS (global positioning system) and locus software 8.1 version was used to record location of the pits, augers, and the boundaries. Soil profile were dug 1.5 m width 2 m depth pit was opened and described in situ. The soil pit was clean and Soil Colour, texture, structure, mottles, consistence, pores, plant rooting pattern and

other soil features were described based on guidelines for Soil Survey Staff (2014), also undisturbed soil samples were collected from each genetic horizon for bulk density determination. Soil colour chart was determined using Munsell Soil Colour, structure was determined according to grade, size and types, soil consistence was described at dry and moist conditions and boundary were identify based on topography and distinctness.

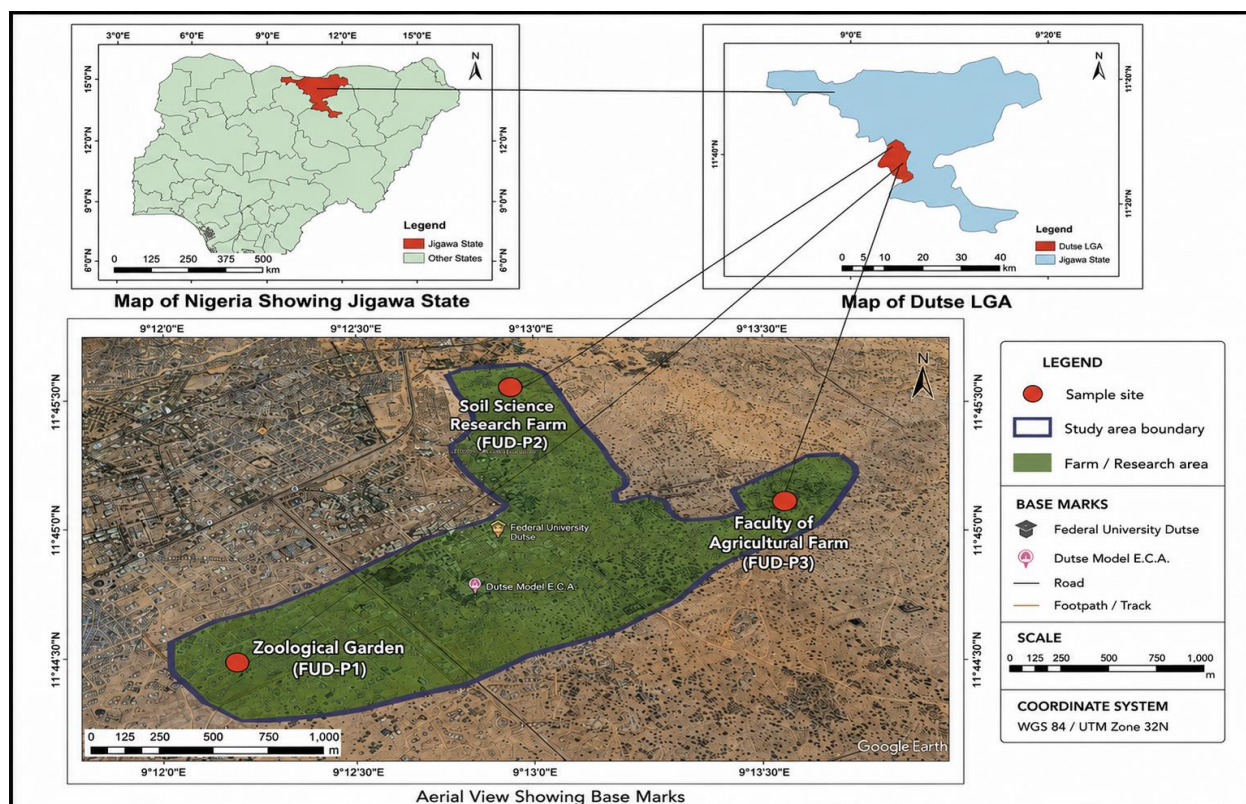


Figure 1: Map of Dutse LGA showing the sampling sites

Laboratory Analyses

The soil samples were air-dried, ground and sieved through a < 2mm sieve were used for laboratory analysis. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Bulk density was determined from the weight of undisturbed soil samples using the core sampler (Blake and Hartge, 1986). The moisture content at field capacity (FC) was measured at the soil water potentials of -1/3 and -15 bars, respectively, using the pressure plate apparatus technique (Richards, 1965). The particle density was determined and expressed as an oven-dry weight of a given quantity of solid soil particles per unit volume of water displaced by the solid particles using a standard pycnometer. Total porosity (TP) was calculated from the measured bulk

density and particle density using the following equation: (Vomocil, 1965).

$$TP = \left(1 - \left(\frac{\rho_b}{\rho_p} \right) \right) * 100$$

Where:

TP = Total porosity (%)

ρ_b = Bulk density ($Mg\ m^{-3}$)

ρ_p = Particle density ($Mg\ m^{-3}$)

The pH of the soil was obtained potentiometrically in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter (Van Reeuwijk, 1995). Organic carbon was measured using the wet oxidation method (Walkley and Black, 1934) whereby the carbon was oxidized under standard conditions with

potassium dichromate in sulfuric acid solution. Total N was described by the micro Kjeldahl method (Jackson, 1967) while available P determined by (Bray 1 method (Bray and Kurtz, 1945). The exchangeable bases (Ca^{2+} , Mg^{2+} , K^+ , and Na^+) in the soil were extracted with 1 M ammonium acetate (NH_4OAc) solution at pH 7.0 using extract from the CEC determination (Ross and Kettering, 1995). Exchangeable Ca^{2+} and Mg^{2+} in the leachate were measured by atomic absorption spectrophotometer, while exchangeable K^+ and Na^+ were determined by flame photometry. Cation exchange capacity (CEC) of the soil was obtained from the NH_4^+ saturated samples that were subsequently replaced by K^+ using KCl solution. The excess salt was removed by washing with ethanol and the ammonium that was displaced by K^+ was measured using the micro-Kjeldahl procedure (Chapman, 1965). Base saturation was computed as the sum of total exchangeable bases divided by cation exchange capacity (Agbenin, 1995) while silt: clay ratio was calculated as silt divided by clay.

Data Analysis

Analysis of Variance (ANOVA) was used to determine significant differences in the physical and chemical properties of the three soil profiles.

RESULTS AND DISCUSSION

The area of the study was delineated into three soil profiles specifically, FUD-P1, FUD-P2 and FUD-P3. The morphological, physical and chemical properties of the soil are showed in Tables 1, 2, 3 and 4 respectively.

Morphological characteristics of soil of the study area

The morphological properties of the soils in the study area are presented in Table 1. The three pedons differed in depth. FUD-P3 was the deepest, with > 185 cm, then FUD-P1, which extended beyond 114 cm. FUD-P2 was the shallowest, with a depth of < 85 cm. The shallow depth of FUD-P2 was related to the water table encountered below the last horizon at 84 cm, which limited further profile examination. In contrast, the higher depth of FUD-P3 allowed more soil horizons and morphological features to be observed. The soil colour of FUD-P1 ranged from very pale brown (10YR 7/4) under dry conditions to strong brown (7.5YR 5/5) when moist in the topsoil. In the subsoil, the colour changed from brownish yellow (10YR 6/6) when dry to reddish yellow (7.5YR 6/6)

under moist conditions. In FUD-P2, the topsoil was very pale brown (10YR 7/3) when dry and brown (7.5YR 5/4) when moist. The subsoil was light grey, with Munsell colour codes ranging from 10YR 7/2 to 10YR 7/1. These grey colours may indicate periodic water saturation or restricted drainage in the lower horizons, which is consistent with the water table observed near the bottom of the profile (Table 1). In FUD-P3, the topsoil was very pale brown under both dry (10YR 7/3) and moist (10YR 7/4) conditions. The subsoil ranged from light brown (7.5YR 6/4) when dry to yellowish brown (10YR 5/4) and light yellowish brown (10YR 6/4) under moist conditions. The yellowish brown colours may signifies better drainage and soil aeration than the grey colours observed in FUD-P2. Differences in soil colour among the pedons and between horizons within each pedon may be related to variations in organic matter content, drainage conditions and the movement of iron compounds within the soil profile (Shobayo, 2019; Bello et al., 2026; Girei et al., 2026). The soil structure varied among the three pedons. In the topsoil, FUD-P1 had a weak, fine granular structure, while FUD-P2 had a weak, medium granular structure. FUD-P3 displayed a strong, fine granular structure. In the subsoil, the structure changed to moderate, medium sub angular blocky in all three pedons. Similar patterns were reported by Kebede et al. (2017), Fekadu et al. (2018) and Nurgisa et al. (2025), who observed granular structures in surface horizons and sub angular blocky structures in deeper horizons. The granular structure in the topsoil may be linked with organic matter accumulation and biological activity, which help bind soil particles into aggregates. The consistence varied from slightly sticky to slightly plastic of topsoil and subsoil of FUD-P2 and non-sticky non plastic at FUD-P1 and P3 except- horizon 4 and 5 in FUD-P3 (66-119cm) and (119-185cm) which is slightly sticky. The dry consistence varied from slightly hard to hard, while the moist consistence varied from loose, very friable to friable in all the pedons. The boundary of topsoil in FUD-P1 were clear smooth and changed to diffuse smooth at subsoil. In FUD-P2 horizon 1 and 4 were clear smooth and gradual wavy and gradual smooth in horizon 2 and 3. FUD-P3 were abrupt wavy in the topsoil and changed into gradual wavy in the subsoil. This could be the influence of crop production couple with anthropogenic activities such as continuous cultivation by plowing and actual land-use history of each pedon.

Table 1. Morphological characteristics of the soil of the Federal University Dutse

Pedon	Horizon Depth (cm)	Horizon Designation	Colour		Structure	Textural Class	Consistence	Boundary	Mottles	Inclusions
			Dry	moist						
FUD-P1	0-12	Ap	10YR 7/4	7.5YR 5/5	3wfg	LS	nsnp, 2vfs	cs	n	grm, 2mf
	12-44	Bw1	10YR 6/6	7.5YR5/8	3wfsbk	LS	nsnp, 2fs	ds	n	grm, 2ff
	44-78	Bw2	7.5R 6/6	7.5YR 5/8	3wfsbk	SL	nsnp, 2fs	ds	n	2fm
	78-114	Bw3	7.5YR 6/6	7.5YR 6/8	3wfsbk	SL	nsnp, 2fs	ds	n	2fm
	>114	C	7.5YR 7/6	7.5YR 7/8	3wfsbk	LS	nsnp, 2fs	ds	n	2ff
FUD-P2	0-10	Ap	10YR7/3	7.5YR5/4	3wmg	LS	Ss,2 fs	cs	n	grm, 2mm
	10-28	Bw1	10YR7/2	7.5YR5/3	3wmsbk	LS	Ss,2 fs	gw	n	grm, 2cm
	28-52	Bw2	10YR7/1	10YR7/3	3mmsbk	SL	ss, 2fs	gs	n	grm, cc
	52-84	C	10YR7/1	10YR7/3	3mmsbk	LS	sssp, 2fh	cs	n	grm,2cc
FUD-P3	0-5	Ap	10YR7/3	10YR7/4	3wfg	SL	nsnp, 2ls	aw	n	grm, 2cf
	5-30	Bw1	7.5YR6/3	10YR5/4	3mmsbk	SL	nnnp, 2vfh	gw	n	grm, 2ff
	30-66	Bw2	7.5YR6/3	10YR5/3	3mmsbk	SL	nsnp, 2fh	gw	n	grm, 2ff
	66-119	Bw	7.5YR6/3	10YR6/3	3mmsbk	SL	ss2fh	gw	n	grm, 2ff
	119-185	C	10YR7/3	10YR6/4	3mmsbk	SL	ss, 2fh	gw	n	cc,2mm

FUD; Federal University Dutse; P1-P3; soil profile pits; 3wfg; weak fine granular; 3wfsbk; weak fine sub angular blocky; weak medium granular; weak medium sub angular blocky; weak moderate medium sub angular blocky; 3sfg; structureless fine granular; LS; loamy sand; SL; sandy loam; nsnp; non sticky non plasticity; 2vfs;very friable soft; 2fs; friable soft; ssfs; slightly sticky fine soft; slightly sticky slightly plasticity fine hard; 2ls; loose fine; 2fh; friable hard; cs; clear smooth; ds; diffuse smooth; gw; gradual wavy; gs; gradual smooth; abrupt wavy; aw; cw; clear wavy; n; none; (Field work 2025)

Physical characteristics of soil of the study area

The particle size distribution of the FUD soils showed that sand content ranged from 66 to 82%, silt from 12 to 22%, and clay from 4 to 18% (Table 2). The mean values ranged from 70.0 to 77.0% for sand, 14.0 to 19.5% for silt, and 5.0 to 14.8% for clay. Sand content increased with depth in FUD-P1 but decreased with depth in FUD-P3. FUD-P1 had the highest sand content, indicating a predominantly sandy soil texture. These differences in particle-size distribution may reflect variations in parent material and soil-forming processes, including the movement of fine clay particles from upper to lower horizons. Similar findings were reported by Zata et al. (2013, 2020). Sand had relatively low variability in FUD-P1 (3.36%), FUD-P2 (5.39%) and FUD-P3 (5.35%). This indicates that sand content was fairly uniform within the pedons. The silt fraction ranged from 12 to 22% from surface soil to subsurface soil. FUD-P1 found silt values between 12 and 18%, while FUD-P2 had higher values, ranging from 18 to 22%. In FUD-P3, the silt content varied from 14 to 16% and showed no clear increase or decrease with depth. The higher silt content in FUD-P2 may indicate differences in the redistribution or accumulation of fine particles. There was a significant difference ($p < 0.05$) in mean silt content among the pedons. Silt showed low variability, with CV values of 20.20%, 9.82% and 7.40% for FUD-P1, FUD-P2 and FUD-P3, respectively. The higher value in FUD-P1 indicates higher changes in silt content with depth. The clay ranged from 4 to 18% from topsoil soil to subsoil. FUD-P1 indicates an increase in clay from 6% in the Ap horizon to 12% in Bw3, signifying an accumulation of clay with depth. FUD-P2 had low clay contents, ranging from 4 to 6%, with little variation among the horizons. In contrast, FUD-P3 measured a noticeable increase in clay from 8% in the Ap horizon to 18% in Bw2 and Bw3, then a slight decrease to 16% in the C horizon. There was a significant difference ($p < 0.05$) in mean clay content among the pedons. Clay displayed moderate variability in FUD-P1 (35.36%), FUD-P2 (23.09%) and FUD-P3 (28.02%).

Bulk density values in the FUD soils ranged from 1.19 to 1.68 Mg m^{-3} , with mean values ranging from 1.37 to 1.57 Mg m^{-3} . There was significant difference at ($p < 0.05$) among the pedons. Bulk density increased with depth in FUD-P1 but decreased with depth in FUD-P2 and FUD-P3. The lower bulk density observed in FUD-P3 may be related with differences in soil texture, structure and pore distribution. Although clay accumulation can influence soil density. These findings are similar with those stated by Gambo et al.

(2025), Sharu et al. (2025) and Santuraki et al. (2025). These values indicate low variability in bulk density within all three pedons. FUD-P3 showed higher variability whereas FUD-P2 had the lowest. Water-holding capacity (WHC) also varied among horizons and pedons. In FUD-P1, WHC ranged from 40 to 48%, with a mean of 44.80%. The highest values observed in the Ap, Bw2 and Bw3 horizons, while the Bw1 and C horizons recorded lower values. In FUD-P2, WHC ranged from 40 to 56%, with a mean of 44.00%. In FUD-P3, WHC ranged from 40 to 60%, with a mean of 51.20%. The highest WHC identified in the C horizon, while Bw3 found the lowest value. The higher WHC in FUD-P3 may be related with its higher mean clay content compared with FUD-P1 and FUD-P2. Clay particles have a larger specific surface area than sand particles and can retain more water. Soil texture and bulk density influence water retention because they affect pore-size distribution and the movement of water through the soil (Farooq et al., 2024; Liu et al., 2024). The CV values ranged from 9.78 to 18.18%, indicating low to moderate variability. However, statistical analysis showed no significant differences in WHC among the three pedons ($p > 0.05$). Soil porosity ranged from 35.20 to 55.26%, with mean values ranging from 39.66 to 45.43% (Table 2). FUD-P3 recorded the highest mean porosity than FUD-P1 and FUD-P2. The higher mean porosity in FUD-P3 may be as a result of its lower mean bulk density. Soil porosity is influenced by bulk density, organic matter and soil structure, which affect the volume and arrangement of pore spaces (Robinson et al., 2022; Tian et al., 2022). CV values ranged from 10.97 to 16.50%, indicating low to moderate variability. Though, the differences in mean porosity among the three pedons were not statistically significant ($p > 0.05$). The soil moisture content ranged from 14.24 to 40.74%, with mean values ranging from 17.81 to 28.14%. FUD-P3 observed the highest mean moisture content than FUD-P2 and FUD-P1. The higher values in FUD-P3 may be as a result of its lower bulk density. Soil texture and organic matter can influence soil water content and retention, while pore spaces affect water storage and movement (Adewole et al., 2024). The CV values ranged from 17.78 to 34.15%, indicating moderate to relatively high variability. But, the differences among the pedon means were not statistically significant ($p > 0.05$).

The silt-to-clay mean ratio was 1.96 in FUD-P1 with a CV of 44.13%, indicating high variability. The ratio decreased from 3.0 in the Ap horizon to 1.0 in Bw3, then increasing to 2.6 in the C horizon. In FUD-P2, the silt ratio ranged from 3.0 to 5.0, with the highest value

occurring in Bw1 and the lowest in the Ap horizon. The mean ratio was 4.03, with a CV of 22.26%, indicating moderate variability. In FUD-P3, the ratio ranged from 0.7 to 1.7, with the highest value in the Ap horizon and the lowest in Bw2. The mean ratio was 1.02, with a CV of 40.06%, indicating high variability. There was a significant difference at ($p < 0.05$) in the mean silt: clay ratio among the pedons. The silt-to-clay ratio was higher than 0.15 across all the study sites, signifying that the soils retain a measurable proportion of silt relative to clay. This may indicate varying degrees of weathering and pedogenic development; however, the ratio alone is insufficient to establish soil maturity.

Chemical characteristics of soil of the study area

The soil pH (H₂O) values ranged from 6.5 to 9.7, with mean values ranging from 6.90 to 9.22 (Table 3). FUD-P1 had a mean pH of 6.90, indicating near-neutral conditions, whereas FUD-P2 and FUD-P3 had mean pH values of 8.60 and 9.22, respectively, indicating alkaline conditions. The high pH observed in FUD-P3 may be related with the accumulation of basic cations in the soil. Topsoil pH values were generally higher than those of the subsoil in FUD-P1 and FUD-P2, while FUD-P3 indicated a different pattern. Soil pH influences nutrient availability and uptake by plants. Although the pH of FUD-P1 is within the range suitable for many crops, the high alkalinity of FUD-P2 and FUD-P3 may limit the availability of certain nutrients (Chude et al., 2011). There was a significant difference at ($p < 0.05$) in the mean pH among the pedons. The CV ranged from 3.29% in FUD-P2 to 7.97% in FUD-P1, while FUD-P3 had a CV of 7.57%. These values indicate low variability in soil pH across the three pedons. Electrical conductivity (EC) ranged from 0.01 to 0.47 dS m⁻¹, with mean values ranging from 0.02 to 0.32 dS m⁻¹. Based on these values, all pedons were classified as non-saline, indicating that salinity is unlikely to be a major constraint to crop production. There was a significant difference ($p < 0.05$) in EC among the soils. The CV of EC ranged from 48.51% in FUD-P2 to 132.64% in FUD-P1, while FUD-P3 recorded 52.10%. These values indicate high to very high relative variability, mostly in FUD-P1. The high CVs indicates differences in EC among horizons relative to their low mean values. Organic carbon (OC) contents across the pedons were generally low, ranging from 0.10 to 0.50%, with mean values of 0.21 to 0.42%. The topsoil contained higher OC than the subsoil, except in FUD-P3. This pattern may be attributed to the accumulation and decomposition of plant residues, including leaves, twigs and other organic materials, near the soil surface through

microbial activity. The low OC contents suggest limited organic matter reserves and may contribute to low soil fertility and reduced nutrient availability. These conditions may be associated with the semi-arid environment, continuous cultivation and bush burning, which can reduce organic matter accumulation and accelerate its depletion. The CV of OC ranged from 54.29% in FUD-P3 to 89.35% in FUD-P2, while FUD-P1 recorded 66.32%. These values indicate high relative variability in OC within the three pedons. FUD-P2 showed high variability, implying that OC was less uniformly distributed among its horizons.

Total Nitrogen (TN) was also low (0.01-0.07%) with mean values of 0.04-0.0%, topsoil value were higher in FUD-P1 and P2 but lower in FUD-P3, this implying that the TN have strong relationship with OC in the soil system (Mathew et al., 2025). Statistically, all the locations in TN are the same at ($P < 0.05$). The CV of TN ranged from 46.65% in FUD-P3 to 87.24% in FUD-P2, while FUD-P1 recorded 62.75%. These values indicate high variability in TN, particularly in FUD-P2. Available phosphorus content have higher value at topsoil FUD-P1 and decrease with increasing depth compare to FUD-P2 and P3 whereas the values of FUD-P1 and P2 at subsoil have higher values than FUD-P1. The values varied from 28.83-6.mg/kg with mean of 18.90-15.33mg/kg (Table 3). Based on the rating of available P recommended by Hazelton et al. (2016) the available P content of the soils in the all the pedons was in the range of low to medium. The available P from the locations had no significant difference ($P > 0.05$). The available phosphorus (AVP) content of the FUD soils ranged from 6.57 to 28.83 mg kg⁻¹ among the topsoil and subsoil horizons. FUD-P1 decrease in AVP with depth, with values ranging from 24.45 mg/kg in the Ap horizon to 9.85 mg/kg in the C horizon, while FUD-P2 ranged from 6.57 mg/kg in the Ap horizon to 18.98 mg/kg in Bw1 then relatively high values in Bw2 and C. FUD-P3, AVP varied with depth, increasing from 14.96 mg/kg in the Ap horizon to 20.07 mg/kg in Bw1 then decreased and increased irregular with depth. The higher AVP content in the surface horizon of FUD-P1 may be related to the addition and decomposition of plant residues, which can contribute phosphorus to the soil. The CV of available phosphorus ranged from 35.42 mg/kg in FUD-P3 to 39.02 mg/kg in FUD-P2, while FUD-P1 recorded 37.47 mg/kg. These values indicate moderate variability in available phosphorus within the three pedons. The pedons had medium to high exchangeable calcium (Ca) which ranged from 3.0-1.0cmol (+)kg⁻¹, magnesium (Mg) ranged from 01.50-

0.1cmol (+)kg⁻¹, potassium (K) ranged from 0.49-0.1cmol (+)kg⁻¹ and sodium (N) 0.73-0.01cmol (+)kg⁻¹ with mean values of 1.67-1.60cmol (+)kg⁻¹, 0.16-0.20cmol (+)kg⁻¹, 0.10-0.16cmol (+)kg⁻¹ and 0.03-0.13cmol (+)kg⁻¹ respectively.

The exchangeable bases in all the soils follow a consistent pattern; Ca high, Mg moderate, K low and N very low. The all showed significant difference at ($p < 0.05$). The dominance of Ca may be due to low weathering of parent material which produce calcareous soil in the soil. Similar higher calcium values were stated by Singh et al., 2013; Jimoh et al., 2018). The CEC of the soil ranged from 1.85-11.60cmol (+) kg⁻¹ with mean values of 2.05-7.51cmol (+) kg⁻¹ with CV of 13.99 and 47.51. The topsoil had higher values than the subsurface soil in FUD-P1 and P2 compare to FUD-P3. The higher values observed in exchangeable Ca of subsoil of FUD-P3 may be attributed to water movement to soil profile is limited and high clay content and CEC in the subsoil of FUD-P3 reflects higher ability to retain positively charged ions such as calcium. Also higher values of calcium in north western Nigeria were stated by Abdulkareem et al., 2012; Jimoh et al., 2016). The CEC in the different locations were statistically different at ($p < 0.05$). The CV values indicate low variability in FUD-P2, moderate variability in FUD-P1 and high variability in FUD-P3. Total Exchangeable acidity values (0.09-0.50) with mean values of 0.37-0.43cmol (+) kg⁻¹, the values were low according to the rating by (Chude et al., 2011). This indicates that the soil cannot cause a problem to crop production. This agree with the findings of (Nabayi et al., 2022). The values indicate moderate variability across the three pedons. FUD-P3 showed high variation whereas FUD-P1 showed the lowest Base saturation values (40.31-93.91%) with the mean of (57.82-72.17%), BS was moderate to high according to the ratings of Chudi et al. (2011). Moderate to high BS in all the pedons is indicating high values of exchangeable bases specifically Ca at subsoil. This is in conformity with the results of Sekhar et al. (2014) and Imadojemu, (2024) stated that moderate to higher values of BS is contributing to high values of Ca on soil colloid. BS was statistically the same within the pedons ($P > 0.05$). The CV values indicate low variability in FUD-P2 and moderate variability in FUD-P1 and FUD-P3.

Soil Classification

The soils have been classified based on the USDA Soil Taxonomy (Soil Survey Staff, 2014) and correlated with the World Reference Base (WRB) for soil resources. All the pedons indicated that the soil were in the stage of formation, the soil were classified under the order of Inceptisols carrying ent formative element at sub order level are group as Ustepts because the soil have been found in area of soil moisture regime. At the great group level the soils were characterized by medium to high base saturation by (NH₄OAc) and are group as Haplustepts at order group and at subgroup are qualified as Typic Haplustepts and correlated as Cambisols under World Reference Base.

CONCLUSION

The study revealed variations in the morphological, physical and chemical properties of the soils across the three pedons. Bulk density was generally moderate, indicating that soil compaction may be a concern in some horizons. Soil pH ranged from near neutral to strongly alkaline conditions, which may influence nutrient availability. Organic carbon, total nitrogen and organic matter contents were generally low, signifying limited organic matter reserves and a need to improve soil fertility through organic residue incorporation and appropriate nutrient management. Available phosphorus ranged from low to moderate levels, suggesting that phosphorus availability may limit plant growth in some areas. Base saturation was generally moderate to high, indicating that exchange sites were occupied by appreciable proportions of basic cations.

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Conflict of interest

The authors confirm that the study was conducted without financial relationships that could constitute a potential conflict of interest.

Table 2: Physical characteristics of the soil of the study area

Pedon	Horizon Depth (cm)	Horizon Designation	Sand %	Silt %	Clay %	Textural class	Bulk density Mg m ⁻³	Particle density Mg m ⁻³	WHC %	Porosity %	Moisture content (%)	Silt: Clay Ratio
FUD-P1	0-12	Ap	76	18	6	SL	1.46	2.77	48	47.29	14.55	3.0
	12-44	Bw1	82	12	6	LS	1.50	2.66	40	43.60	15.05	2.0
	44-78	Bw2	76	12	10	SL	1.67	2.66	48	37.21	19.52	1.2
	78-114	Bw3	76	12	12	SL	1.68	2.66	48	36.84	25.70	1.0
	>114	C	78	16	6	LS	1.55	2.77	40	44.04	14.24	2.6
Mean			77.60a	14.0a	8.00a		1.57a	2.70a	44.80a	41.80a	17.81a	1.96a
SD			±2.61	±2.83	±2.83		±0.10	±0.06	±4.38	±4.58	±4.90	±0.86
CV (%)			3.36	20.20	35.36		6.32	2.23	9.78	10.97	27.53	44.13
FUD-P2	0-10	Ap	76	18	6	SL	1.62	2.50	56	35.20	23.46	3.0
	10-28	Bw1	76	20	4	LS	1.57	2.50	40	37.20	22.20	5.0
	28-52	Bw2	82	18	4	LS	1.60	2.70	40	40.74	17.88	4.5
	52-84	C	72	22	6	SL	1.45	2.66	40	45.48	15.97	3.6
Mean			76.50a	19.5b	5.00a		1.56a	2.59b	44.00a	39.66a	19.88a	4.03b
SD			±4.12	±1.91	±1.15		±0.08	±0.11	±8.00	±4.51	±3.53	±0.90
CV (%)			5.39	9.82	23.09		4.88	4.06	18.18	11.37	17.78	22.26
FUD-P3	0-5	Ap	76	14	8	SL	1.42	2.40	48	40.83	14.35	1.7
	5-40	Bw1	70	16	14	SL	1.54	2.40	52	35.83	24.95	1.1
	40-70	Bw2	68	14	18	SL	1.35	2.66	56	49.24	30.91	0.7
	70-120	Bw3	66	16	18	SL	1.35	2.50	40	46.0	29.75	0.8
	120-185	C	70	14	16	SL	1.19	2.66	60	55.26	40.74	0.8
Mean			70.00b	14.8a	14.80b		1.37b	2.52b	51.20a	45.43a	28.14a	1.02a
SD			±3.74	±1.10	±4.15		±0.13	±0.13	±7.69	±7.50	±9.61	±0.41
CV (%)			5.35	7.40	28.02		9.28	5.18	15.03	16.50	34.15	40.06

Means followed the same letter are not significantly different at p<0.05 using Tukey HSD

Table 3: Chemical properties of the soil of the study area

Pedons	Horizon Depth (cm)	Horizon designation	pH (H ₂ O)	pH (KCl)	EC (dS/m)	OC (%)	TN (%)	OM (%)	AVP (mg/kg)
FUD-P1	0-12	Ap	7.9	5.0	0.12	0.68	0.071	1.17	24.45
	12-44	Bw1	7.0	5.3	0.03	0.36	0.041	0.62	19.34
	44-78	Bw2	6.7	3.8	0.01	0.16	0.018	0.28	14.23
	78-114	Bw3	6.7	3.6	0.01	0.3	0.034	0.52	11.68
	>114	C	6.5	4.0	0.01	0.14	0.015	0.24	9.85
Mean			6.96b	4.34b	0.04b	0.33a	0.03a	0.57a	15.91a
SD			± 0.55	± 0.76	± 0.05	± 0.22	± 0.02	0.37	± 5.96
CV (%)			7.97	17.51	132.64	66.32	62.75	64.91	37.47
FUD-P2	0-10	Ap	9.0	7.0	0.06	0.50	0.054	0.86	6.57
	10-28	Bw1	8.6	5.8	0.03	0.16	0.017	0.28	18.98
	28-52	Bw2	8.4	5.4	0.02	0.10	0.011	0.17	19.34
	52-84	C	8.4	5.1	0.06	0.10	0.012	0.17	16.42
Mean			8.60a	5.83a	0.02b	0.21a	0.02a	0.37a	15.33a
SD			± 0.1	± 0.83	± 6.96	± 0.19	± 0.02	± 0.33	± 5.98
CV (%)			3.29	14.24	48.51	89.35	87.24	89.19	39.02
FUD-P3	0-5	Ap	8.0	6.3	0.06	0.2	0.022	0.35	14.96
	5-40	Bw1	9.7	6.1	0.25	0.2	0.031	0.48	20.07
	40-70	Bw2	9.6	7.8	0.47	0.6	0.068	1.07	10.95
	70-120	Bw3	9.3	6.7	0.41	0.7	0.075	1.21	28.83
	120-185	C	9.5	6.6	0.41	0.4	0.049	0.79	19.71
Mean			9.22a	6.70a	0.32a	0.42a	0.04a	0.78a	18.90a
SD			± 0.70	± 0.66	± 0.17	± 0.23	± 0.02	± 0.37	± 6.70
CV (%)			7.57	9.85	52.10	54.29	46.65	47.44	35.42

Means followed the same letter are not significantly different at p<0.05 using Tukey HSD

Table of 4: Chemical characteristics of the study area

Pedons	Horizon Depth (cm)	Horizon Designation	Cmol (+) kg ⁻¹								
			Ca	Mg	K	Na	TEB	CEC	ECEC	TEA	BS (%)
FUD-P1	0-12	Ap	3.0	0.5	0.27	0.01	3.78	4.91	4.11	0.33	76.98
	12-44	Bw1	1.0	0.4	0.22	0.01	1.63	2.06	1.97	0.33	79.12
	44-78	Bw2	1.0	0.3	0.49	0.11	1.90	4.30	2.70	0.50	44.18
	78-123	Bw3	1.0	0.4	0.27	0.12	1.79	3.69	2.49	0.50	48.50
	>123	C	2.0	0.2	0.1	0.01	2.31	5.73	2.15	0.33	40.31
Mean			1.60a	0.36b	0.27a	0.05b	2.90a	4.14a	2.68a	0.37a	57.82a
SD			± 0.89	± 0.11	± 0.14	± 0.06	± 0.86	1.39	± 0.85	±0.09	18.71
CV			55.90	31.67	52.31	28.32	37.64	33.48	31.54	22.5	32.36
FUD-P2	0-10	Ap	1.0	0.2	0.23	0.04	1.47	2.26	2.11	0.50	71.35
	10-28	Bw1	1.0	0.2	0.12	0.06	1.38	8.99	5.26	0.33	74.59
	28-52	Bw2	1.0	0.4	0.08	0.01	1.90	7.56	7.10	0.33	80.54
	52-84	C	1.0	0.3	0.19	0.04	11.6	6.62	3.26	0.33	62.19
Mean			1.0a	1.0a	0.16a	0.04b	2.57a	2.05a	2.94a	0.37a	72.17a
SD			± 0.1	± 0.1	± 0.07	± 0.02	± 0.50	± 0.29	± 0.55	0.09	7.66
CV			0.1	34.82	43.60	54.97	19.34	13.99	18.66	24.32	10.62
FUD-P3	0-5	Ap	1.0	0.1	0.05	0.10	1.25	1.85	1.83	0.33	67.56
	5-40	Bw1	3.0	1.3	0.05	0.54	4.89	8.99	5.22	0.33	54.39
	40-70	Bw2	5.0	1.3	0.10	0.70	7.10	7.56	7.10	0.5	93.91
	70-120	Bw3	4.0	1.5	0.06	0.72	6.28	11.6	4.12	0.33	54.13
	120-185	C	4.0	1.2	0.09	0.73	6.02	7.56	4.80	0.66	79.62
Mean			3.40b	1.08a	0.07b	0.56a	4.18a	7.51b	4.61a	0.43a	69.92a
SD			± 1.52	± 0.56	± 0.02	±0.24	± 1.85	3.57	+1.91	±0.15	+17.07
CV			44.46	51.72	35.50	47.93	44.25	47. 51	41.37	34.88	24.41

Means followed the same letter are not significantly different at p<0.05 using Tukey HSD

REFERENCES

- Ahmed, S., & Abubakar, A. (2026). Assessing Subnational Climate Policy Alignment in Nigeria: Evidence from Jigawa State and a Comparative Analysis with Katsina State. *FUDMA Journal of Sciences*, 10(18), 100-105.
- Amare, H., Admase, H., & Ewunetu, T. (2024). Influence of land-use types and topographic slopes on the physico-chemical characteristics of soils in Northwestern Ethiopia. *Frontiers in Soil Science*, 4, 1463315.
- Adewole, A. O., Eludoyin, A. O., Chirima, G. J., & Newete, S. W. (2024). Field-scale variability and dynamics of soil moisture in southwestern Nigeria. *Discover Soil*, 1(1), 12.
- Balaselvakumar, S., and Hemavarthinii, S. B. (2026). Soil Genesis and Formation. Integrated Fundamentals of Soil Science: Processes, Properties and Sustainable Management, 28-59.
- Bawden, M. G., Carroll, D. M., & Tuley, P. (1972). *The land resources of north east Nigeria*. Volume 3. The land systems.
- Bello, B. O., Akande, S. A., Kareem, A. S., Olonisakin, T. M., Adeniyi, R. Y., & Adewumi, T. K. (2026). Influence of Parent Material on Soil Properties along a Toposequence in Iresa-Apa, Southern Guinea Savanna. *Asian Journal of Research in Agriculture and Forestry*, 12(2), 87-97.
- Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*, 59(1), 39-46.
- Farooq, U., Ajmal, M., Li, S., Yang, J., & Ullah, S. (2024). Evaluation of Pedotransfer functions to estimate soil water retention curve: A conceptual review. *Water*, 16(17), 2547.
- Fekadu, E., Kibret, K., Bedadi, B., & Melese, A. (2018). Characterization and classification of soils of yikalo sub watershed in lay gayint district, northwestern highlands of Ethiopia. *Eurasian Journal of Soil Science*, 7(2), 151-166.
- Gambo, A., Fullen, M. A., & Baldwin, T. C. (2025). Characterization and classification of soils on a toposequence around Dutse Jigawa State, Nigeria. *Discover Soil*, 2(1), 97.
- Gee, G. W., & Bauder, J. W. (1986). Particle-size analysis. Methods of soil analysis: Part 1 Physical and mineralogical methods, 5, 383-411
- Girei, A., Auwalu, A., Nabayi, A., Santuraki, H.A., & Yau, S. L. (2026). Characterization and Classification of Soils Along Toposequence in Teaching and Research Farm of Federal University Dutse, Jigawa State. *FUDMA Journal of Agriculture and Agricultural Technology*, 12(2), 76-93.
- Haile, G., Lemenih, M., & Agegnehu, G. (2024). Soil property and crop yield responses to variation in land use and topographic position: Case study from southern highland of Ethiopia. *Heliyon*, 10(3).
- Hazelton, P., & Murphy, B. (2025). Interpreting soil test results: What do all the numbers mean?. CSIRO publishing.
- Halliru, S. L., & El-ladan, Y. (2022). Spatio-temporal analysis of rainfall, temperature and wind for evidence of climatic variability and change in jigawa state, northern Nigeria (1981-2020). *Sokoto Journal of the Social Sciences*, 12(3), 160-175.
- Ibrahim, J. A., Lazarus, M. A., Akande, D., Agaku, D. T., & Sim, H. (2020). Impact of toposequence on soil properties and classification in Zaria, Kaduna State, northern Guinea Savanna, Nigeria. *EQA-International Journal of Environmental Quality*, 38(3), 48-58.
- Idris Medugu, N., Rafee Majid, M., & Johar, F. (2011). Drought and desertification management in arid and semi-arid zones of Northern Nigeria. *Management of Environmental Quality: An International Journal*, 22(5), 595-611.
- Ike, C. R., Orakwe, L. C., Okore, I. K., Chukwuma, E. C., Ibeh, C. U., & Diobi, C. C. Effects of topo position on physico-chemical properties of the soil at Ezeagu area of Enugu state, southeastern Nigeria. *Journal of Agricultural and Biosystems Engineering* 1 (2).
- Imadojemu, P. E. (2024). Mineralogical Characteristics of Soils in Southern Taraba State Northeast, Nigeria. *Asian Journal of Soil Science and Plant Nutrition*, 10(2), 514-529.
- Jackson, C. R., Thompson, J. A., & Kolka, R. K. (2014). Wetland soils, hydrology, and geomorphology. In D. P. Batzer & R. R. Sharitz (Eds.), *Ecology of freshwater and estuarine wetlands* (pp. 23-60). University of California Press
- Jimoh, A. I., Malgwi, W. B., Aliyu, J., & Shobayo, A. B. (2016). Characterization, classification and agricultural potentials of soils of Gabari district, Zaria, northern Guinea savanna zone Nigeria. *Biological and Environmental Sciences Journal for the Tropics*, 13(2), 102-113.
- Kebede, M., Shimbir, T., Kasa, G., Abera, D., & Girma, T. (2017). Description, characterization and classification of the major soils in Jinka Agricultural Research Center, South Western Ethiopia. *Journal of Soil Science and Environmental Management*, 8(3), 61-69.
- Liu, L., Lu, Y., Horton, R., & Ren, T. (2024). Determination of soil water retention curves from thermal conductivity curves, texture, bulk density,

- and field capacity. *Soil and Tillage Research*, 237, 105957.
- Macaulay, B. (2014). Land degradation in Northern Nigeria: The impacts and implications of human related and climatic factors. *African Journal of Environmental Science and Technology*.
- Mathew, D., Audu, I. P., Monday, S. A., John, A. E., Augustine, A., Ogar, O. M., & Abubakar, A. F. (2025). Characterization and classification of soils derived from two different parent materials in niger state, Nigeria. *Journal of Agriculture and rural development studies*, volume 2 issue 4
- Nurgisa, S. Z., Yitbarek, T., & Chimdi, A. (2025). Characterization and classification of soil for sustainable land management: A case study of Arjo Dhidhesa Estate Sugar Factory, Western Ethiopia. *Agrosystems, Geosciences & Environment, Geosciences & Environment*, 8(4), e70259.
- Obaje, N. G. (2009). *Geology and mineral resources of Nigeria* (Vol. 120, p. 221). Berlin: Springer.
- Olagunju, T. E. (2015). Drought, desertification and the Nigerian environment: A review. *Journal of Ecology and the Natural Environment*, 7(7), 196-209.
- Ouyang, N., Zhang, Y., Sheng, H., Zhou, Q., Huang, Y., & Yu, Z. (2021). Clay mineral composition of upland soils and its implication for pedogenesis and soil taxonomy in subtropical China. *Scientific reports*, 11(1), 9707.
- Rilwanu, T. U. Y. (2023). Lower Plains of Northern Nigeria. *Landscapes and landforms of Nigeria* (pp. 53-69). Cham: Springer Nature Switzerland.
- Rennert, T., Lenhardt, K. R., & Dietel, J. (2024). Interplay of weathering, formation of secondary mineral soil constituents, and soil organic matter in South German Umbrisols. *Geoderma Regional*, 36, e00767.
- Robinson, D. A., Thomas, A., Reinsch, S., Lebron, I., Feeney, C. J., Maskell, L. C., & Cosby, B. J. (2022). Analytical modelling of soil porosity and bulk density across the soil organic matter and land-use continuum. *Scientific reports*, 12(1), 7085.
- Ross, D. S., & Ketterings, Q. (1995). *Recommended methods for determining soil cation exchange capacity*. In J. T. Sims and A. Wolf (Eds.), *Recommended soil testing procedures for the northeastern United States* (2nd ed., pp. 62-69). University of Delaware, Agricultural Experiment Station.
- Santuraki, H. A., Abdullahi, M., Abubakar, A., Mahmud, A. T., Nabayi, A., & Maunde, M. M. (2026). Assessment of the physicochemical properties of soils in Warwade Village, Dutse Local Government Area, Jigawa State, Nigeria. *FUDMA Journal of Earth and Environmental Sciences*, 3(1), 166–175.
- Santuraki, H. A., A.I. Zata & Emmanuel, A. (2026). Morphological and Physical Characterization of Semi-Arid Soil of Dutse, Jigawa State, North Western Nigeria. *FUDMA Journal of Sciences*, 10(15), 234-241.
- Santuraki, H., Zubairu, I., Auwalu, A., Nabayi, A., Mahmud, A., & Adamu, U. (2025). Comparative assessment of physicochemical properties under continuous and minimally disturbed cultivation in Jigawa State, Nigeria. *Journal of Agriculture, Forestry and Fisheries*, 22(2), 109–113.
- Sharu, M. B., Noma, S. S., Abubakar, G. A., & Eniolorunda, N. B. (2025). Morphological and Physical Characterization of Zagga soils a semi-arid landscape in northwestern Nigeria. *Fudma Journal of Sciences*, 9(11), 185-190.
- Shobayo, A. B. (2019). Soil mapping and in-situ soil description of selected land area of Funtua, Nigeria. *Nigerian Journal of Soil Science*.
- Singh, B. T., Nandini D. K., Bijen K. Y., Bishworjit N., Nongdren K. S. L. and Herojit S. A., (2013). Characterization, and Evaluation for Crop Suitability in Lateritic Soils. *African Journal of Agricultural Research* vol. 8(37) pp 4628
- Tian, M., Qin, S., Whalley, W. R., Zhou, H., Ren, T., & Gao, W. (2022). Changes of soil structure under different tillage management assessed by bulk density, penetrometer resistance, water retention curve, least limiting water range and X-ray computed tomography. *Soil and Tillage Research*, 221, 105420.
- Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29-38.
- Van Reeuwijk, L. P. (Ed.). (1995). *Procedures for soil analysis* (5th ed.). International Soil Reference and Information Centre (ISRIC), Technical Paper No. 9.
- Vomocil, J. A. (1965). Porosity. In C. A. Black (Ed.), *Methods of soil analysis*. Part I: *Physical and mineralogical properties, including statistics of measurement and sampling* (Agronomy Monograph No. 9, pp. 299–314). American Society of Agronomy.
- Yost, J. L., & Hartemink, A. E. (2019). Soil organic carbon in sandy soils: A review. *Advances in agronomy*, 158, 217-310.
- Zata, A. I., Ibrahim, A., & Mustapha, S. (2013). A detailed soil survey and characterization of some usterts in northeastern Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences*, 4(4), 552-556.
- Zata, A. I., Salem, A., & Musa, H. (2020). Effects of different land use types on infiltration capacity in

hydric soils of Dadin Kowa Gombe State, Nigeria.
*International Journal of Agriculture and Rural
Development*, 23(2), 5196-5206.